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Analog-to-Digital Assembly Manual

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INTRODUCTION

The TAPR ADC (Analog to Digital Convertor) Module is an accessory to the METCON product. It is used for measuring voltages at a remote site for reporting via packet radio. When completed, it should deliver years of high-performance service.

This kit contains all parts and components necessary to populate the METCON ADC printed circuit (PC) board. There is no cabinet, case or power supply included or available from TAPR.

Please follow the directions in this manual carefully. It has been revised based on feedback from numerous builders.

Don't forget to carefully inspect the carton in which this kit came for any last-minute additions/corrections to the instructions provided in this manual.

As always, if you find errors or have questions or suggestions for this kit, please write or fax the TAPR office. If you have technical support questions, refer to the "IMPORTANT! Read Me First!" insert.

If you exercise care, construction of this kit should take you from one (1) to three (3) hours, depending on your experience.

So, clear off your workbench, warm up your soldering iron, and enjoy!

PARTS LIST

Sort the parts into egg cartons, muffin tins, or other containers as you inventory them. This will aid you in building. Check off the part in the () space provided as you locate and verify it against this list.

Capacitors

Ceramic, Monolithic

() 08	100 pF	101	MONO-101C
() 04	0.01 uF	103	MONO-103Z

Electrolytic, Radial lead

() 01	10 uF	106	RAD16V-106
() 01	100 uF	107	RAD25V-106

Connectors

() 08	3 pin male header	HDR-03M
() 01	7 pin male header	HDR-07M
() 02	7-pin shells	SHELL-07F
() 14	Pins for shell	
() 04	2-position wire-clamp	RDI2SV
() 04	3-position wire-clamp	RDI3SV

ICs

ICs are inserted in anti-static foam. Please do not remove them until they are called out in the construction steps that follow.

ICs often contain many numbers, and the "core" number may have a prefix and/or a suffix. A 74HC14, for example, may be marked MC74HC14P or SN74HC14N. TO92 indicates a three-lead plastic-bodied case.

A four-digit number starting with 90, 91, or 92 is probably a date code, not the part number. A date code might be 9123 or 9004.

() 03	LMC660 Quad Op Amp	LMC660
() 01	LM78L05 Voltage Regulator (TO-92)	78L05
() 01	LM385 Voltage Reference (TO-92)	LM385
() 01	ADC0838 A to D Converter	ADC0838

IC Sockets

() 03	14 pin	DIPS-143
() 01	20 pin	DIPS-203

Resistors

1/4 Watt, 5% Carbon Film

() 01 220 ohm (red-red-brown-gold) CFR1/4-221

1/8 watt, 1% Metal Film

() 01 18.2K ohm (brown-gray-black-red-brown)
or 1822 MFR1/8-1822

() 34 100K ohm (brown-black-black-orange-brown)
or 1003 MFR1/8-1003

() 01 107K ohm (brown-black-violet-orange-brown)
or 1073 MFR1/8-1073

() 01 118K ohm (brown-brown-gray-orange-brown)
or 1183 MFR1/8-1173

Single-turn Trimpot

() 02 20K ohm 203 STRIM-203

Miscellaneous

() 08 push-on jumper JMP-02

() 01 10-conductor cable assembly CBL-10

() 01 ADC PC Board

() 01 ADC Assembly Manual

() 01 ADC Reference Manual

CONSTRUCTION

Note that the PC board has two trace sides with plated-through holes joining them. This means that you must use a temperature-controlled soldering iron, fine 60/40 or 63/37 rosin core solder and painstaking care when making each and every joint. The reward will be a superior device of excellent reliability. The alternative will most likely be erratic operation.

In addition to the soldering iron and solder, you will need small flush or semi-flush cutting pliers and small-tipped long nosed pliers. A magnifying glass may prove helpful to identify the values of the small components. A lead-bending jig will help maintain a neat appearance for the resistors and other axial leaded parts.

Pay careful attention to the directions that follow. Keep the tip of your soldering iron bright and clean, wiping it frequently on a wet rag or sponge. Make solder joints carefully, but swiftly. Prolonged heat on a PC board pad can be as disastrous as too much heat, and ruining this PC board can be expensive! Two to three seconds should be enough time to apply heat to any joint.

Component installation will generally proceed from left to right and top to bottom of the PC board when the board is held so that the silkscreen legend "METCON ADC" is in the lower left-hand corner of the PC board.

Check the PC board to make sure that the exposed, tinned pads are clean and shiny. If they are not, scrub

the board lightly with a household cleanser (such as Ajax or Comet), rinse in fresh, clean water then dry with a soft towel.

() PC board clean.

IC SOCKETS

Refer to Figure 1 for parts placement. Figure 1 is also provided in an enlarged format on page 11.

NOTE: IC sockets are polarized. The end nearer pin 1 is marked with a notch, a beveled corner, or the numeral "1" embossed in the plastic body of the socket. The PC board silkscreen is marked with a notch at the pin 1 end.

When installing an IC socket, be sure all pins are through the PC board, then tack solder a diagonally opposite pair of pins. Double check that the socket is flush against the PC board surface and that all pins are through, then solder the remaining pins. Finally, resolder the original two tack-soldered pins.

Install the following parts:

() U1 socket	14 pin IC socket
() U2 socket	14 pin IC socket
() U4 socket	14 pin IC socket
() U5 socket	20 pin IC socket

Solder connections should appear bright and shiny, with a concave fillet between the PC board pad and the socket pin. Gray, grainy-looking joints, round solder blobs or pads not completely and evenly covered with solder will result in an unreliable joint. These joints should be resoldered, using a good grade of rosin-core flux to ensure the joint is clean and that the solder adheres.

Now, double check the solder connections you have made.

() Solder joints OK.

Take this opportunity to verify that there are no leftover IC sockets.

() No IC sockets remaining.

RESISTORS

Resistors used in this kit are in three forms: discrete, axial-leaded carbon resistors, discrete axial-leaded metal film (precision) resistors and single-turn trimpots.

Due to space limitations and other conflicts, all resistor locations on the PC board may not have the identifier printed on the board. The circuit board layout sheet provided with this kit will identify the locations of all components, however, so continue to pay close attention to the manual, the layout sheet and the PC board.

Discrete resistors have color-coded bands (or numerical markings) denoting their value. Some precision resistors may have the value printed on the body of the part. A 10,000 ohm device might be identified with the number series "1002" or "10K" instead of a color code. The color code will be given in each step to aid you in identifying the value. If you have any doubt about a resistor's value, we suggest you measure it with an ohmmeter before you install it. We have tried to limit the number of different values, but it is better to be careful than to try and remove and reinstall a resistor on a plated-through-hole PC board!

When installing discrete resistors, bend the leads and then insert the resistor so that its body is flush with the PC board surface. Then bend the leads slightly to secure it in place. If you are using a lead-bending jig, resistor leads are on 0.5" (12.7 mm) centers. After placing a number of resistors, you will be instructed to solder the leads and clip the excess lead lengths. At that time a count of solder joints will be given as an aid to ensure you don't overlook a lead or two.

In the steps that follow, be careful to use 1% precision resistors only when called for, and carbon film resistors at all other times.

If you have access to a digital ohmmeter, perform the following sorting steps. If you do not, skip this section and proceed to the section **Installing Resistors**.

The goal of this section is to sort eight (8) groups of four (4) each 100k resistors. If you do not have this capability, don't worry about it. If you do, sorting the resistors will provide greater precision in the measurements made by your ADC Module.

NOTE: The accuracy of your ohm-meter isn't terribly critical. The ability of your ohm-meter to repeatedly measure a given value is important. So, a 3% accurate instrument with a repeatability of 1/2% is perfectly suitable.

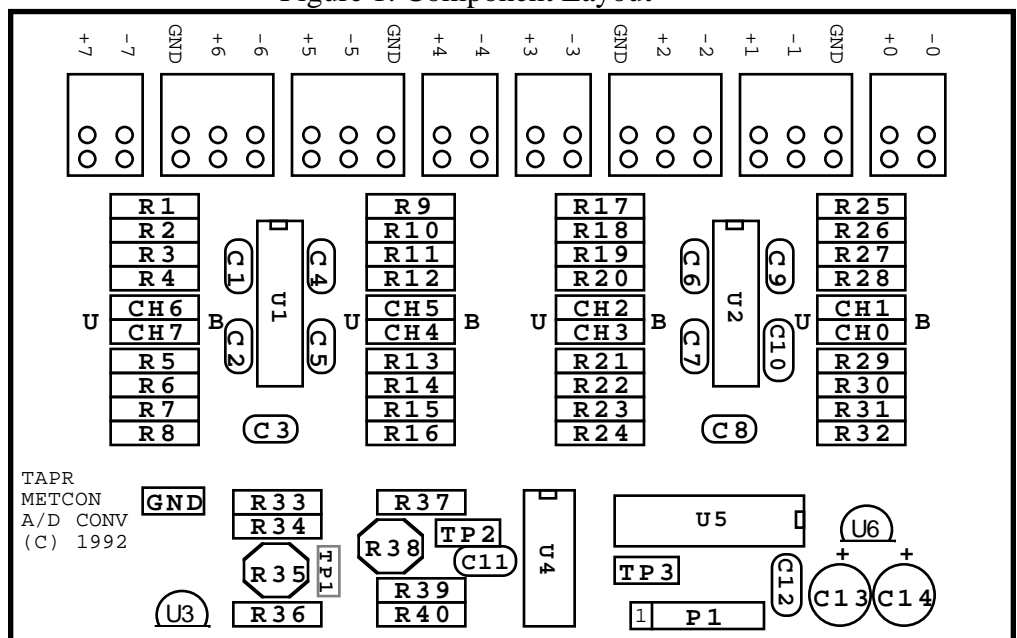
- () Locate and segregate the 100K 1% resistors.
- () Mark a large piece of paper with numbers 1 through 32.
- () As you measure a resistor, place it by a number on the paper and record the value you measured.
- () Continue until all 34 resistors have been measured.
- () Combine the resistors into eight groups of four resistors. Each of the four resistors in a group should have the same or very close values. The actual values aren't important; matching the measured values is important. You will have two resistors left over that will be used at R34 and R40.
- () In the next section, use resistors from a group for R1-R4; then another group for R5-R8, then R9-R12, and so forth.

Installing Resistors

Install the following resistors:

- () R1 100K 1% (brown-black-black-orange-white) or 1003
- () R2 100K 1% (brown-black-black-orange-white) or 1003
- () R3 100K 1% (brown-black-black-orange-white) or 1003
- () R4 100K 1% (brown-black-black-orange-white) or 1003
- () R5 100K 1% (brown-black-black-orange-white) or 1003
- () R6 100K 1% (brown-black-black-orange-white) or 1003
- () R7 100K 1% (brown-black-black-orange-white) or 1003
- () R8 100K 1% (brown-black-black-orange-white) or 1003
- () Solder and clip sixteen (16) leads.

Figure 1: Component Layout



- () R9 100K 1%(brown-black-black-orange-white) or 1003
- () R10 100K 1%(brown-black-black-orange-white) or 1003
- () R11 100K 1%(brown-black-black-orange-white) or 1003
- () R12 100K 1%(brown-black-black-orange-white) or 1003
- () R13 100K 1%(brown-black-black-orange-white) or 1003
- () R14 100K 1%(brown-black-black-orange-white) or 1003
- () R15 100K 1%(brown-black-black-orange-white) or 1003
- () R16 100K 1%(brown-black-black-orange-white) or 1003

() Solder and clip sixteen (16) leads.

- () R17 100K 1%(brown-black-black-orange-white) or 1003
- () R18 100K 1%(brown-black-black-orange-white) or 1003
- () R19 100K 1%(brown-black-black-orange-white) or 1003
- () R20 100K 1%(brown-black-black-orange-white) or 1003
- () R21 100K 1%(brown-black-black-orange-white) or 1003
- () R22 100K 1%(brown-black-black-orange-white) or 1003
- () R23 100K 1%(brown-black-black-orange-white) or 1003
- () R24 100K 1%(brown-black-black-orange-white) or 1003

() Solder and clip sixteen (16) leads.

- () R25 100K 1%(brown-black-black-orange-white) or 1003
- () R26 100K 1%(brown-black-black-orange-white) or 1003
- () R27 100K 1%(brown-black-black-orange-white) or 1003
- () R28 100K 1%(brown-black-black-orange-white) or 1003
- () R29 100K 1%(brown-black-black-orange-white) or 1003
- () R30 100K 1%(brown-black-black-orange-white) or 1003
- () R31 100K 1%(brown-black-black-orange-white) or 1003
- () R32 100K 1%(brown-black-black-orange-white) or 1003

() Solder and clip sixteen (16) leads.

- () R33 220 ohm (red-red-brown-gold)
- () R34 100K 1%(brown-black-black-orange-white) or 1003
- () R36 107K 1%(brwn-black-violet-orange-white) or 1073
- () R37 18.2K 1% (brown-gray-black-red-white) or 1822
- () R39 118K 1%(brwn-brwn-gray-orange-white) or 1183
- () R40 100K 1%(brown-black-black-orange-white) or 1003

() Solder and clip twelve (12) leads.

() No discrete resistors remaining.

Carefully inspect the board for any poor solder joints, and correct any that you find.

() All solder connections look simply wonderful!

The trim pots will be installed later.

CAPACITORS

The next components to be installed are capacitors. These come in ceramic monolithic radial-leaded devices which are non-polarized, and electrolytic radial-leaded devices which are polarized. You will first install the ceramic, non-polarized parts.

CERAMIC CAPACITORS

These parts should be mounted close to the top surface of the PC board. You will be instructed when to solder, so just install parts and secure by bending leads until then.

You may need to straighten or bend some leads to make them fit the PC board hole spacings.

The PC board lacks space for silkscreening the capacitor values so the following technique is used.

NOTE: Unmarked capacitor locations are for RFI suppression capacitors of 100 pF (typical) value. These capacitors should not be installed unless you have a confirmed RFI problem.

Locations marked with a dot are power supply bypass capacitors of 0.01 uF value and will be installed in the following steps:

Install the following parts:

- () C3 0.01 uF (103) near U1 pin 7
- () C8 0.01 uF (103) near U2 pin 7
- () C11 0.01 uF (103) near U4 pin 4
- () C12 0.01 uF (103) near U5 pin 20

() Solder and clip eight (8) leads.

You should have eight (8) 100 pF ceramic capacitors remaining for possible use in RFI suppression.

() Eight (8) ceramic capacitors remaining.

POLARIZED CAPACITORS

The next components you will install are the polarized capacitors. These may be aluminum electrolytic or tantalum types.

Electrolytic capacitors are cylindrical with radial leads (meaning both leads come out one end). The negative lead is usually marked with a black band filled with minus signs. In addition, this lead is usually shorter than the positive one.

Tantalum capacitors, in addition to having incredibly small, hard to read print, mark the positive lead with little plus signs on one side of the part. Tantalums are usually a sort-of teardrop shape.

The PC board silkscreen is marked with a plus (+) sign near the positive lead. The positive lead pad is square.

Be sure to get the positive lead in the square pad, no matter which type of part you are installing.

Test points are provided for calibrating the reference supplies on the ADC Module. Test points are made by forming a cut off component lead around a 1/8" (3mm) drill bit, then placing the resulting loop of wire through the two holes in the PC board provided. The loop of wire then serves as the test point or grounding point for a DVM probe or other test device.

Solder the wires and clip them as you install each test point.

- () GND test point - loop
- () TP1 test point - loop
- () TP2 test point - loop
- () TP3 test point - loop

You should have no remaining connectors or other PC mounted components except the 100 pF ceramic capacitors for possible RFI suppression.

You have completed all soldering operations on the PC board. At this point, you should take a break for at least five or ten minutes and relax.

Now that you are back, you need to perform a careful inspection of the PC board. Now, once again inspect each of the solder connections, preferably with a magnifying glass. We cannot over-emphasize the importance of these connections.

- () All solder joints inspected and look great to me!

You also need to carefully inspect the top of the board in case some solder accidentally found its way through the holes and flowed to cause a short circuit somewhere. Or, perhaps a component got damaged while work was proceeding elsewhere on the board. It is better to find and fix all such problems now.

- () This board is inspected and looks good.

You should have eight (8) push on jumpers, four (4) ICs and two (2) 7-conductor shells, one (1) length of 10-conductor ribbon cable, and 14 socket pins.

Cable Fabrication

The A-to-D board attaches to the METCON module via a 7-conductor cable. The A-to-D board should be mounted physically near the METCON unit, so the included length of cable should be more than long enough. You may wish to make it shorter.

- () Separate the ribbon cable between the violet and gray wires. You will then have a length of 7-conductor cable with brown and violet wires at the edges, and a length of 3-conductor cable with a gray and a black wire at the edges.
- () Discard the length of 3-conductor cable (OK, put it in your junk box!).

- () Prepare the ends of the 7-conductor cable by separating the wires for a length of about one (1) inch (22mm). Strip about 1/8" (3mm) of insulation from the wire end. Twist the wires strands together and lightly tin them with solder. Do this for all fourteen (14) wire ends.
- () Attach a cable connector pin to each wire end. Place the wire end in the pin and carefully fold the tabs over on the wire. Solder it (use solder very sparingly!). After it cools, fold the longer tabs over the wire insulation. Do this for all fourteen (14) wire ends. See Figure 2 below for clarification of this step.

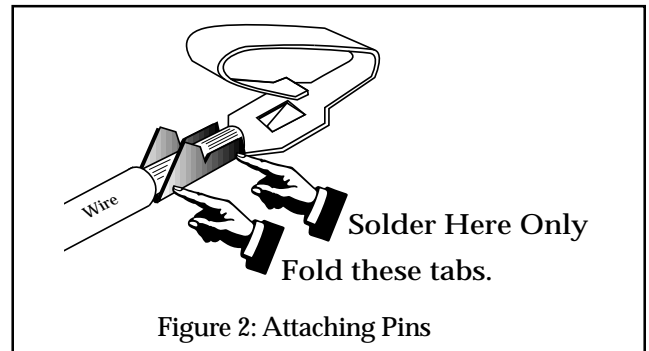


Figure 2: Attaching Pins

- () Insert the pins at one end of the cable into a 7-pin connector shell. The pins go only one way. You should press them into the shell until they "click" into position. Note the shell is marked with the numeral "1" or "7" embossed at one end. The wires go in the following order:

<u>PIN</u>	<u>COLOR</u>
1	Brown
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet

See Figure 3 below for clarification of this step.

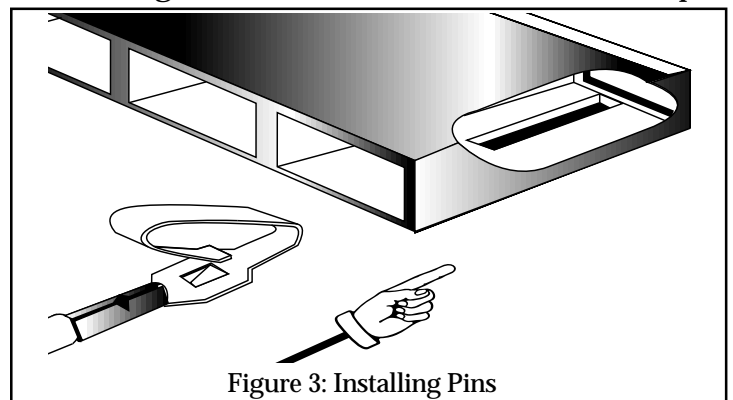


Figure 3: Installing Pins

- () In a similar manner, attach the other connector shell to the free end of the cable.

Initial Test and Calibration

- () Plug one end of the cable into the METCON board, with the *brown* lead side of the cable at pin 1.
- () Plug the other end of the cable into the ADC Module board at P1, with the *brown* lead side of the connector at pin 1.
- () Apply power to METCON
- () Measure the voltage between U5 pin 20 and U5 pin 10. It should be between +4.7 and +5.3 VDC. If it is not, troubleshoot the board, find and fix the problem. Do not proceed until this condition is met or you may cause serious damage to the ICs on the ADC board.
- () Remove power from the METCON.
- () Observing anti-static precautions, install the ICs:

U1	LMC660
U2	LMC660
U4	LMC660
U5	ADC0838
- () Apply power to METCON.
- () Using an accurate digital voltmeter, measure the voltage between **GND** and **TP1** on the ADC Module. The voltage should measure somewhere between 2.2 and 2.8 VDC.
- () Adjust R35 for a reading of 2.550 VDC. The accuracy of this adjustment affects the overall accuracy of the ADC Module.
- () Measure the voltage between **TP2** (positive) and **TP3** (negative) on the ADC Module.
- () Adjust R38 for a reading of 1.280 VDC. The accuracy of this adjustment affects the accuracy of the "0" voltage point when using the ADC module for bipolar measurements.
- () Between each set of four 1% resistors on the board are channel configuration blocks, with each block composed of 3 jumper posts. Each block is labeled with a channel number and each side of the block is labeled either U or B. Place a push on jumper between the center and U pins on each of the blocks. You will need 8 push on jumpers for this step.
- () Connect a terminal to METCON using a null modem cable.

- () Issue an AMAP command by typing "=AM<RET>" on the keyboard and observe METCON's response on the terminal's display as a test to ensure that your terminal can communicate with METCON.

***ALPHA _____

- () Connect a jumper from GND to the -0 input of the ADC module.
- () Connect a jumper from TP1 to the +0 input of the ADC module.
- () Issue an AMAP command by typing "=AM<RET>" on the keyboard and observe METCON's response on the terminal's display.
- () You should see each ADC channel's value in the ADC field, and the value for Channel 0 should be 255 (might also be 254 or 253).
- () Remove the jumper to the +0 input.
- () Jumper +0 and -0 to ground.
- () Issue another AMAP command and see that the channel 0 value is 0 (might also be 1 or 2).
- () Move the push-on jumper at CH0 from the center and U pins to the center and B pins.
- () Issue another AMAP command and see that the channel 0 value is 127 (might also be 125, 126, 128 or 129).

***BRAVO _____

- () Go through the steps between ALPHA and BRAVO but test channel 1 instead of channel 0.
- () Go through the steps between ALPHA and BRAVO but test channel 2 instead of channel 0.
- () Go through the steps between ALPHA and BRAVO but test channel 3 instead of channel 0.
- () Go through the steps between ALPHA and BRAVO but test channel 4 instead of channel 0.
- () Go through the steps between ALPHA and BRAVO but test channel 5 instead of channel 0.
- () Go through the steps between ALPHA and BRAVO but test channel 6 instead of channel 0.
- () Go through the steps between ALPHA and BRAVO but test channel 7 instead of channel 0.

NOTE: +INPUT and -INPUT signals may range between -15 VDC and +15 VDC without damage to the ADC module. However, meaningful measurement data will only be obtained when input signals are limited to the values discussed below.

Installation and Configuration

The ADC Module expects inputs in the range of 0 to +2.55 volts for all channels whose **CHx** 3-pin jumpers are set to the **U** (unipolar) position.

If you wish to measure signals whose values may vary above and below zero, set that channels **CHx** jumper to the **B** (bipolar) position. In this configuration, the input voltage range is -1.28 to +1.27 VDC.

All unused inputs should have their inputs shorted together. For example, if you are not going to use channel 7, install a jumper wire between ADC Module inputs -7 and +7. This will prevent the input amplifier for that channel from drifting to a level beyond the ADC0838 chip's valid input range.

The input voltage ranges could be altered by changing the values of the resistors associated with the channel whose range you wish to change. However, this is not recommended. You should scale the desired signal to the range of the ADC Module by use of external resistor networks or other means, or consider using the METCON V-to-F module.

Absolute Signal Input Limits

The absolute allowable input limits for proper operation of the ADC Module are as follows.

With the **CHx** jumper set to the **U** position:

+INPUT more positive than -1 VDC and less positive than +4 VDC.

-INPUT more positive than -3.55 VDC and less positive than +4 VDC.

Voltage across + and - INPUTs not less than 0 and not more than 2.55 VDC.

With the **CHx** jumper set to the **B** position:

+INPUT more positive than -2.5 VDC and less positive than +2.5 VDC.

-INPUT more positive than -3.8 VDC and less positive than +2.5 VDC.

Voltage across + and - INPUTs not less than -1.28 and not more than +1.27 VDC.

Hardware Description

This section provides additional information the Analog to Digital Converter (ADC) module for use with the METCON-1 telemetry and control system. This module is connected to METCON through a

short 7-conductor cable. The firmware within METCON polls the ADC module through this cable to read the values at the eight (8) inputs of the ADC0838 chip (U5), the Analog to Digital Converter integrated circuit.

ADC Voltage Inputs

This module measures up to eight (8) external differential voltages in the range of 0.00 to +2.55 volts or -1.28 to +1.27 volts. Each input is buffered by a balanced amplifier with an input impedance of 200K ohms. Each input is independently set to either of two input scales, and the scales may be changed by appropriate resistor value selection. The common mode input range extends from at least -1.0 to +2.5 volts.

Circuit Description

U3 is a temperature stable voltage reference for setting the full scale value for U5, the Analog-to-Digital Converter (ADC). The reference voltage chosen for the ADC module is 2.550 volts. Because of this choice, each bit equals 10 millivolts. Thus the eight-bit value read from U5 is in units of 10 mV, or hundredths of a volt. The basic voltage reference of U3 is 1.240 volts. It is scaled to 2.550 volts by means of R34, R35 and R36. R35 provides for about 5% variation of the reference voltage so that it may be set exactly to 2.550 volts.

The offset voltage, labeled U, is typically about 1 volts. A value greater than zero is used to ensure that it's within the range of possible op-amp outputs.

Each op-amp differential circuit can be biased to either **U** (analog common) or **B** (1.28 volts above analog common).

When the jumper is installed in the **U** (unipolar) position the range of useful differential inputs is 0.00 to +2.55 volts. In the **U** position, a 0.00 differential input voltage will cause the op-amp output voltage to be 0+U (the analog common voltage) volts and the A/D converter will output a count of 0. A differential input voltage of 1.28 volts will cause an op-amp output of 1.28+U volts and the A/D converter will output a count of 128. A differential input voltage of 2.55 volts will result in an op-amp output of 2.55+U volts and a corresponding count of 255.

When the jumper is installed in the **B** (bipolar) position, the range of useful inputs is -1.28 volts to +1.27 volts. In the **B** position, a 0.00 differential input voltage will cause the op-amp output voltage to be

0+B (1.28 volts above the analog common voltage) volts and the A/D converter will output a count of 128. A differential input voltage of -1.28 volts will cause an op-amp output of -1.28+B volts and the A/D converter will output a count of 0. A differential input voltage of 1.27 volts will result in an op-amp output of 1.27+B volts and a corresponding count of 255.

So, when **U** is selected the differential voltages must be positive to get a useful output, and the output is read directly in units of 10 mV. When **B** is selected, the differential voltages may be positive or negative for useful output. The A/D output is added to -128 and the signed result will be the measured voltage in units of 10 mV.

There are eight (8) analog inputs to the ADC module. Only one channel, channel 0, will be discussed. All other channels operate in the same way.

The input signal is applied across -0 (negative) and +0 (positive). U2C and associated resistors provide a differential input. C10 is used to limit RFI and should only be installed if there is a confirmed RFI problem. The value of C10 is chosen as needed to combat specific RFI problems.

ADC Errors

The ADC0838 does a pretty good job of accurately converting voltage to a bit pattern that the METCON microcomputer can read. The errors are less than 1/2 **LSB** (that is, less than 5 mV) so the ADC0838 itself won't cause much of a problem.

In some applications, you can connect the ADC0838 directly to the device that you want to measure. One caution when doing so is that the ADC should be connected to a low impedance point (assuming your device has a low impedance output). The problem is that the ADC0838 pushes and pulls small amounts of current into and out of its ADC input pins during the conversion process. If the device to be measured presents a large impedance to the ADC0838, these small currents will flow through that impedance creating a voltage drop or rise. That voltage will add to or subtract from the voltage you are trying to measure and will result in errors.

One way to work around the source impedance problem is to use an op-amp, perhaps in a differential configuration to remove common mode noise, to buffer the signal and present a low impedance to the ADC0838 input. That's what we did with the METCON ADC Module.

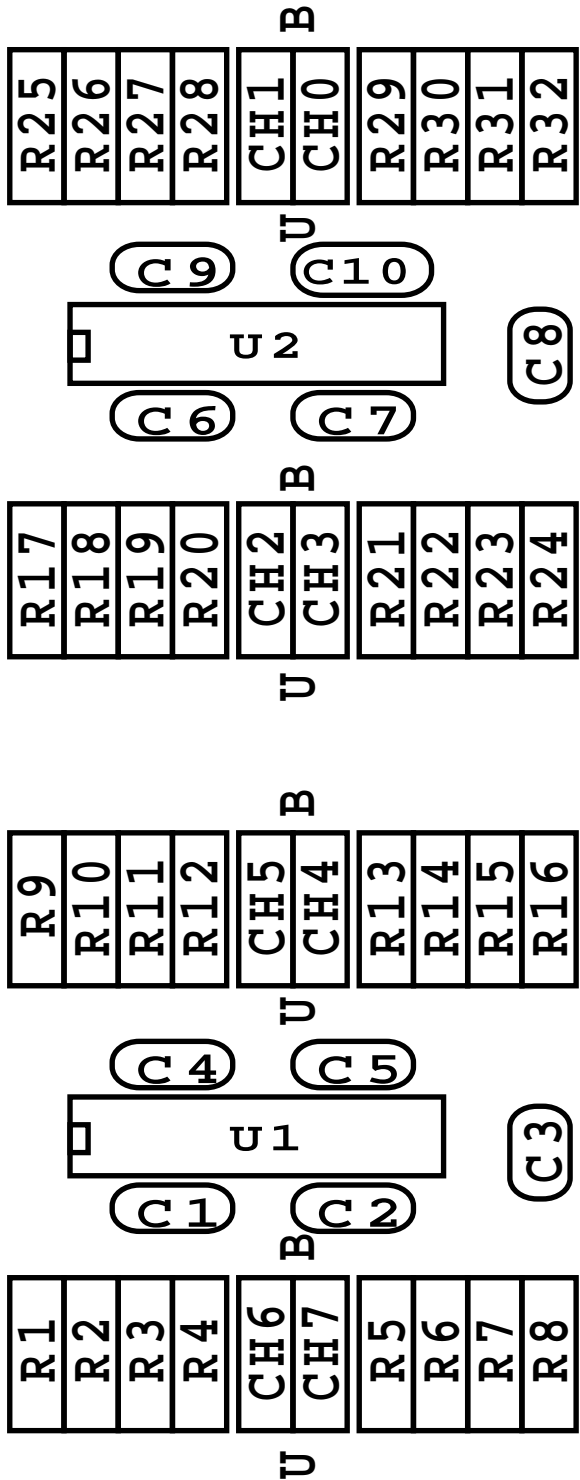
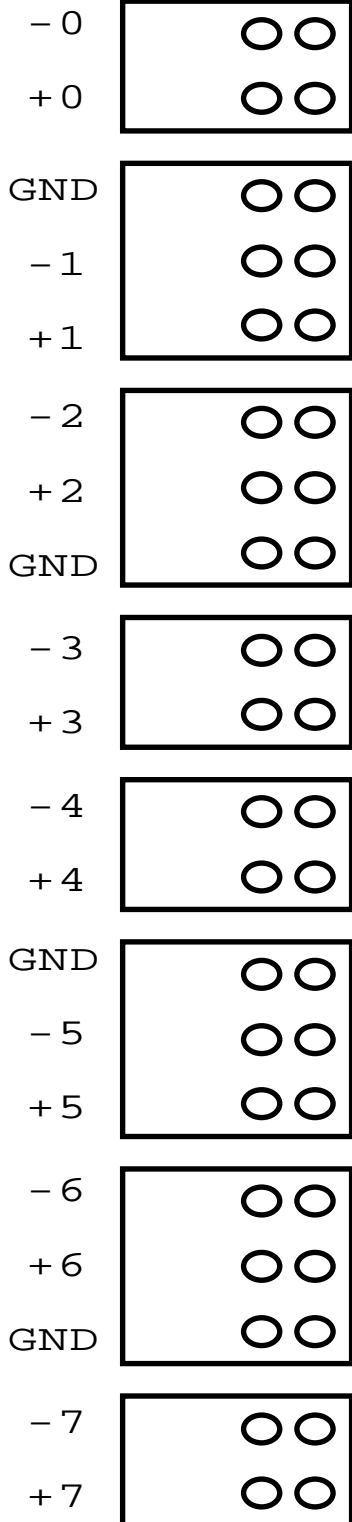
However, this has problems too! The differential amplifiers have two major sources of errors.

First, there's the tolerance of the resistors used. Ideally, these resistors would be perfectly matched. It doesn't really matter if the resistors are 90K or 100K or 110K ohms. What does matter is that the four resistors used in each op-amp section be the same value. Even 1% resistors can lead to errors of a few tens of millivolts. This is worse than the ADC chip is capable of resolving, so you will see errors caused by resistor tolerance mismatches.

Second, the op-amps themselves have voltage and current offsets. We chose op-amps that have low offsets, but they have them nonetheless. Part of the offset problem can be reduced by closely matched input resistors. Or, better (more expensive) op-amps could be used. These would be op-amps specially designed for lower voltage and current offsets.

Notes

1. See the National Semiconductor *Data Acquisition Linear Devices Databook* for an excellent discussion of how the ADC0838 operates.
2. Common mode noise is noise voltage that is present in both the positive and negative input lines. For example, noise coupled into a twisted pair of wires is usually the same value in sign and magnitude, so it is common mode. A differential amplifier, such as the one used for the ADC Module inputs, subtracts out this common mode noise and looks only at the difference voltage across its inputs. It is this characteristic that leads to the name, differential amplifier. Of course, the common mode noise rejection of the amplifier depends on many things, and it is only on the order of a volt or two in this circuit.



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