

ANTENNA GROUND

VK5JST

AERIAL ANALYSER

SET FREQUENCY

- 12.5-31MHz
- 6.8-16MHz
- 3.7-9MHz ○
- 2.2-5MHz ○
- 1.3-3MHz ○



DOWN



UP

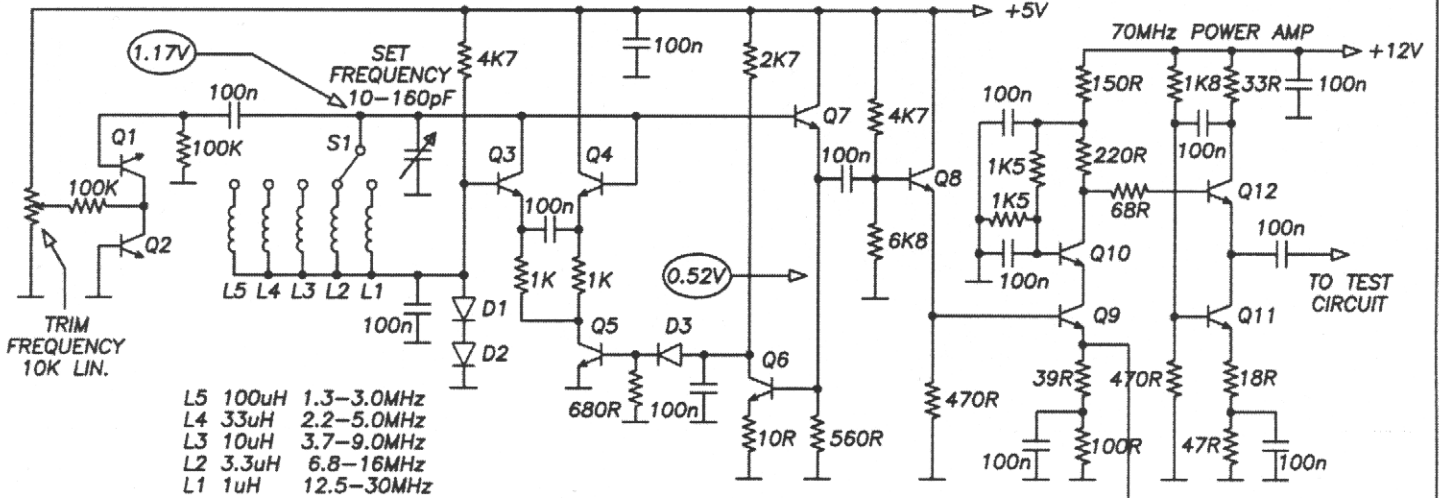
05.136MHz R=050Ω
X=000Ω SWR=1.00_

4DIGITS

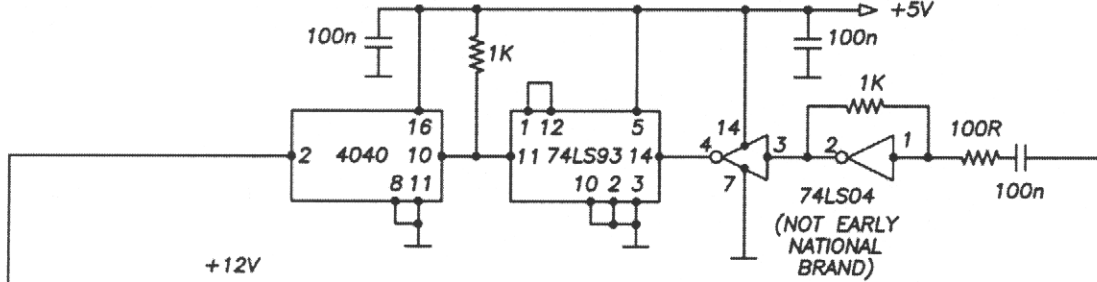
POWER



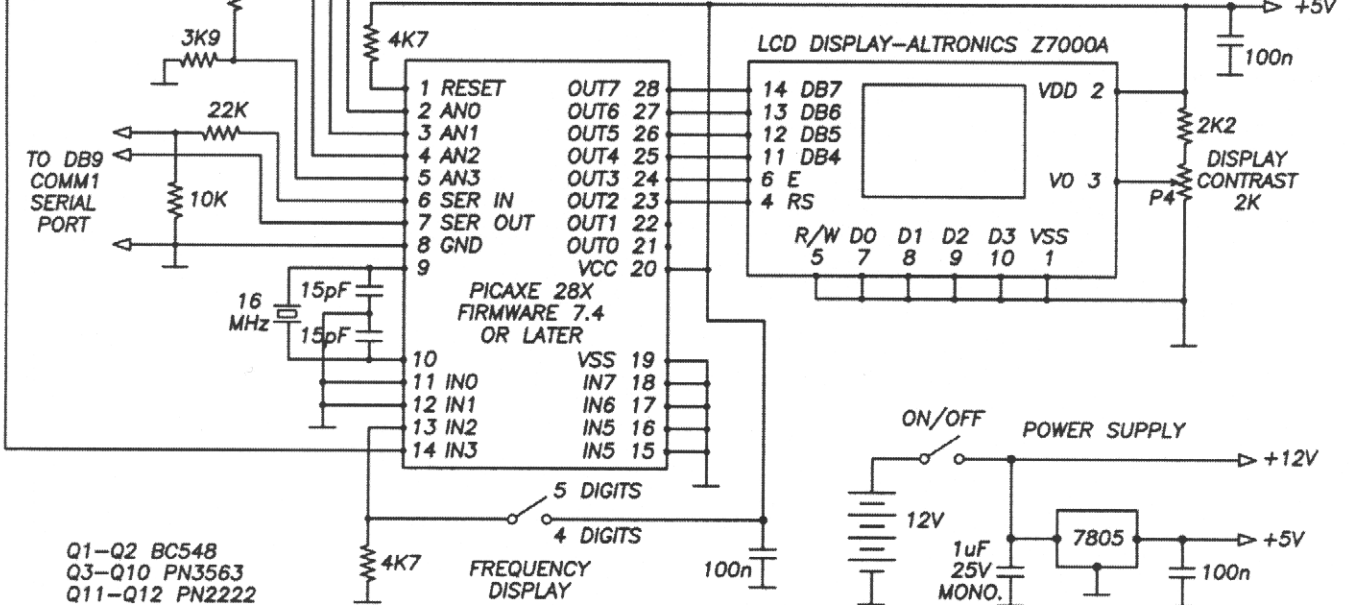
SIGNAL GENERATOR



AMPLIFICATION AND PRESCALING FOR FREQUENCY COUNTING



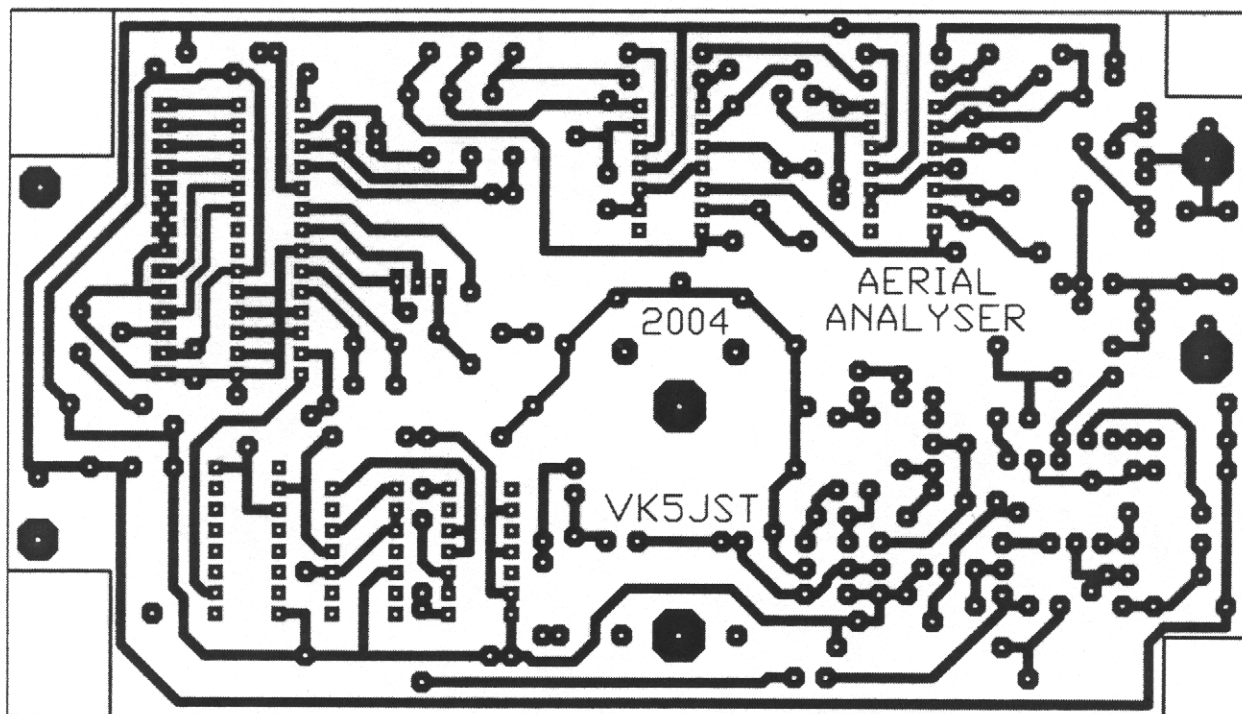
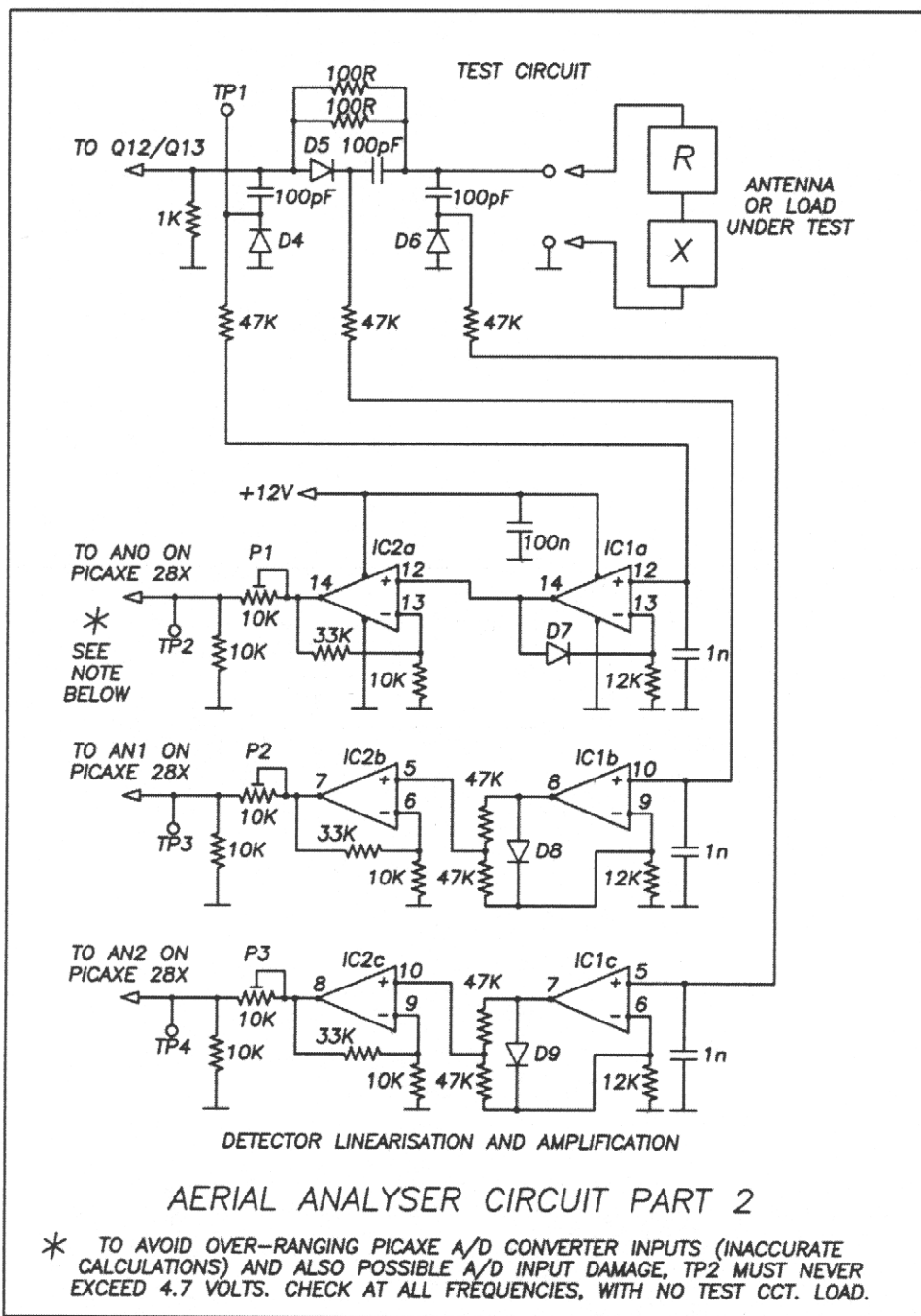
LCD/MICROPROCESSOR CONTROL



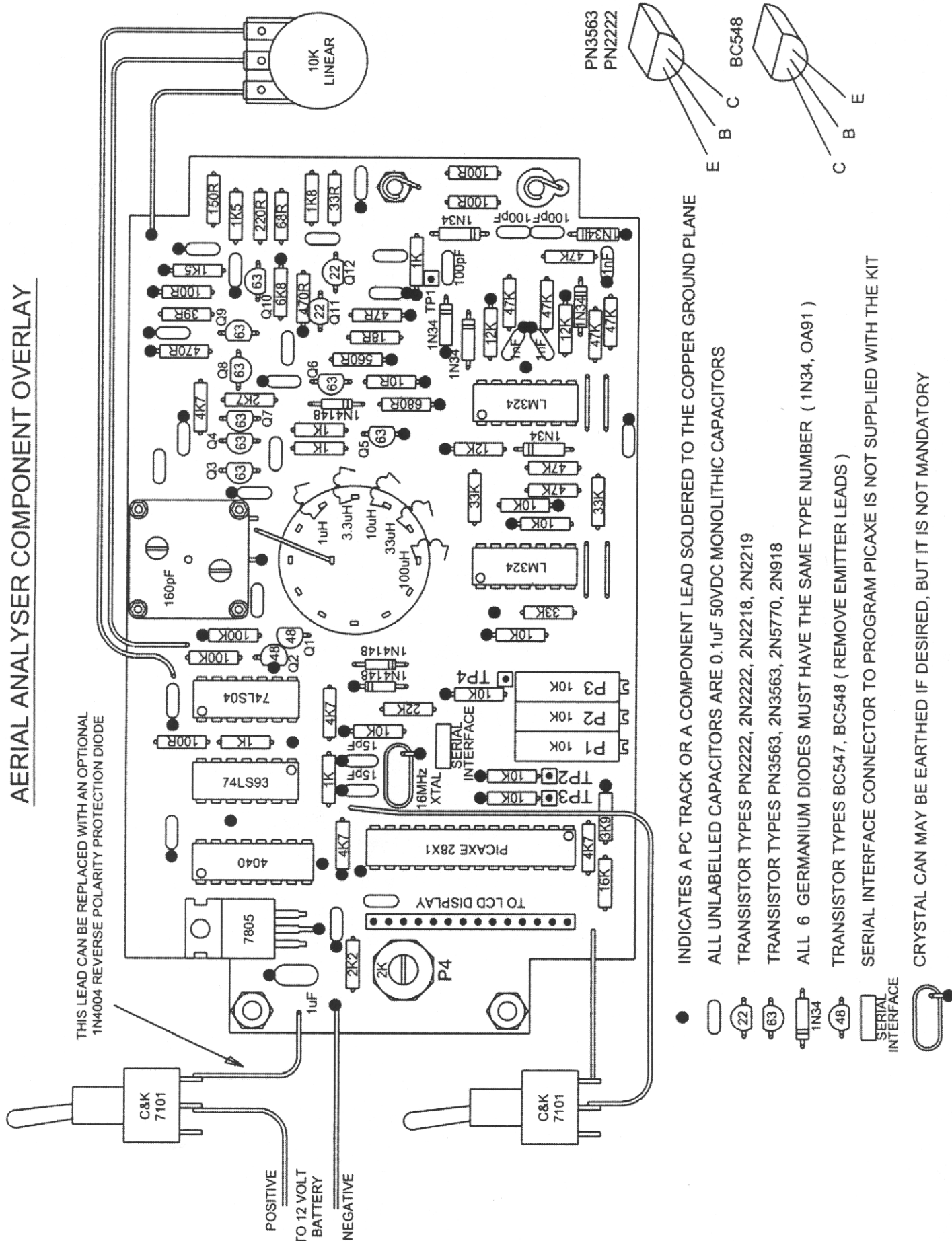
- Q1-Q2 BC548
- Q3-Q10 PN3563
- Q11-Q12 PN2222
- D1-D3 1N4148
- D4-D9 1N34
- IC1-IC2 LM324

AERIAL ANALYSER CIRCUIT PART 1

VK5JST-SEP. 2004



AERIAL ANALYSER COMPONENT OVERLAY

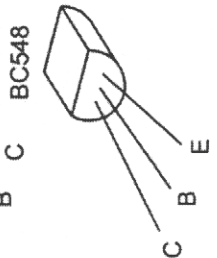
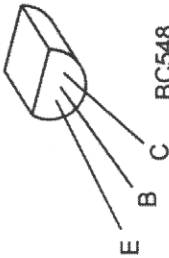


THIS LEAD CAN BE REPLACED WITH AN OPTIONAL 1N4004 REVERSE POLARITY PROTECTION DIODE

POSITIVE
TO 12 VOLT BATTERY
NEGATIVE

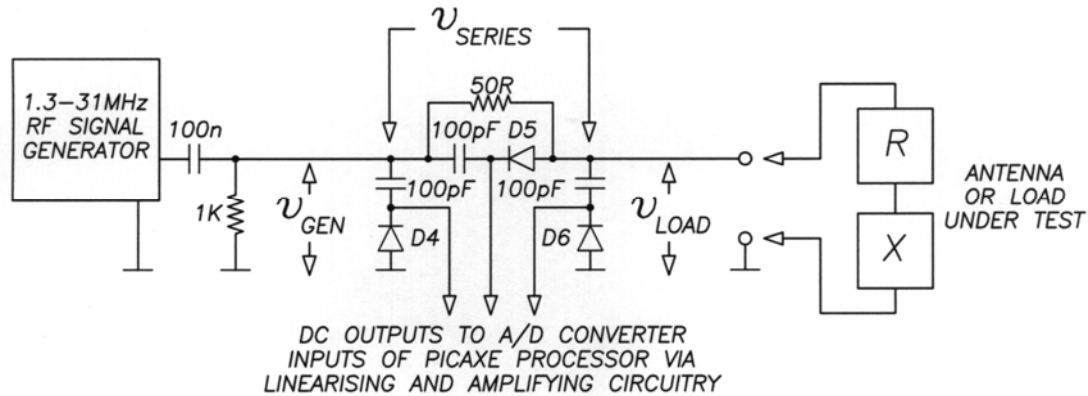
- INDICATES A PC TRACK OR A COMPONENT LEAD SOLDERED TO THE COPPER GROUND PLANE
- ALL UNLABELLED CAPACITORS ARE 0.1uF 50VDC MONOLITHIC CAPACITORS
- TRANSISTOR TYPES PN2222, 2N2222, 2N2218, 2N2219
- TRANSISTOR TYPES PN3563, 2N3563, 2N5770, 2N918
- ALL 6 GERMANIUM DIODES MUST HAVE THE SAME TYPE NUMBER (1N34, OA91)
- TRANSISTOR TYPES BC547, BC548 (REMOVE EMITTER LEADS)
- SERIAL INTERFACE CONNECTOR TO PROGRAM PICAXE IS NOT SUPPLIED WITH THE KIT
- CRYSTAL CAN MAY BE EARTHED IF DESIRED, BUT IT IS NOT MANDATORY

PN3563
PN2222



PLEASE NOTE THAT THESE INSTRUCTIONS ARE THE MINIMUM NEEDED TO COMPLETE THE KIT. MUCH GREATER DETAIL (AND OTHER GOODIES) INCLUDING COMPREHENSIVE DIAGNOSTIC DATA AND ADDITIONAL SOFTWARE ARE TO BE FOUND ON THE WEB SITE OF VK5JST
[\(<http://www.users.on.net/~endsodds>\)](http://www.users.on.net/~endsodds)

IMPORTANT.....The Picaxe chip and LCD display are static sensitive devices. Avoid damage by using correct handling procedures. Essentially this means bringing everything to earth potential so that no discharges can occur. This means you, the chip being unpacked or handled, the solder, soldering iron and mainboard.



THE THEORY

Before starting construction, it is worth briefly considering the principles of operation so that construction can proceed logically. Heart of the unit is the test circuit shown above (please also see main circuit). To enable measurement of the full characteristics of the load, a 50 ohm resistor is placed between it and the variable frequency RF generator feeding the test circuit. Three AC voltages are then measured, by rectifying them to form DC. The peak value of each ac voltage is stored in a capacitor and the resulting dc passed on to the Picaxe processor. The three voltages are the generator output voltage (V_{GEN}), the voltage across the 50 ohm series resistance (V_{SERIES}) which represents the load current, and the voltage across the load (V_{LOAD}). From these three outputs, the SWR, the series load resistance, and the magnitude (but not sign) of the series load reactance can be calculated, and the mathematics for this is detailed in the original article to be found on the home page shown above. This leaves the question of how to determine whether the load reactance is capacitive or inductive. To answer this, the user simply changes the generator frequency slightly. If the magnitude of the series reactance increases as the frequency is increased then it is an inductor. And vice versa for a capacitor.

Note that if the load resistance is a pure 50 ohm resistor, then exactly half of the ac generator voltage applied to the test circuit will appear across the 50 ohm load, and half across the 50 ohm resistor in the test circuit. This comment also applies to the dc voltages derived from these ac voltages, and this handy fact is used to calibrate the instrument to read 50 ohms and an SWR = 1 when it is being set up.

HOW IT WORKS

The process starts with an RF signal generator. This must provide a stable, flat, high level sinusoidal output into the test circuit, combined with a low output impedance. The need for frequency stability is obvious, while the low output impedance and flat output characteristic guarantee the largest possible signal into the microprocessor analog to digital converter inputs from the test circuit detectors. This ensures that independent of the load applied to the test circuit, the calculations will have maximum accuracy. The sinusoidal output ensures that the measurement occurs only at a single frequency and is not upset by what happens at harmonics of the generator frequency.

These goals are attained by using an RF oscillator with an AGC circuit. Q3 and Q4 provide broadband gain (coupled collector to base then emitter to emitter), and the frequency of oscillation is set by the variable 160pf

tuning capacitor and inductors L1 – L5. Fine tuning is provided by back to back varicap diodes fabricated from the reversed biased collector base junctions of Q1 and Q2. The level of oscillation is set by the current flowing through Q3 and Q4, which in turn is set by the AGC circuitry Q5 and Q6. At switch-on when there is no oscillation, the 2K7 resistor in the collector of Q6 turns Q5 hard on causing maximum current through Q3 and Q4, and hence rapid build up of oscillation. As the oscillation increases, Q6 acts as an envelope detector and its collector potential falls, starving Q5 of base potential and hence limiting the current through Q3 and Q4. This process stabilizes the level of oscillation. AGC action is excellent because the AGC system has a very high gain, and the result is a very constant level of oscillation at the emitter of Q7 of around 600mV p-p.

This output is then buffered and amplified by a wideband power amplifier, comprised of Q8 through Q12. The amplifier provides a voltage gain of 5, and an output impedance of a few ohms to drive the test circuit with around 3 V p-p. The emitter follower Q8 provides a low impedance drive to a cascode voltage amplifier Q9 and Q10 (the cascode structure eliminates Miller effect and ensures a very wide bandwidth). These transistors in turn drive an emitter follower Q12 with active pull down Q11, ensuring equal current source and sink capabilities. The 70MHz bandwidth ensures the RF drive level to the test circuit remains flat to 30MHz.

Drive for the frequency counting function of the microprocessor is stolen from the emitter of Q10, and is amplified and buffered using a 74LS04. This is then divided by 1024 in the following 74LS93 and 4040 divider chips, and the resulting frequency is measured with the Picaxe to form a frequency display. Dual gating intervals are provided for frequency counting function of around 0.1 second and 1 second under the control of a logic level on pin 13 of the microprocessor. The shorter gating interval allows the user to “track” and easily set the generator frequency, while the longer gating interval allows the accurate frequency measurements which are necessary on very odd occasions. In practice, the 1 second gate which gives 5 digit frequency accuracy will almost never be used, as this accuracy is only really necessary for very narrow band HF antennas such as multi element wire yagis. Also note that in line with standard frequency counter practice, the display will “blink” as is updated with new information at the end of each gating interval. To save precious microprocessor memory, only one display routine is used, and in the four digit mode, the last digit of the 5 digit frequency display is permanently set to zero.

The 3 voltages discussed previously in the “Theory” section are derived from the test circuit using germanium diode envelope detectors. Note that only point contact germanium diodes can be used here (D4 – D9) as despite what the schools usually teach, germanium diodes have a zero turn on potential provided the load resistance they drive is high enough (in this circuit around 50 Megohms). This is not the case with silicon diodes (with turn on potentials around 500mV) or even with the best “zero bias” hot carrier diodes, which actually have turn on potentials of around 100mV. For SWRs of around 10 (a 5 ohm load on the test circuit) only about 150mV peak will be applied to D6. For accurate calculation, it is very important to have linear detection. Even with germanium diodes, the bottom end of the detector characteristic is very non-linear and must be linearised somehow. This is achieved by using the diode characteristic against itself in negative feedback loops around IC1A, B, and C. Each linearised output is then amplified by 4.3 (IC2A, B, and C) before being applied to the A/D converter inputs of the microprocessor. Much software muscle is then used to produce displays of resistance, reactance and SWR.

BUILDING THE ANALYSER

The first item to complete is the instrument case. The blank PCB can be used as a template to accurately mark and drill the box lid for all terminals, mounting pillars and switches. Once this is done, the central hole for the frequency selecting switch in the lid can be used to position the engraved front panel, which in turn is used to mark out the hole for the liquid crystal display. This hole is carefully formed, and the front panel is then attached to the box lid with contact adhesive, or double sided adhesive tape.

Next, using the component overlay provided, mount all components on the PCB starting with the lowest profile items and working upwards. The four links next to the two LM324 op amps go in first, followed by the six feed through connections, which connect various pads on the track side to the ground plane. It is firmly suggested that component leads are not bent over significantly on the track side of the board during soldering, as in the event of a mistake, this can make component removal very difficult and possibly cause permanent damage to the pcb. Use IC sockets. This allows progressive testing of the circuitry rather than the “apply power to everything and hope” approach.

Assume nothing!! Use your digital voltmeter to check the value of every resistor before installation. Check the pinouts of your transistors by using the current gain checking feature on your DVM. An indicated current gain of more than 50 shows you have the correct pinout. The printed circuit layout used is rather unusual in that a lot of component leads are soldered directly to the ground plane. This is deliberate as it is good rf practice, keeps the pcb cheap due to the lack of plated through holes, and allows the board to be made at home if desired. Keep the leads on all monolithic bypass capacitors to the absolute minimum possible length.

Minimising stray capacitance in the test circuit is important, as it appears in parallel with the load and can very slightly upset measurements at high frequencies and high SWRs. It can be minimised by mounting the following components away from the ground plane by 1-2mm (a) D5 and the associated 100pf and 47K (b) D6 and the associated 100pf and 47K and (c) the two 100 ohm test circuit series resistors.

Before mounting the band switch, remove the nut and lock washer and move the washer with the end stop pin so that the pin goes into hole position 5. This limits the switch rotation to five positions. Then place the switch into the printed circuit board so that pin 1 is near to the tuning capacitor body. This should be possible, using one of the four holes provided in the pcb for the locating pin on the switch body. Unfortunately, there are many variants of this single pole 12 position rotary switch design and at any one time it may not be possible to obtain exactly the same unit from our suppliers. Please see the comments on the VK5JST website if you have difficulties with the switch. It is NOT necessary to take the switch apart despite comments to the contrary on the web. In fact doing this is inviting disaster.

Double-check all your soldering and component orientation/values very carefully, particularly those which will appear under the LCD when mounted. Finally, mount the LCD, spacing it away from the main PCB by 5-6 mm with a thin piece of polystyrene foam or similar. Use thin flexible tinned copper wire (0.5 mm dia) to interconnect these two boards - this will allow the LCD to be hinged away from the main board if there is an error or omission. Position the display correctly first, by just inserting the two outside connecting wires between the display and main board, and then soldering these to lock the display into final position. Then drop the central wires through the display and main board holes, soldering and trimming each wire in turn.

The main board is then mounted on the front panel. It is supported at one end using countersunk screws and 10mm long nylon spacers, while the other end is supported by the two test terminals. The bottom of the case will need to be relieved so that the knob on the main tuning capacitor can protrude from the side of the case. Likewise the case bottom must be drilled to accommodate the miniature fine-tuning potentiometer, which mounts next to the batteries in the case bottom. Complete all wiring to the two switches, the battery holders, and the fine frequency adjusting potentiometer. Attach the battery holders to the case bottom with contact adhesive or double sided tape. Note that the unit requires a supply of 12 VDC. This means 8 @1.5V zinc carbon batteries must be used in the battery holders supplied. If you wish to NiCd or NiMH rechargeable cells (1.2 VDC) then 10 cells must be provided and the case bottom needs to be fitted with a 10 cell holder (not supplied) which will just fit the case if the reinforcing ribs at either end of the case are carefully removed (use a sharp wood chisel). Note that the much higher capacities of modern batteries also allows the use of rechargeable AAA cells. This completes all work on the case.

SET UP AND TESTING

With all ICs unplugged, apply 12 volt to the PCB. Check the output of the 5 Volt regulator with a multimeter (4.75- 5.25VDC). The contrast pot should be adjusted so that the top line of the LCD displays all black squares. If you have an oscilloscope (50MHz or more preferred), fit it with a correctly set up X10 probe and monitor the emitter of Q7. Note that an X1 probe, which is really around 1 meter of coaxial cable with convenient connectors on each end, will totally wreck instrument operation due to excessive capacitive loading. A clean sine wave at a level of 600mV p-p +/- 10% should be present at Q7 emitter, independent of the frequency selected. Likewise, 3 volts peak to peak of rf at the "hot" rf test circuit terminal, or the junction of Q12 emitter/ Q11 collector, shows the oscillator and buffer amplifier are working properly. Fit the 2@LM324s. If you don't have a scope, correct operation of the oscillator and buffer amplifier will be indicated by around 1.4VDC appearing at IC1 pin 14 at all frequencies (the peak value of the rectified ac at the input to the test circuit).

With the "TRIM FREQUENCY" pot set centrally, the main tuning capacitor set to minimum capacitance, and the 12.5 to 30MHz range selected, monitor the "hot" test circuit terminal with a frequency counter and use the

trimmer on the main tuning capacitor to set the output frequency to 31MHz. Now check the frequency coverage on all ranges. Finally, set the oscillator frequency to 2MHz. Switch off.

Plug in the 74LS04, 74LS93, and 4040. Switch on. Your scope should show around 2KHz of 5V p-p square wave at pin 14 of the PICAXE if the pre-scaler is working correctly. Check prescaler operation (divide by 1024) on all other frequency ranges and then re-set the frequency to around 2MHz. Without a scope you will have to wait until the Picaxe is plugged in to check prescaler operation. This will be shown by the LCD indicating the correct frequency.

Connect two 100 ohm 1% 1/4watt metal film resistors across the test terminals (50 ohms). Monitor TP2 with a DVM and adjust P1 until a DC voltage of exactly 4.500 volts appears. Then adjust P2 and P3 until exactly 2.250 volts appears at TP3 and TP4 when checked with the DVM. This completes initial calibration. Switch off and plug in the Picaxe. Switch on.

Your analyser should now be alive! For the first 1.5 seconds the battery voltage should be indicated with an accuracy of around +/- 5%, and then the display should show a frequency of around 2MHz, $R=050\text{ohms}$, $X=000\text{ohms}$, and $\text{SWR}=1.00$. Recheck the voltages at TP2, 3 and 4 if this is not the case, and also measure the battery drain (around 100mA total). Also check that the fast and slow frequency gating intervals are correct (4 or 5 digit mode). If the frequency indicated is around 8MHz and the gating is very slow, the Picaxe is using its internal RC default clock of 4MHz instead of the external 16MHz crystal, and you have a fault in the crystal circuit connected to pins 9 and 10 of the Picaxe. This is also possible if you have decided not to use the preprogrammed Picaxe supplied, but instead have loaded the Picaxe yourself with an early version of the software written for the Picaxe 28X rather than the Picaxe 28X1 supplied with the kit. See the VK5JST homepage for a fix.

Remove the 2 @100 ohm load resistors and replace them with a single 270 ohm 0.25 watt metal film resistor with short leads. The analyzer should now indicate a resistance of 270 ohms +/- 10% together with an SWR of around 5.4 and a reactance of zero. If the reactance X is not zero, adjust P3 by a small amount until it is. Recheck the analyzer with the 50 ohm load again. This double check forces best linearity over the impedance range.

Depending on the circuit conditions for which your crystal was made, you may wish to slightly change the count periods specified in the "count" statements in the software so that the analyser shows an exactly correct frequency. You can also modify the battery voltage indicated at switch on, and this can be adjusted in two ways. The value of one of the resistors which form the voltage divider connected to Picaxe pin 5 (16K and 3K9) can be adjusted, or you can modify a constant provided in the battery measuring routine within the Picaxe software. If you wish to modify the analyser software, please see the procedure detailed on the VK5JST homepage. Connect a 300mm length of hook up wire between the test terminals and select a frequency of around 30MHz. Depending on the wire diameter and the shape of the single turn coil you have made, the skin effect resistance will be around 4-10 ohms and the inductive reactance around 80 ohms. When the wire is disconnected the instrument will display the reactance and loss resistance of the few pF of stray capacitance in the test circuit and will not indicate an open circuit until the frequency falls below about 15MHz. Another way of looking at this is to say that the instrument is displaying the characteristics of a very short length of transmission line connected to the test circuit (the terminals etc). There are typically around 4 pf of strays in the test circuit and standard coaxial cable has a capacitance of 100 pf/metre and so the strays equate to an unterminated length of coax of around 40mm. In any practical HF measurement, this will be absorbed into the antenna and feed line being measured and is so short it is negligible.

Congratulations, and enjoy using your analyser.

AHARS November 2011

PARTS LIST

RESISTORS

1- 10R
1- 18R
1- 33R
1- 39R
1- 47R
1- 68R
4- 100R
1- 150R
1- 220R
2- 470R
1- 560R
1- 680R
5- 1K
2- 1K5
1- 1K8
1- 2K2
1- 2K7
1- 3K9
4- 4K7
1- 6K8
7- 10K
3- 12K
1- 16K
1- 22K
3- 33K
7- 47K
2- 100K

POTS AND TRIMPOTS

1- 10K linear 16mm pot and knob
3- 10K multiturn cermet trimpots
1- 2K trimpot

CAPACITORS

2- 15pF NPO 50V ceramic
3- 100pF 50V ceramic
1- 160pF variable capacitor
3- 1nF 50V monolithic caps.
19- 0.1uF 50V monolithic caps
1- 1uF 50V monolithic cap.

HARDWARE

1- liquid crystal display
2- C&K type 7101 SPST switches or equiv.
1- 12 position single pole rotary switch and knob
2- 10mm long 3mm bore nylon standoffs
1- red 4mm binding post terminal
1- black 4mm binding post terminal
4- 14 pin DIL IC sockets
1- 16 pin DIL IC socket
1- 28 pin DIL IC socket
2- 4 X AA battery holders
1- Jiffy Box UB1
1- PCB
1- engraved front panel
1- 16MHz quartz crystal
4- header pins
Miscellaneous 3mm screws, washers, nuts, wire
1 set of documentation

SEMICONDUCTORS

2- BC547 or equiv.
8- PN3563 or equiv.
2- PN2222 or equiv.
6- 1N34 or equiv.
3- 1N4148 or equiv.
2- LM324
1- 74LS04
1- 74LS93
1- 4040
1- 7805
1- PICAXE 28X1
1- 1N4004 (optional-see overlay)

INDUCTORS

1- 1uH RFC (brown, black, gold)
1- 3.3uH RFC (orange, orange, gold)
1- 10uH RFC (brown, black, black)
1- 33uH RFC (orange, orange, black)
1- 100uH RFC (brown, black, brown)



INSTRUMENT CONTROLS

A Test terminals. Use a balun if you are making measurements on a balanced system such as a dipole.

B Frequency Range Selection

C Coarse frequency adjustment

D Fine frequency adjustment – gives around 4KHz of variation at 1.3MHz and around 500KHz variation at 31 MHz

E Liquid Crystal Display – This will “flash” each time the display is updated with information either every 100ms or 1sec depending on the frequency resolution selected by F.

F Frequency Resolution Switch - This switch selects the frequency counter gating interval and hence the number of digits actively displayed. In the four digit position the last digit of the frequency display is permanently set to zero and the resolution is 10KHz. The display is updated every 100ms and this allows the user to rapidly set the operating frequency. In the five digit position all frequency digits operate, the gating interval is 1second, and the display resolution is 1KHz.

G Power Switch – Instrument draws about 100milliamps, giving a battery life of at least 4 hours when cheap 400 milliamp hour zinc carbon cells are used.

OPERATING INSTRUCTIONS

1. Insert 8 AA size batteries in the holders provided inside the unit. See comments in the body of the kit instructions if you wish to use rechargeable cells.
2. Turn on the power switch and the display will come up with the initial screen showing the battery voltage for 1.5 seconds. The main measuring screen then comes up showing the frequency in the top line followed by the resistive part of the load. The second line displays the load reactance, and the SWR based on a 50 ohm system.
3. Select either a 4 or 5 digit frequency display. 4 digit resolution should almost always be used unless measurements are being made on a very narrow band HF antenna.
4. Adjust the operating frequency so that the reactance shown is as near zero as possible. A reactance of zero occurs at the natural frequency of resonance of your antenna and the analyser will then show the feed resistance and SWR of your antenna system.

OTHER NOTES

1. 4mm connectors have been deliberately selected so that the stray capacitance is minimised in the test circuit, and so components or wire antennas can be conveniently connected to the instrument. See the VK5JST home page for adaptors for baluns and coaxial cable.
2. The Picaxe used in the Aerial Analyser can be easily re-programmed by downloading the Programming Editor (called BAS805.exe) from the Revolution Education website – <http://www.picaxe.co.uk>. The VK5JST website has a lot of alternative software written by other amateurs. A popular option is to include your call sign in the start up screen on the instrument.
3. Experimenters may wish to try extending the analyser frequency range upwards and downwards. Extra positions are provided for this on the frequency range switch. See VK5JST site for details.