Homebrew Poor Man Antenna Analyzer (HPMAA)
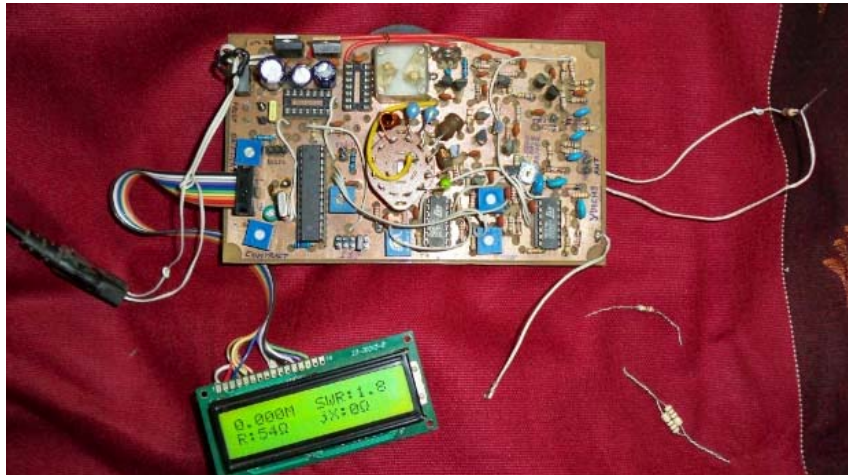
Started From The End of August, 2010
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1. Abstract

The need of a useful tool for measuring antenna impedance and its resonance frequency is a must for an amateur radio who wants get an optimum performance. Unfortunately, there are many unlucky HAM who could not spend much money for it. In Indonesia a medium quality one costs about four million rupiahs (or US$400), such a big cash for us. One solution that could solve this problem is homebrewing it using locally available components which would be cost only about US$30.

There were many techniques appeared in the net, however I adopted such a simple technique in my week end project, i.e. Vector Analysis technique. Several HAMs had been worked for this technique, including VK5JST, UT2FW, ZL2PD and RX3ADU. It occupies a broadband regulated amplitude oscillator, a set of diode detector and a microcontroller for its calculation. According to those references, I decided to mixed their designs in order to adapt locally available components at my town as well as reduce its development cost. Several modifications had been done, they were transistor types on VFO block, Prescaler circuit on frequency counter block and an ATMEGA-8 microcontroler on MCU block. Furthermore, several features had been added, such as "Debug Mode" that switch it into debugging and calibrating purpose, "PC Data Logger Mode" that sends all calculating result into PC via a serial communication for further processing. The ATMEGA-8 was occupied for several reasons such as easly found, inexpensive price, 28 pins and a huge flash program memory.

The tool could measure within entired HF band, where the frequency is represented by two digits fractional as like as an SWR display. The R and jX are represented by two digits integer number, because a very accurate reading for them is unnecesary. The jX is always positive, due to limitation of the calculation method, however it can be determined by a proper operational procedure.

When the PC.5 is set LOW, it means "Debug Mode" is activated. Normal calculation will be stopped, meanwhile four values would be displayed on LCD, they are Number of Clocks entering T1, Pure integer value read by ADCs – Vin, V50 and Vout. This mode is quite worked for me.

If we need to record calculation result into PC for further processing, such as plotting into spreed sheet or simply create a graphical presentation, we should activated PB.1 to become LOW. This feature will do two things, displaying calculation result into LCD as well as sending it into PC via serial communication simulatnously. Furthermore, when PC.5 and PB.1 are activated together, debug data will be displayed into LCD, at the same time sent it into PC.

Its overall performance has been satisfied my expectation so far. I hope it can solve most Indonesian HAM searching for, an inexpensive, easy construction, locally availabled components and joy of building an own Antenna Analyzer. The Circuit Diagram, PCB Art Work and Firmware HEX for this project are attached in this article, could be freely utilized for personal or education purposes. Please keep my footprint on it.

2. Science Behind

As I had told before, it works using Vector Analysis Method which evaluates three different voltages, they are Vin, V50 and Vout. Vin is input voltage of R50 and antenna/ load. V50 is voltage of the R50, and finally Vout is voltage of the antenna/ load. Kirchoff 's Law says that Vin = V50 + Vout. Remember, that equation is not only satisfied real number but also imaginary one. When managing the imaginary number calculation, a Vector Analysis is such an easy way to cope with it. Perhaps, that is way this method was called by. Picture below should give us more easier way to understand what we are dealing with.
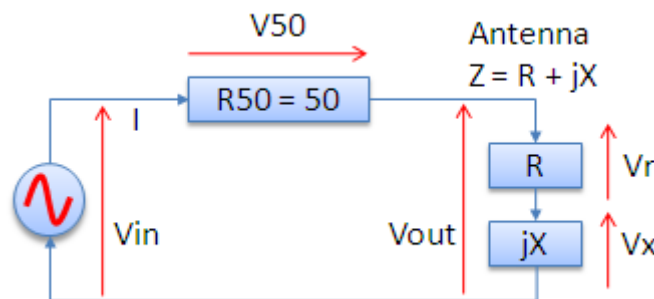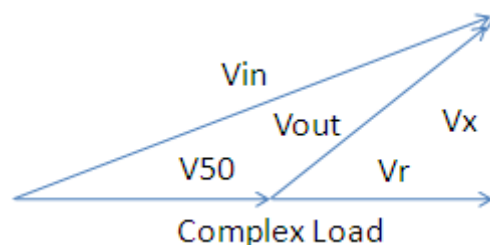

Figure 1 Diode Detector Schematic

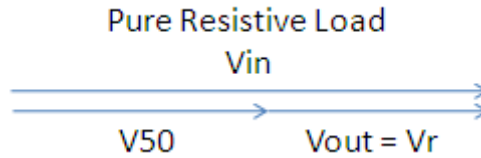**Figure 2 Vector Analysis For Complex Load**
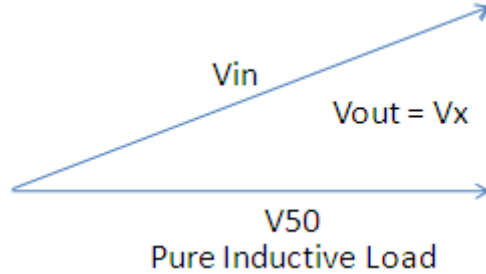
Figure 3 Vector Analysis For Pure Resistive Load

Figure 4 Vector Analysis For Pure Inductive Load

Those pictures clearly shows relation between all three voltages, Vin, V50 and Vout. Two famous postulates are ruled here, they are Kirchoff's Law and Phytagoras's Law. Both laws forces every possible condition occurred in the diode detector is always satisfy an ideal term, so that the calculation will give right results. Here they are:

Let say antenna/ load voltage is Vout = Vr + Vx, where Vr is resistive voltage and Vx is imaginary voltage. We assume that antenna input impedance is $Z = R + jX$.

Before we go deeply into both Laws, first of all is checking the Vin, V50 and Vout. There are three possible conditions, they are:

- If Vin << (or almost zero), it means VFO is not working. Stop next calculation.
- If V50 << (or almost zero), it means Load is Open Circuit. Stop next calculation.
- If Vout << (or almost zero), it means Load is Closed Circuit. Stop next calculation.

OK, here we come … Kirchoff's Law says …

Vin = V50 + Vout … (i)

Two possible conditions are:

- If Vin ≤ V50 + Vout, condition is verified, assumes the antenna as imaginary load ($Z = R + jX$) see picture 2.
- If Vin > V50 + Vout, condition is not verified, forces Vin = V50 + Vout, where Vout = Vr, assumes antenna as pure resitor (real load $Z = R + j0$) see picture 3.

Phytagoras's Law says …

$Vin^2 = V50^2 + Vout^2$ … (ii)

Two possible conditions are:

- If $Vin^2 < V50^2 + Vout^2$, condition is not verified, forces $Vin^2 = V50^2 + Vout^2$, where Vout = Vx, assumes antenna as pure inductive load ($Z = 0 + jX$) see picture 4.

- If $Vin^2 \geq V50^2 + Vout^2$, condition is verified, assumes antenna as imaginary load $(Z = R + jX)$ see picture 2.

Next calculation is solving the values of R, X and SWR as follow:

$Vr = (Vin^2 - V50^2 - Vout^2) / (2 * V50) \dots$ (iii)
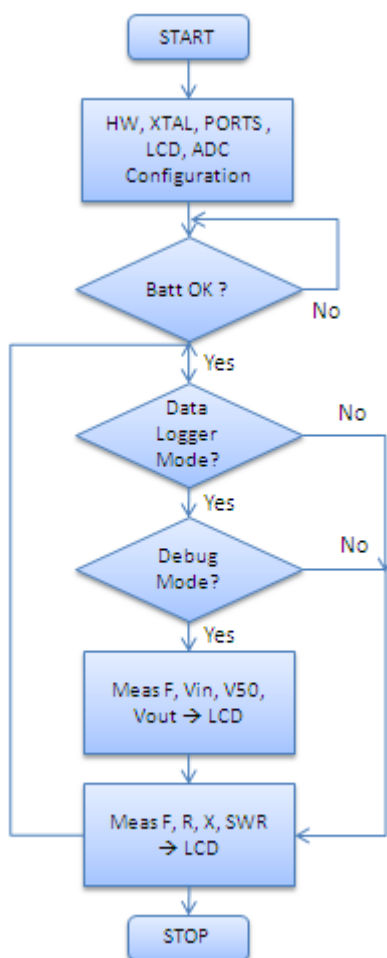
$Vx = SQRT(Vout^2 - Vr^2) \dots$ (iv)

$I = V50 / 50 \dots$ (v)

$R = Vr / I \dots$ (vi)

$X = Vx / I \dots$ (vii)

$X = SQRT((R + 50)^2 + X^2) \dots$ (viii)

$Y = SQRT((R - 50)^2 + X^2) \dots$ (ix)

$SWR = (X + Y) / (X - Y) \dots$ (x)

Due to limitation of the method, it could only provide positive imajinary value, where is not meant inductive load. Either inductive or capacitive load, the $Vin \leq V50 + Vout$ is always occurred. Now the challenge is how to determine whether the load is inductive or capacitive. Since imajinary load could have two possibilities, i.e. inductive $jX = jwL$ and capacitive $-jX = 1/jwC$, where $w = 2\pi f$. By increasing the f (frequency) slightly during measurement and evaluating the changing of imaginary value shown by LCD, we can determine what the imaginary load is. If imaginary value shown by LCD is increased that it means inductive load and vice versa.

3. What Does MCU Do ?

ATMEGA-8 is occupied using external X'tal clock, i.e. 8MHz (it has top maximum value of 16MHz). Different with other MCU outside there, the ATMEGA-8 will do as fast as its X'tal clock i.e. 8MIPS (Mega Instruction Per Second), such a quite fast computation ability. It has 24 pins, where all of them are fully occupied efficiently. Please note, I use ATMEGA-8, not ATMEGA-8L, however both can be used fit with our firmware. They have some different abilities, such as their top external X'tal frequencies, i.e. 8MHz for ATMEGA-8L and 16MHz for ATMEGA-8. Since each location will have different available component, so that I chosed the 8MHz external X'tal in order to make the design more adaptabled.

A easy found and unexpensive 16x2 LCD is attached at PORTD and PORTB, using 4 bit mode. Meanwhile some of the ADC Port (PORTC) are used for Battery Checking (ADC0), Vin (ADC1),

V50 (ADC2) and Vout (ADC3). The rest are utilized as other purposes, i.e. ADC4 for controlling the frequency counter gate (74LS00) and ADC5 for controlling value added feature "Debug Mode" at LOW state. Other value added feature that is "Data Logger" via serial communication into PC is activated by set "LOW" the PORTB.1, thus data will be transmitted and received via PORTD.1 and PORTD.0 respectively. Both two features mentioned above could be run simultanously. Frequency counter is done by using T1 interupt, where the clock signal enters MCU via PORTD.5. A High-Speed CMOS Logic Dual 4-Stage Binary Counter 74HC393 is occupied to pre-scale incomming clock at 1:64 ratio. Its reset controller is not used in order to keep it simple hence reduce number of MCU's PORT utilized as controller. For two digit fraction frequency display, it doesn't give any error significantly. The last four PORTs, i.e. PORTB.2 till PORTB.5 are roled as ISP – In Circuit Serial Programming, it is such my favourite feature. Generally, the MCU will do procedures as depicted in the flowchart.

4. How The Hardware Works ?

As depicted in the block diagram below, the HPMAA is consisted of 5 main blocks, they are:
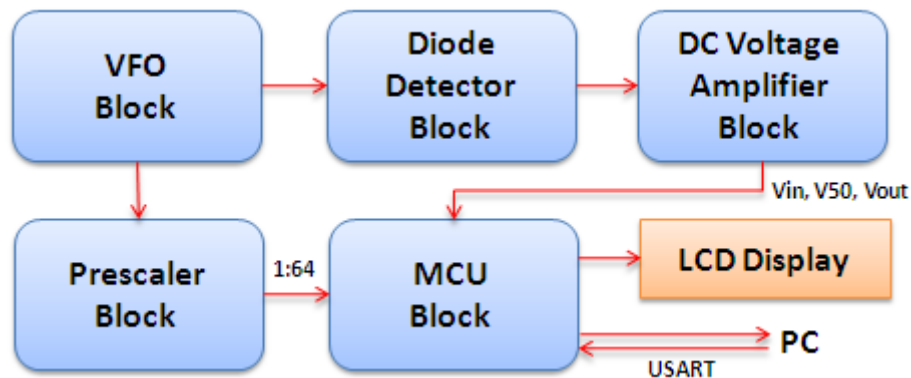

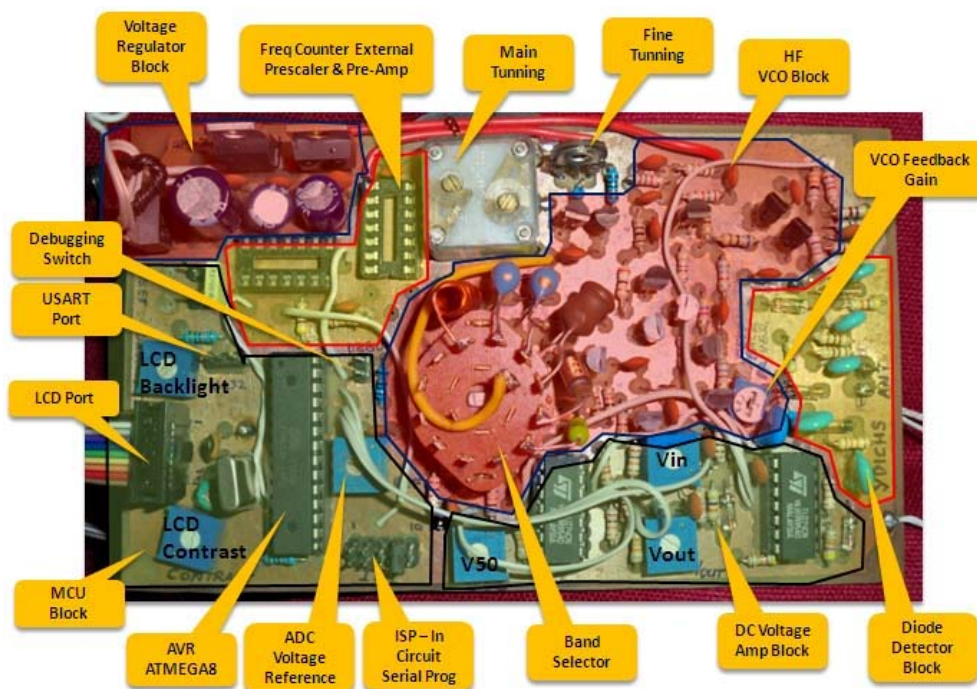**Figure 5 Homebrew Poor Man Antenna Anlyzer's Block Diagram**

Figure 6 Block Position and Component Layout

VFO Block

The Vector Analysis method requires a constant amplitude for entire measuring frequency range, in this particular case is HF Band 0.5-30MHz. Syntheziser was done by T3, where the oscillation frequency is determined by tank circuit that is formed by Bank of Inductors, Varco as well as T1 and T2 that are acted as varactor diode "Fine Tune". Band range is changed by manual rotary switch. The configuration is quite simple and conventional in order to keep its simplicity, hence reduce cost and development difficulty.

T7 is ruled as buffer and signal sampler that is used as negative feedback into syntheziser, by controlling internal resistance of the T4 and T5, hence stabilizes the amplitude produced by syntheziser. T6 is ruled as RF small signal amplifier loaded into rectifier D3. D3 changes incoming RF signal (AC) to became a Directing Current (DC). T8 is done as a buffer, which is fed into a broadband RF Pre-Amp formed by T9 and T10. Finally, to boost the signal T11 and T12 are occupied as broadband RF Amplifier. In order to increase the accuracy it is supplied by 12 volt, hence give output that will be swinged max. 12V peak-to-peak. The signal has to be able to activated diode detector beyong the VFO.

Diode Detector Block

The detector is formed using three germanium diode, notice: utilizing silicon or other kind of diodes may reduce measurement accuracy and linearity. D4 samples dan rectifies Vin voltage, D5 for V50 and D6 for Vout.

DC Linear Amplifier Block

Signal DC Vin, V50 and Vout then amplified by cascading DC amplifier which are formed by two inexpensive LM324s. A compensated circuits that are formed by D7, D8 and D9 which are the same types with D4, D5 and D6, in order to minimise unlinearity area introduced by D4, D5 and D6, hence keep measurement accuracy.

Each DC amplifier are added variable resistor to control the voltage level fed into ADC-1, ADC-2 and ADC-3. As datasheet said, each ADC input shouldn't exceed 4.7V. So that, we have to ensure for entire measurement frequency range, the Vin must not exceed 4.7V at an open circuit load.

External Prescaler Block

An analog HF signal should be convert into clock form before fed into MCU via T1. T13 is ruled as simple broadband HF pre-amp that boosts incoming signal to proper level. The 74HC00 does as a buffer as well as signal form converter. It has also gate which controls opening periode of the gate during frequency measurement.

The 74HC393 is occupied as External 1:64 Prescaler before fed into MCU, since MCU maximum frequency that can be measured usualy as high as X'tal Clock used, i.e. only 8MHz (if T Gate is 1 second). Using external 1:64 prescaler can increased top frequency limit to become 512Mhz theoritically, however in real world the 74HC393 top frequency limit is only tens MHz.

MCU Block

As had been told before, the MCU does calculation to determine Frequency, SWR, R, jX and others value added features. I will not decribe it again here.

Homebrew PCB Development

Figure 7 Preparing PCB Artwork on Glossy Photo Paper and Hot Iron
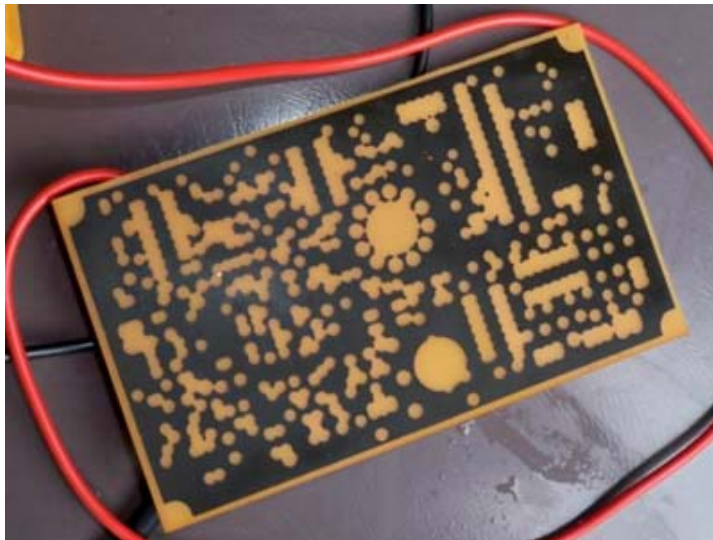

Figure 8 Soaking Into Soap Water

Figure 9 Transferred Artwork At a Double Layer PCB

Figure 10 After Etching – Double Layer: Ground Cladding

5. Development Hints

Working on an HF frequency is full of challenge, but please don't be panic. By proper development tips we can produce a high enough quality design. One should be kept in mind is connecting them as short as possible.

Let me share my priceless experience during developing its prototype on the project board. I used two pieces of project board that were joint together. The MCU and Prescaler blocks were laid on the first board, meanwhile the second one on another board. The result is quite weird and odd, the LCD was not initialized properly, LCD showed random and unreadabled characters. This problem had been made me "head ache" for all day long, while searching tons of information how to solve it on the net, untill incidently I reset it using a piece of wire that connected directly on the LCD's ground supply rail, even the physical jointing is quite good. Finally, I was enlighten that the connection should be done as short as possible with a good common ground supply rail. It remained me to a message on the net, that said an *"EMC issue"* could become a hidden problem that is very difficult to be coped with, that wasn't attract my intention at that time when I found it in the net.

The using of double layer PCB where one side is ruled as flat ground clading is highly recommended. I had prepared art work PCB either single or double layer for your experiment. A proper choosing of the components is also one of our succeed key. Especially for the tank circuit, it is recommended to use a negative temperature components, such as NPO or Polysteren Capacitors. The VFO is free running and has no locking mechanism such as PLL or Huff-Puff, so that its could be not so stable. In the firmware v.1.0, I haven't added a Huff-Puff feature into project. I hope it will be added someday. So please keep tuned for the next update version.

As I had mentioned previously, that the diode detector block and DC amplifier block should utilize germanium diodes with VHF operating frequency ability. The germaniun diode generally has a low forward voltage i.e. about 0.2V. The forward voltage is a voltage threshold that is naturally introduced by a barrier between PN junction. The threshold must be exceeded in order to force diode to be connecting state (active). Unfortunatelly, diode's line that is laid on its active region is not a linear one, that introduces a nature problem, i.e. unlinearity detection, hence influent the overall measurement results. This natural behaviour can be minimise by a compensation circuit, which is formed by same type of diodes used on the detector block. Choosing other diode types should gain worse performance than germanium ones. Unfortunatelly, it is most a challanging one to find germaiun diode at my local market now days. If we unlucky to find them, we can replace

them with germaniun transistor. Still unlucky, so please accept your destiny to replace them with cheap and easily founded silicon diode such as 1N4148 and feel its consequencies. Hi…

Actually, there are other methods can be utilized to calculate antenna's characteristics that were claimed gives better performance than this traditional diode detector, however this old method is the simplest and chepest one, that is fit with my objectives above. Meanwhile, for more perfectionist HAM, I have been developing next week end project using other method which more modern and more expensive.

6. How To Calibrate ?

Since we occupy set of DC amplifier just after the diode detector, so that it is possible the signal level out from the DC amplifier will vary from their actual values, hence will affect into overall calculation results.

Adjusting ADC Inputs

As we had known before, that maximum level permitted into ADC is 5V, above this value the Microcontroller will be simply burned out. So that, please protect your valuable component. Before everything worked properly, I recommend to unconnect three DC amplifier outputs from each ADC input port, i.e. ADC-1, ADC-2 as well as ADC-3.

Between Vin, V50 and Vout, the Vin is always had the highest level. Thus, if Vin level is always <4.7Volt for entire HF Band (at Open Circuit Load), the others voltage will be safe for each ADC input.
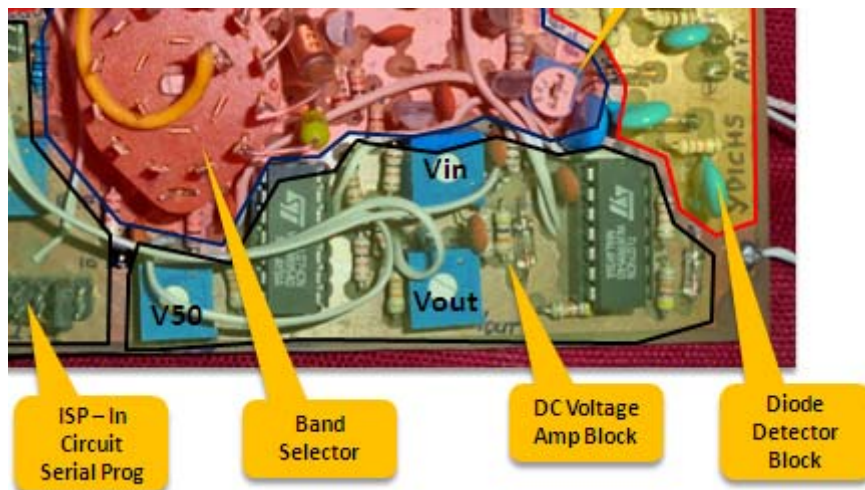
Figure 11 DC Voltage Amplifier

This adjustment can be done by evaluating voltage using digital multimeter at the output of DC Amplifier which boosts the Vin (TP2). Here is the procedure:

1. With an "open circuit load" attached into measuring ports, scan entired HF band by rotating main dial tuner, meanwhile keep eye into digital multimeter reading.
2. Find the frequency where the level is reached its maximum, note this frequency.
3. Tune back the frequency at its maximum (as you had been noted above).
4. Adjust the VR named as VIN until the voltage of the Vin (TP2) is not exceeded 5 Volt, let say 4.5 Volt. Something should remember, the higher is more accurate, however we have to

protect the microcontroller anyway. In PCB actually I had added a place for a 4.7V Zener Diode, but I haven't test it yet.
5. For a while, Vin adjustment is finish.

Now we have to adjust both V50 (TP3) and Vout (TP4). The procedure is follow:

1. Firstly, attached a accurate Resistor, let say 50 Ohm with 1% tolerance, into measurement ports.
2. Set the frequency at the centre of HF band, i.e. 15MHz.
3. Measure the Vin (TP2), by adjusting both VR named V50 and VOUT, both V50 (TP3) and Vout (TP4) should have voltage level half than Vin (TP2). Let say, if Vin = 4.5 volts, both V50 and Vout should be 2.25 volts.
4. Do the same procedure for some different frequencies.
5. Do the same procedure for several value os resistors, for example: 100 Ohm 1%, 2 serial 10 Ohm 1% or 20 Ohm, etc.

Adjusting Frequency Meter

Since frequency meter uses an internal software to measure the VFO frequency, we can not adjust it unless recompling its firmware. However, a sligthly adjustment still can be done by triming a VC attached on the X'tal 8MHz. It is ruled as VXO. But please, don't force it to go to far from its fundamental frequency. I designed this frequency counter with a low accuracy, because it is only display maximum 5 digits, including 3 fraction digits.

7. Its Performance

Figure 12 Frequency Measurement Test

Figure 13 SWR, R and X Measurement Test

This paper was written at 23th October 2010 where the project has not been completed yet. Several problem were still existed, they are:

- The signal waveform at the last band (21-32MHz) have both unpure sinusoidal and quite small amplitudo, hence introduces unaccurated and unreliabled measurement result. The non sinusoidal waveform at the time domain means uncleaned spectrum at the frequency domain. Meanwhile, small amplitudo forces the diode detector to be worked at its unlinear zone (near to its cut-off zone). I will manage to this problem at the near future, so please stay tune.
- Even the frequency counter algorithm had been working properly, but I haven't install its external pre-scaler circuit at my project. My consentration is still at the VFO.

I have tried to measure several resistor's values for this occasion, they are 26 Ohm (two parallel 51 Ohms), 50 Ohm (two parallel 100 Ohms) and 110 Ohms (two parallel 220 Ohms) by ignoring the last band i.e. 21-32MHz. The result was satisfied my expectation, the tool had been succeed to measure near to its real value, meanwhile the VFO stability was acceptable for most bands.
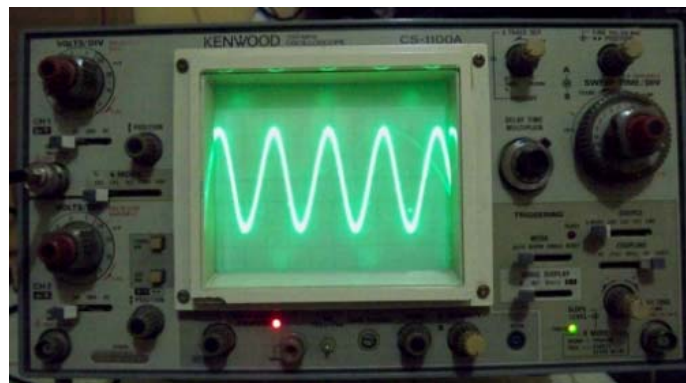
Figure 14 VFO output waveform 1.6-20MHz – Perfectly Sinusoidal Waveform
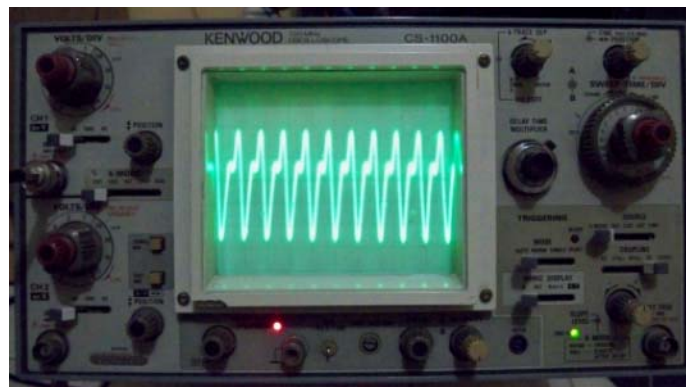
Figure 15 VFO output waveform 20-32MHz – Uncleaned Sinusoidal Waveform

8. Opportunity For Improvement

The tool has not been enclosured yet, since the experiments is still in progress. A simple grounded metal or PCB box might improve its performance.

I thing we can add a simple Frequency Locked Loop (FLL) for its VFO, however it could introduce an additional delay for the whole process, but worthy to be tried in order to improve the VFO's stability.

An additional small signal RF amplifier might be inserted on the VFO, since its highest band amplitude signal is quite small, in order to improve measurement reliability.

9. References

[1]. www.users.on.net/~endsodds/analsr.htm - The VK5JST homepage. It contains tons of informations regarding to the VK5JST Aerial Analyzer. It is a must read site.
[2]. http://www.zl2pd.com/digitalZmeter.html - The ZL2PD homepage. It contains a modification type of the VK5JST Aerial Analyzer, mainly on its VFO and Microcontroller board.
[3]. http://www.xs4all.nl/~pa0fri/Diversen/VK5JST/Ant_analyzereng.htm – The PA0FRI homepage. It containts modification of the VK5JST at most blocks.
[4]. http://www.rigexpert.com/index?s=articles&f=aas – Short Review about method behind famous antenna analyzer in the world. It is quite recommended page to be written.
[5]. http://www.atmel.com/ - The ATMEL official homepage.

H1 MOUNT-HOLE2.8
H2 MOUNT-HOLE2.8
H3 MOUNT-HOLE2.8
H4 MOUNT-HOLE2.8
H5 MOUNT-HOLE5.5
H6 MOUNT-HOLE5.5

+5V

C4 100n
GND
R4 4k7
R9 5k7 BC547
R11 4k7
C38 100n
GND   VCO-12BV   VCO-12CV   100n   GND
VCO-12AV
Z = R + jX

X1 X2
VIN 10k
TP2
C18
IC1D LM324N
IC2D LM324N
R34 33k
R36 10k
GND
C16 4k7
D7
R32 12k
R33 10k
GND
D8
1n

SW-1A
T1 BC547
C1 100n
T3 BC547
T4 BC547
T8 BC547
P$3 P$2 P$1
VARCO-BC
GND

C12 100n
GND
C7 100n
R17 150
R21 1k8
R22 33
C9 100n
R46 220
T12 2N2222
C11
T10 BC547
R14
R21 68
R28 2N2222
100
R06
TP5A TP5B
GND

C19 1n
IC1C LM324N
R35 47k
IC2B LM324N
R33 33k
V50 10k
TP3
R37 12k
R39 47k
R40 47k
R41 33k
R45 10k
C35 4k7
D8
1n
GND

FINE 10k
T2 BC547
R1 100k
R2 100k
GND
BAND

R5 1k
R6 1k
C5 100n
T5 BC547
R12 6k8
R13 470
R7 680
C2 100n
R8 10
R10 560
C6 100n
1N4148 LO35-7
D3
D1 D2 1N4148

L1 10H 33uH 10uH 33uH 100uH 133uH

R18 39
C10 100n
R19 100
R23 470
R24 18
R25 47
C13 100n
R27 47k
T9 BC547
C15
C17 100p
R26 1k
D4 AA112
D5 AA112
D6 AA112
R29 47k
R31 47k
R30 47k
GND

C20 1n
IC1B LM324N
R42 47k
R44 12k
R46 47k
R47 47k
IC2C LM324N
R48 33k
VOUT 10k
TP4
R50 10k
C31 4k7
D9
1n
GND

V2/+UB V1/+UB V1/-UB V2/-UB
+5V
GND GND

C23 C22 100n 100n
GND GND
V1/2 & 74HC00N
V1/3 & 74HC00N

R51 1k2
T13 BC547
R52 10k
C21 100n
GND
V1/1 & 74HC00N
V1/4 & 74HC00N
J2 J25MM
J1 J20MM

V2/1 CTRDIV16 CT=0
74393N
V2/2 CTRDIV16 CT=0
74393N
J3 J5MM
J4 J30MM
PD5

+5V
RST-A
N$73
R53 1k
C26 100n
GND

RST RST

VREF 10k
GND
C27 100n
GND

IC3 MEGA8-P
PC6(/RESET)
GND
AREF
AVCC
PB6(XTAL1/TOSC1)
PB7(XTAL2/TOSC2)
GND
VCC
PD0(RXD)
PD1(TXD)
PD2(INT0)
PD3(INT1)
PD4(XCK/T0)
PD5(T1)
PD6(AIN0)
PD7(AIN1)
PB0(ICP)
PB1(OC1A)
PB2(SS/OC1B)
PB3(MOSI/OC2)
PB4(MISO)
PB5(SCK)
PC0(ADC0)
PC1(ADC1)
PC2(ADC2)
PC3(ADC3)
PC4(ADC4/SDA)
PC5(ADC5/SCL)

22 25
8MHz Q1

R3 100k +5V
R55 18k +5V
TP6
TP7
R56 4k7
TO-PC
R54

DEBUG

PD0
PD1
PB0 10
PD7 8
PD6 6
PD4 4
PD3
PD2
LCD
GND
+5V

CONTRAST 10k +5V
GND
BCKLIGHT 10k +5V
GND

ISP
RST-B
PB3
PB5
PB4
+5V

PB1 R35 100k +5V

BATTERY BATTB BATTA
GND
IC5 7812TV VI VO GND
C28 100n
GND
12V
IC4 7805TV VI VO GND
C29 C32 100n 100uF
GND GND
IC6 7805TV VI VO GND
C30 C33 100n 100uF
J5 +5V
J6 J7 J15MM J25MM
C31 C34 100n 100uF
GND GND

DRAWN BY CHOLIS YD1CHS
TITLE: VCO_01
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Date: 9/1/2010 4:49:39 AM
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