ZL2PD Amateur Radio Website

Main

Version:

June 14, 2010:
Revised: v2.0

ZL2PD Digital HF Antenna Analyser

This instrument measures complex impedance over the 1.6 - 33 MHz HF spectrum. It also calculates and displays the VSWR of the impedance referenced to 50 ohms. The most common application of the meter is as an antenna analyser. The design was published in 'Break-In', New Zealand's amateur radio magazine in Jan/Feb 2006, and is republished here with the permission of the editor.

Note: 'Break-In' is a term used in amateur radio to describe a system which allows another person's signal to be heard in the brief intervals between transmitted Morse Code symbols.

Introduction

Why is it that having reached the top of the mountain and just begun to enjoy the rewards of the climb, you realise that there's another peak just that little bit higher to be seen in the distance? Such was the case a month or so after I completed an *analog* antenna analyser.

The analog meter did everything demanded of it, but there were times when a little more information would have been useful. I'd seen the next mountain top. (The analog meter is described on another page on this website)

I discovered, for example, that there are times when full information about the complex impedance being measured can be useful. An impedance is made up of two components; the *real* or resistive part, 'R', and the *reactive* part, 'X'. The reactive component may be capacitive or inductive.

Complex impedance can be displayed in two ways; Either as a magnitude plus a phase angle (i.e. A magnitude of "A" ohms at a phase angle of "B" degrees) or as a series combination of real and reactive components (i.e. C +/- jD ohms) where 'j' indicates the value of "D" is reactive. If "D" is positive, the impedance is inductive. If negative, the impedance is capacitive.

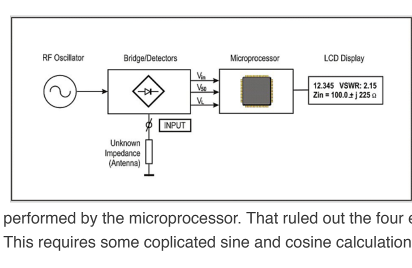
While it is possible to measure and display these components of a complex impedance using analog circuitry, this type of equipment can be complex. It is possible however to build some simple circuitry, and by making a careful series of analog measurements, some calculations will allow the real and reactive components of a complex impedance to be determined. An example is the "three meter" method used by Peter Dodd, G3LDO (See references 1 and 2, for example) (Note: All references appear at the end of this webpage). Another popular approach uses the bridge described in my page on the analog antenna analyser.

These days, it's far easier to use a microprocessor to carry out both measurements and calculations. Well, OK, it's easy to say, but more difficult and time-consuming to do! (The calculations required are briefly summarised in Appendix A for those interested in the details)

This page, then, describes this microprocessor-based antenna analyzer. It uses the 87C552, a device from the 8051 family, and it uses a standard two line LCD display to show frequency, resistive and reactive impedance components, and VSWR, over the range 1.6 to 33 MHz. The prototype was able to measure impedance typically within 5%, in line with results reported for most amateur-grade commercial analysers.

Measuring Impedance at HF

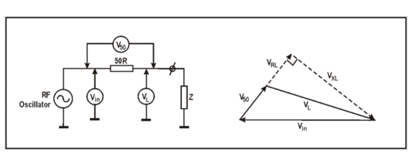
Here's the basic block diagram of an antenna analyser (See below - Right click for a closer look) Those interested in further general information on antenna analysers should also see my other page describing the analog version of this instrument.



The bridge and detector section is the key part of these meters. There are a number of bridge designs available. One of the most commonly used methods is the four element bridge. This is the type used in my other earlier analog analyser.

In this case, however, I required a bridge which minimised the number of complex calculations to be performed by the microprocessor. That ruled out the four element type. It also ruled out the three-meter bridge. This requires some coplicated sine and cosine calculations, or the use of some large lookup tables.

In a touch of serendipity, I happened across some work by Jim Tregellas, VK5JST at a timely moment. This was subsequently published in WIA's 'Amateur Radio' magazine (Reference 3) and has gone on to become very popular, in part because the processor he uses is more readily available. In his antenna analyser, based on the PIC microprocessor and using embedded BASIC software, the bridge required only a single resistor. This is shown in the diagram below. With some minor changes, Jim's oscillator and simple bridge were quickly adapted for my analyser.



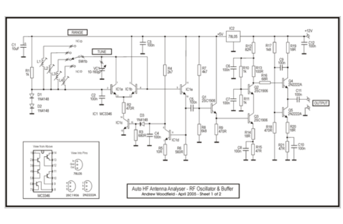
The three bridge outputs measure the three components of the voltage vector triangle shown in this diagram; the oscillator level, the voltage across the 50 ohm resistor, and the voltage across the load impedance. Of course, if the load is resistive, then $V_{50} + V_L = V_{in}$.

Reactive measurements are limited in this meter to those which resolve to a VSWR of less than 20:1. This is simply for reasons of preserving some level of accuracy. At extreme VSWR levels, the calculations become quite inaccurate with this measurement method.

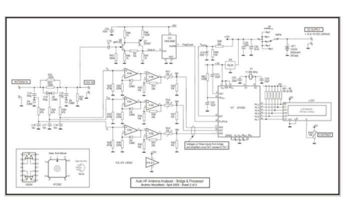
The bridge voltages detected by this bridge are amplified in the meter using low cost LM324 op-amps. The bridge also uses the diode compensation method described in reference 4. This further enhances overall accuracy.

Circuit Details

The schematics are shown below. Right click on the diagrams to see more details.



RF oscillator section of the digital antenna analyser



Bridge/detector and microprocessor section of the digital antenna analyser

The Microprocessor

The decision to use the Philips 87C552 device was due to a combination of need, habit and circumstance. Most of my designs over the years have been based on the 8051 family, popularised in New Zealand through the tireless efforts of the local agent. As a result, I have acquired fairly extensive development equipment and software for this family. This made the 8051 device family a logical choice for me.

This meter also required a microprocessor with several analog to digital (A/D) converters for measurement of the bridge voltages. Several months before this project started, I was very grateful to Eric Apperley, a fellow engineer, for the timely donation of some used 87C552 chips which were surplus to his requirements. These have eight 10-bit A/D converters on-board, and so these chips were ideal for the task.

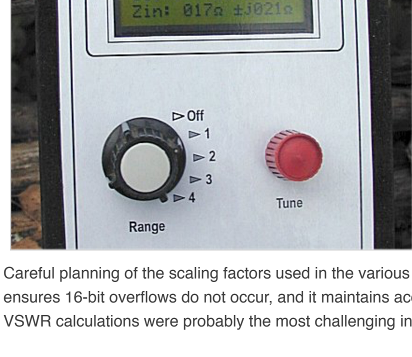
Sufficient accuracy is obtained by using the A/D inputs in 8-bit mode, so other 8051 chips are readily able to be used. The code is well commented, so converting it to use other 8051 chips should be fairly easy for anyone keen to make use of their own 8051-type chips.

The software is all written in assembler. I had a variety of high level language compilers available, but after experimenting with them for this project briefly, I fell back on old habits and cranked out the code over a few weeks of free evenings and some idle travel time during some of my 'day job' work, designing networks for a couple of offshore broadband wireless projects. This microprocessor development turned out to be an ideal stress reliever, actually.

The nice thing about writing in assembler is that the software, even if badly written, tends to end up being very compact compared with any sort of code generated by a high level language compiler. This code is written in the form of a series of subroutines for ease of development and testing, and it ended up at around 2250 bytes in total. For those looking to use other 8051 chips, the source code is available (see the end of the article for download details) and it's all thoroughly commented, mainly for my own benefit.

As an aside, I find that, after a month or two away from a design, unless the code is well commented, it's hard for me to pick up from where I left off.

The other benefit of using assembler is that the resulting code usually runs very quickly. Very! It runs in just 8 mS from start to finish in this case. It's a little too fast in fact for the LCD display, so there is a delay added in the code to allow for that limitation. This makes this meter update at a very fast rate, quite handy in some cases.



Others wanting to adapt this design to chips they may have should note that, aside from the A/D code, no software relies on any special features of the 87C552 chip. It is quite easy to use almost any other 8051 chip, for example the Atmel AT89C4051, by replacement of the short A/D subroutine.

Other than finding the time required, writing the code for the 87C552 proved to be relatively straightforward. Simple 16-bit integer add, subtract, divide and square root routines are used. The latter, based around an old school textbook method of successive subtractions, works quickly and accurately. The divide routine is adapted from one given in reference 5. Careful planning of the scaling factors used in the various calculations took much of the time required. This ensures 16-bit overflows do not occur, and it maintains accuracy through the various string of calculations. The VSWR calculations were probably the most challenging in this respect.

A previously developed block of code was used for the five digit frequency counter routine. The 74HC4040 chip divides the internal oscillator frequency by 256 to allow the slow 87C552 to measure it correctly. Philips brand HC devices are preferred for this device, since they work up to 80 MHz. Fairchild chips should be avoided!! My tests indicated they don't like to operate much above 25 MHz.

The counter software assumes the use of an 11.052 MHz crystal on the microprocessor, but other crystals can be used with very minor changes to the constants used in the counter code. The source code contains the details for those interested.

A final addition to the instrument was the battery voltage measurement. It allows for a battery range of about 10 to 15 V. This value is only displayed along with the initial startup message, just as a quick indication of instrument life. It's not a super-accurate measurement but, this level of accuracy is quite adequate for this purpose. The battery voltage displayed on my prototype was about 0.2V low. All we need to know is if the battery has more than about 10V, the level at which you'd want to be recharging those NiCds.

Those wanting more accuracy (i.e. Better than 2%) can carefully adjust the value of the 22k resistor by a few hundred ohms. Be careful - An incorrect value here can result in excessive voltages going into the microprocessor.

The LCD Display

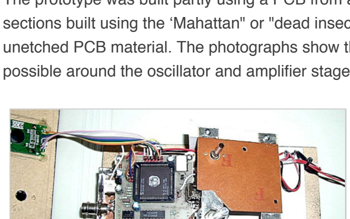
A standard 2 line by 16 character alphanumeric LCD display module is used, interfaced via the so-called "simple 4-line interface" according to the makers of these displays. OK, so rather than using eight data lines and a further three control lines, this "4-line" interface uses only seven I/O lines, plus power supply and display contrast voltage lines. Um, by my count that's 10 wires. OK, so it's better than the "8-line" interface which needs 14 wires. But still.....

While saving a few I/O lines (hardly necessary with this 64 pin 87C552 device, I know, but I was thinking of others trying to use chips with an 8051 chip with fewer I/O pins), this interface has a reported disadvantage of reduced display contrast. I tried the interface with three different displays, and only noticed this effect with an older display. The more recent LCD displays appear to have resolved this particular issue.

One important aspect to note is that different LCD displays have slightly different power and ground connections. While 100% code compatible, one display I have from Dick Smith has the exact opposite DC pin assignments to the display from Jaycar. I'll let you figure out how I discovered this fact. The schematic shows the pinout for the Dick Smith display, but check your display interface connections carefully.

Construction

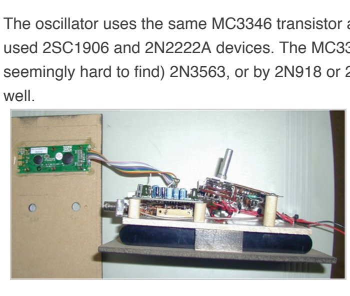
The prototype was built partly using a PCB from a previous 87C552 project, with the bridge and oscillator sections built using the 'Mahattan" or "dead insect" style. This mounts the ICs with their legs-up directly on unetched PCB material. The photographs show the details of my analyser. Keep the ground lines as short as possible around the oscillator and amplifier stages.



Unlike the analog design, the bridge diodes don't really need to be matched. Any minor mismatch can be taken up in the bridge adjustments. Also, as for the previous design, coil details are not shown for the oscillator. I just built the four coils using a couple of rewound 455 kHz IF transformers again, and two coils recycled from a cordless phone.

The variable capacitor I used is a cheap standard plastic type as used in AM/FM radios with both FM and AM capacitors used in parallel. You can also use a recycled variable capacitor from any cheap AM/FM portable radio.

The oscillator uses the same MC3346 transistor array I used in the previous design, and the amplifier section used 2SC1906 and 2N2222A devices. The MC3346 and 2SC1906 can be replaced by the low cost (but seemingly hard to find) 2N3563, or by 2N918 or 2N5770 transistors. Other devices are unlikely to perform as well.



The 12V NiCd battery (the black slab seen at the bottom of the "board stack" in the picture to the left) is also recycled. It is a 2000mAH battery from an old laptop, but it is still in good condition and is able to power the meter for a number of hours of use between recharges. I recharge the battery from my bench power supply which is set to constant current. I can trickle charge it overnight with a 200mA current.

The front panel layout artwork is also available from the Download section below. This can be copied onto plain paper. The front panel artwork can then be covered with clear self-adhesive plastic and glued to the chassis to form a reasonably durable front panel for the instrument.

The enclosure used for the prototype was made from scraps of MDF wood in my garage. I tried to buy a suitable plastic box but the ones I found were either not quite the right shape or size, or they were quite expensive. I decided to try to make one from MDF, and the result is quite satisfactory, and the enamel paint covers the odd error or two.

The electronics are contained in three layers, with the battery held in the lowest section. The bridge is mounted on the top of the panel holding the battery in place, and the microprocessor mounted on top using short 20mm length dowels. The oscillator is mounted on a small vertical piece of MDF and a slightly longer dowel.

While the final assembly is quite light, the woodwork did take some time to build, and the instrument is probably slightly larger than it needs to be as a result, in part because of my limited woodworking skills. Others will no doubt be able to improve on this arrangement.

Alignment

BEFORE you insert your microprocessor into its socket, you first have to align the bridge section of the analyser. To do this:

1. Power up the oscillator and detector sections, and set the oscillator anywhere from 20 to 30 MHz.

2. Short circuit the input load connector. Adjust RV1 and RV2 for 4.6V at TP1 and TP2. (RV1, RV2 and RV3 are 10 turn presets).

3. Remove the short from the input load connector, and leave it open circuit. Measure the voltage on TP1. Adjust RV3 so that the voltage at TP3 is the same as the value measured at TP1.

4. Short the input load connector again, and check that the voltage measured at TP3 is less than 0.1V.

5. Remove the short from the input load connector, and leave it open circuit again. Check that the voltages on TP1, TP2 and TP3 do not exceed 4.75V for any oscillator frequency across the entire range. If necessary, reduce the voltage set using RV1 and RV2 in step 1 and repeat the subsequent alignment steps. (Steps 2 – 4 above)

6. Turn the power off, and install the processor chip.

7. Turn on the instrument, and adjust the LCD display contrast so the display is clearly visible.

8. Check the alignment by connecting a 100 ohm resistor to the input load connector. It should measure 90 to 110 ohms and a VSWR of 2:1 with minimal reactive X values at any frequency across the 1.6 to 30 MHz range.

Using the Analyser

Simplicity. Turn the instrument on, connect the load, and read the LCD display.

I did not add additional software to allow the meter to determine if the reactive value is inductive or capacitive. This is mainly due to the type of oscillator used in the instrument. Since it is not readily digitally controlled, it is more difficult to accurately determine this parameter across the spectrum with the wide range of potential loads.

No, figuring out if it's capacitive or inductive is left to the user. But it's easy to see. If the reactive value *decreases* with increasing frequency, then it's capacitive. If the reactive value *increases* as the frequency rises, it's inductive.

Now, you might, at first glance, think that some results don't appear to be accurate. I was somewhat concerned initially at some of my results. I found that, not unexpectedly, resistors are not always perfectly resistive. My Bird dummy load, for example, was within specification but measured 52 ohms and a little capacitive at 30 MHz.

Also, when measuring loads with any reactive component, this and other similar bridges tend to read the total impedance correctly, but with a phase angle shift of typically up to 5%. This gets reflected in errors in the final R+jX values calculated and displayed by the meter. If you work the numbers out, you'll find the result displayed is seldom off by more than this margin in my experience.

I experimented with several popular bridges to see if one was better than another, and came to the conclusion that they were all much the same. ARRL tests (in 2005) of a number of commercially made antenna analysersusing similar methods independently confirmed my conclusions. Other more complex designs exist if you want errors of less than half of my instrument, but they are more complex and costly to build. If "cheap, easy to build and reasonably accurate" are your key criteria, this meter is hard to beat.

Future Development Options

The prototype processor PCB contains space for a small Philips I2C memory chip with onboard real time clock, as well as interfaces for transceiver audio I/O and RS232. These relate to the previous applications of this PCB. I have no plans to add them to this meter although they do suggest possible future upgrade options. It is possible, for example, to add a date/time stamped memory feature, and provide for remote control and measurement downloads with a PC, either via RS232 or via wireless. Feel free to write the necessary code.

Credits

Sincere thanks to Jim, VK5JST, for the bridge design and advice on the oscillator amplifier at a critical moment, and especially to Eric Apperley for providing the all-important microprocessor.

"Break-In" is a bi-monthly magazine published by NZART, New Zealand's amateur radio organisation. Details about the magazine can be found at **www.nzart.org.nz**

References

1. Peter Dodd, G3LDO, "The Antenna Experimenter's Guide", 2nd Edition, 1996 RSGB (See Chapter 3)
2. W8CGD, "Measurement of R+jX", QST, June 1966
3. Jim Tregellas, VK5JST, "An Experimental Antenna Analyser", 'Amateur Radio' magazine, WIA, May 2005.
4. John Grebenkemper, KI6WX, "Calibrating Diode Detectors", QEX, Aug 1990
5. S. Yeralan and A Ahluwalia, "Programming and Interfacing the 8051 Microcontroller", Addison Wesley, 1995 (Section 3.7.2)

Appendix A: Impedance Calculations

Click **here** here to download the PDF (54kB) containing the methodology and maths behind these calculations.

Downloads

Click **here** here to download the Intel HEX file - Clicking on this link will allow you to download a zipped HEX file (3 kB) for programming an 87C552 chip for use in this analyser

Click **here** to download the Source file - This is a zipped Metalink compatible ASCII TEXT format source file (14 kB) for this instrument. This will allow the code to be modified by experienced 8051 programmers who may wish to add more features.

Click **here** here to download the front panel artwork (3 kB)

Want to go back to the main page? Click **here** to return directly.