Yana Design

(Yet Another Network Analyzer)

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Yana (Yet Another Network Analyzer) builds upon the developments surrounding PHSNA (Poor Ham's Scalar Network Analyzer). My goals were

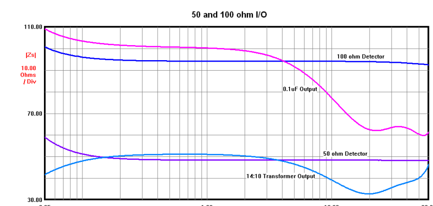
1. Easy to duplicate.
2. Low in cost.
3. Self-contained, complete, and handheld.

The instruments in Yana are:

1. Scalar Network Analyzer.
2. SWR Meter/Antenna Bridge.
3. Power Meter.

I have tried to supply complete documentation, including a number of applications: Yana in action. Yana is not a kit, requires building experience, knowledge of microcontrollers, and some electronics theory: this is not a “check the box” project. However, I believe there is enough information that Yana can be duplicated by experienced experimenters. Further, there is enough flexibility so that each “build” can be personalized.

At the right are graphs showing the impact of DDS and AD8307 modifications. Without modification, Yana is an acceptable 100 ohm system. Performance at 50 ohms is not too great. With the SWR bridge, the Antenna Analyzer is a 50 ohm system. The Generator (Output) is approximately 100 ohms and the Detector is a very good 100 ohm match. (The newer AD8307 module is a good match to 50 ohms.)



The lower two traces show the impact of modifications. The Generator impedance is shifted down to 50 ohms with a transformer and the Detector is changed by the addition of 100 ohms in parallel with the 100 ohm input resistor. The graph shows this is a pretty good 50 ohm system.

1. Easy to duplicate:

The Arduino Nano is inexpensive, easily programmable, and powerful. Modules are available for the AD9851 DDS (DC to 70MHz), the AD8307, a 128x160 ST7735 1.8 inch screen, and a rotary encoder with a button. With some simple self-built perfboard modules, these are enough to assemble Yana. I have also used a coaxial DC receptacle and an sma female pigtail. A ferrite transformer matches the AD9851 output to 50 ohms. And, finally, a pin plug harness to connect Yana all together. All but the screen, rotary encoder, coaxial DC receptacle, and female sma pigtail are screwed to a piece of PCBoard. A fully functional Yana can be assembled on the desk with pin plugs without loss of functionality.

I have incorporated a few optional additions to improve accuracy. A 3.9k smd 0805 part parallels the current control resistor (R6) on the AD9851 module increasing output by 3db. A 100 ohm smd 0805 part parallels the 100 ohm load resistor on the AD8307 module setting the Detector impedance at 50 ohms. (This addition is not necessary on the newer AD8307 module.) A 14:10 output transformer was added to the AD9851 output which mostly shifts the Generator output impedance of the AD9851 module to 50 ohms. And I removed the current-wasting LED from the AD9851 module.

I have supplied a C program which is compiled and loaded into the Nano from a pc running the Arduino development tools. Except for wonderful libraries written by others, I wrote the program from scratch to support the specific goals of Yana. The Yana user is not confronted with a myriad of choices that seem peripheral or irrelevant. (But then, it may not satisfy your notion of a bench SNA, as some versions of PHSNA do.)

I tried a slightly larger, higher resolution screen but decided it really added nothing to functionality (but did slow things down, and was not as good in bright light).

All parts plug together with pin headers. Fritzing is used to show the wiring harness. Fritzing refuses to accept my Inkscape part drawings so, someone, help me eliminate the parts that are implemented as "notes." (Other people use Inkscape to produce Fritzing parts, so what don't I know?)

2. Low Cost:

On 4/7/2016, perusing eBay, the costs (with shipping included) are about:
(eBay search phrase is included.)

Nano	2.20	"arduino nano v3.0 -terminal -mini -prototype"
AD9851 module	14.50	"ad9851"
AD8307 module	9.80	"rf power detector meter"
ST7735 128x160 TFT	3.80	"1.8 inch 128x160 TFT"
Rotary Encoder	1.00	"rotary encoder button"
sma female pigtail	0.80	"sma female pigtail -rp"
	32.10	

For such a powerful tool, I consider this low cost.

3. Self-contained, complete, and handheld:

My Yana (with a name like that, it must be a "she.") is assembled in a 100mm x 68mm x 50mm (3.9in x 2.7in x 1.9in) plastic box. Yana fits easily in my hand. I use two external 18650 Li-Ion batteries from a laptop discarded a decade ago. The on/off switch is the DC plug. (I tend to forget batteries on the inside where they mess up my nice projects.)

An instrument like this needs attachments to exhibit its power. The bridge is built in both leaded and smd resistor versions. I verified these bridges with my N2PK VNA. I made a set of loads (6.25, 12.5, 25, 33.3, 50, 75, 100, 200, 400) assembled on pin headers using standard 10% resistance values. I use the 50 ohm load, a -28.6db attenuator (again using standard values), a Kopski -10dbm calibrator, and a short (for the bridge) to calibrate Yana. Yana will take you through the steps and save the results in eeprom. All parts were selected using a free Harbor Freight DVM. Therefore, no special test instruments are needed to duplicate Yana.

However, I tested results with my HP8656 generator and N2PK VNA, showing that I achieved surprising accuracy for such simple methods: a cheap DVM. That is, my fancy test equipment is not necessary to duplicate Yana with comparable results.

Yana will measure filters from 0db to 70db insertion loss, VSWR from 1 to 8, and powers within the limits of the AD8307. With input open, my Yana sits at a noise floor of -77dbm. I made a 40db tap which will accept 100 watts. (Not needing to reach beyond 70MHz makes the tap easier than that of Hayward and Larkin which reaches 500MHz and tops out at 60 watts.)

So, yes, I think Yana is self-contained, complete, and handheld.

4. Wish List:

I wanted to save scans to an SD card but the SD card libraries are too big. I plan to write a "Print" function to output a csv file from the USB port, but that would require Yana to be near a computer (or tablet).

The Nano ADC divides 5 volts into 1024 steps. At a VSWR of 8, one ADC step is 0.75 VSWR units. The ADC reads +-1 count. Thus graphs of high VSWR are very jagged. You can see this phenomenon on some of the PHSNA graphs on the web. A higher resolution ADC built-in to the Nano would be nice. I will try other presentations to see if they are more desireable.

There are many other enhancements that would violate one or more of my design goals (like balanced output from the AD9851, a better anti-alias filter than the one on the AD9851 board, an amplifier/leveler for the AD9851 output [between 1MHz and 10MHz the output is around 1dbm, so an increase here would not add much], to name a few). Since my noise floor is about -77dbm, not much can be done to improve the AD8307 module sensitivity. Improving the AD8307 power/frequency accuracy by table driven means is just too much effort and would require too much calibration from the user. Though KISS (Keep It Stupid Simple) is not a design goal, it is implied by my goals.

Many people would like a spectrum analyzer. Such an addition would break all three goals so is not contemplated. It would require the addition of a measurement receiver where the AD9851 would be a local oscillator and the AD8307 an IF power detector. The spectrum analyzer would require input attenuators, a mixer, a high gain amplifier, and a number of resolution bandwidth filters. I find no inexpensive module on eBay or the web that would satisfy these needs. Therefore, addition of a spectrum analyzer would break all three goals of Yana.

5. Design:

The main challenge is: can an accurate instrument be built using very inexpensive tools? In this case a free Harbor Freight DVM was used to measure voltage, current, and resistance. Frequency is set using the station receiver. Other aspects of calibration were built using standard value parts measured with the DVM. I think the data presented below show that Yana is accurate and can be duplicated with very inexpensive tools possessed by most hams: Not too shabby and easily duplicated.

An RF analyzer consists of a signal source and a detector. A signal source can be wide- or narrowband, and likewise, a detector can be wide- or narrowband. Here are examples of each of the four possible combinations:

(1) Wideband signal source and wideband detector

A noise figure meter uses a broadband noise generator and a broadband detector: usually a true RMS voltmeter.

(2) Wideband signal source and narrowband detector

BG7TBL offers a wideband high level noise source on eBay. He also offers a spectrum analyzer covering from 135MHz to 4.4GHz. The noise source can be fed to a device under test (DUT) and the results scanned with the spectrum analyzer. A swept spectrum analyzer is a narrowband detector.

(3) Narrowband signal source and wideband detector

Yana is an example of this type. The AD9851 generates a sine wave of a given frequency. The AD8307 detects signals over a wide bandwidth.

(4) Narrowband signal source and narrowband detector

The highly regarded spectrum analyzer with tracking generator designed by Hayward, W7ZOI, and White, K7TAU, and described in Experimental Methods in RF Design by Hayward, Campbell, and Larkin is an example of a narrowband source (tracking generator) and narrowband detector (spectrum analyzer).

A. The AD9851 Module

eBay lists both AD9850 and AD9851 modules installed on the same board design. On the back of the board is the label "AD9850." This board appears to be a copy of the CGPCB Evaluation Board described in the datasheet for the AD9851. The anti-alias filter on this board is intended for an AD9851 running with a 180MHz clock. The clock is usually obtained using the internal 6x multiplier applied to an external 30MHz crystal clock. This is inappropriate for an AD9850 running on a 125MHz clock. Therefore, you will find that hams build an external anti-alias filter when using the AD9850 version of this board. (Building this extra filter violates a design goal of Yana.)

The AD9851 datasheet recommends that in single ended use (the modules are single ended), an anti-alias filter should be terminated at both ends. I tried to remove the output termination and apply a step-down transformer to a 50 ohm termination. The results were dismal. So the datasheet says what it means.

The Nyquist criterion says that a sample rate twice the desired frequency will determine the maximum usable frequency (which would be 180/2 = 90MHz). There are too many spurious responses to reach this limit so that the datasheet recommends a maximum frequency of 40% of the clock frequency which is 72MHz. The on-board anti-alias filter has a cutoff of 70MHz. The smd inductors in this filter have low Q so that this is not the greatest filter. However, it is adequate for Yana.

(1) The anti-alias filter

The filter is designed for 200 ohms. Because it is terminated at both ends by 200 ohms, the view from the outside world is interesting. Well below the cutoff frequency, the filter looks like a piece of wire. Therefore, at low frequencies, the two 200 ohm terminations are in parallel presenting a 100 ohm output impedance. As the cutoff frequency is approached, the impedance will change and become reactive.

I measured the output impedance of the AD9851 module directly and with the 14:10 transformer using my N2PK VNA with myVNA. The results are presented in the opening of these notes. The top trace (direct output through 0.1uF) follows 100 ohms until it drops at about 4MHz. The transformer output follows 50 ohms until about 4MHz where it wanders down then up. Thus Yana is a pretty good match to 50 ohms over HF (3-30MHz). And direct output (no transformer) is within a 2:1 SWR over the same range. Not too bad.

(2) Setting the frequency

I used my station receiver and matched the 10MHz signal from WWV to determine the AD9851 tuning constant. Mine happened to be right on. A check with my AADE frequency counter showed my Yana frequency to be right on the money.

(3) Output Power

With no modification, peak output from the generator is about -3dbm. This drops as frequency rises according to the function sin(x)/*x* because the sine wave is built from little stair steps. As the frequency goes up, the stairs get bigger as a fraction of one cycle. In particular, more energy goes into harmonics and less into the desired fundamental. With a change, the power can be doubled, to about 0dbm by shunting the current source resistor (R6) by 3.9K.

B. The AD8307 Module

(1) Shielding

The AD8307 is incredibly sensitive and a nearby computer (the Nano and AD9851) generate a lot of RF hash. Therefore, the AD8307 must be well-shielded. Using foil tape on plastic, the module can be shielded so the resting noise floor is about -77dbm. The detector starts to deviate from log above 10dbm. Therefore the range of the detector is about 87db. That's pretty good.

(2) Input Impedance

The newer module is correctly set to 50 ohms.

The older module comes with a 100 ohm shunt resistor isolated by two .1uF capacitors. Therefore, the input resistor can safely be measured with an ohm meter to make certain it is 100 ohms. A modification puts a 0805 smd 100 ohm resistor across this input resistor to move the input impedance to 50 ohms. The graph in the opening shows that both the 100 and 50 ohm inputs are close to what they should be. The chip itself has an input resistance which shunt the input so the input impedance is really slightly less than the resistors across the input. The opening graph shows this difference.

(3) Frequency response

The AD8307 is good to 500 MHz and beyond. However, the input circuitry needs compensation to maintain accuracy. Hayward and Larkin (QST, June, 2001) show how to compensate the power meter input to maintain accuracy to 500MHz. Since Yana generates only up to 70MHz, I made no attempt to compensate the input: added simplicity. However, I checked the Detector up to 200MHz and it is good. So the Power Meter will work to measure power on 2 meters.

(3) Normalization of the SNA

Raw ADC

f/db	0	10	20	30	40	50	60	70
0.1	460	407	355	302	247	176	60	55
0.2	460	408	355	303	248	193	94	52
0.3	460	408	355	302	248	195	127	60
0.4	460	407	355	303	249	196	135	62
0.5	460	407	355	302	249	197	140	69
1	460	408	355	302	248	196	144	85
10	457	404	352	300	246	194	142	91
20	446	393	340	288	235	182	130	80
30	430	377	323	272	220	169	113	67
40	412	360	307	254	203	151	98	59
50	395	342	290	237	185	133	82	54
60	377	323	270	220	168	114	70	51
70	356	303	250	199	146	96	59	49

Converted v/dbm =.0257

f/db	0	10	20	30	40	50	60	70
0.1	0	-10.1	-19.9	-30	-40.5	-54	-76	-76.9
0.2	0	-9.88	-19.9	-29.8	-40.3	-50.7	-70	-77.5
0.3	0	-9.88	-19.9	-30	-40.3	-50.3	-63	-76
0.4	0	-10.1	-19.9	-29.8	-40.1	-50.2	-62	-75.6
0.5	0	-10.1	-19.9	-30	-40.1	-50	-61	-74.3
1	0	-9.88	-19.9	-30	-40.3	-50.2	-60	-71.2
10	0	-10.1	-19.9	-29.8	-40.1	-50	-60	-69.5
20	0	-10.1	-20.1	-30	-40.1	-50.2	-60	-69.5
30	0	-10.1	-20.3	-30	-39.9	-49.6	-60	-69
40	0	-9.88	-19.9	-30	-39.7	-49.6	-60	-67.1
50	0	-10.1	-19.9	-30	-39.9	-49.8	-59	-64.8
60	0	-10.3	-20.3	-29.8	-39.7	-50	-58	-61.9
70	0	-10.1	-20.1	-29.8	-39.9	-49.4	-56	-58.3

The output of the AD9851 falls because of the sin $(1/x)$ response of the DDS and because of losses in the circuitry: low Q inductors in the anti-alias filter and the limited bandwidth of the output transformer. I wondered if calibration at 10MHz intervals with linear interpolation would work. Yana's output generator was connected through an accurate step attenuator to Yana's input detector. I measured the ADC count over the range 100KHz to 70MHz obtaining a table of values using the step attenuator (left table above). In the left table, the columns give the raw Nano ADC readings for given frequencies and attenuation of the DDS signal. The 0db column shows the fall-off of DDS output with increasing frequency.

These readings are converted to dbm in Yana. So to each row I added an offset to raise the 0db value up to 460. For example, in the 30MHz row the value added to every entry in the row is 30 = 460 – 430. Then I subtracted 460 from every entry in the table. At this point the table is normalized to 0db and measured in ADC counts. The datasheet says the conversion to dbm is 25mv/db. Checking values I found a better choice to be 25.7mv/db for my particular AD8307 and Nano. The right hand table represents the dbm readings of the ADC. The numbers in a column should match the db entry at the top.

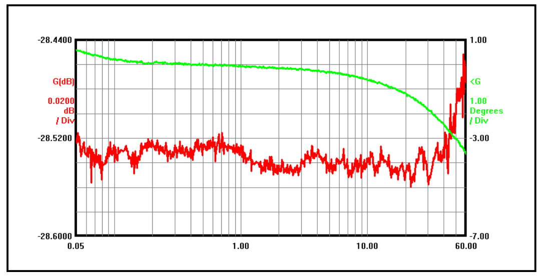
Looking at the table, between 1 and 30MHz the match is very good right out to -70dbm. The values of the AD8307 are only guaranteed +/-1db. Obviously, in this case, my AD8307 is doing much better. Yana is accurate over the entire frequency range for 0 to -50dbm. These values show that Yana is very impressive for such a low cost tool.

The first table shows the fall-off of AD9851 output with increasing frequency. Therefore, the distance to the noise floor is decreasing. So a smaller dynamic range is expected at the high end.

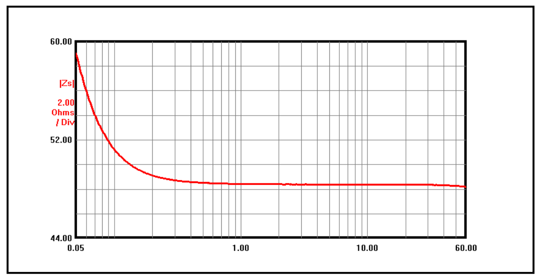
The low end is a surprise. The table shows that accuracy also suffers at high attenuation even though the AD9851 has a robust output. I can think of a couple reasons but do not know the real one. Kopski remarks that calibration of the AD8307 for small inputs is dubious. So the problem might be in the AD8307 itself. On the other hand, if you've followed improvements in H-mode mixers, you know that the choice of ferrite transformer makes a big difference. A mixer operates at very low RF signal levels. Therefore, it might be that at low signal levels, the output transformer is distorting the signal. Take your pick. In any case, Yana is accurate over her full range from 0 to -50dbm. Be suspicious of readings below -50dbm outside the range 1-30MHz.

(4) A calibration attenuator

The values indicate that linear interpolation will work (reducing the number of calibration points to save space). It takes two points to calibrate Yana. Looking at the right hand table, the -30dbm column is close to correct. Therefore, (a) Yana can be calibrated at about -30db, and (b) one calibration frequency will be good enough.



To simplify construction of the -30db attenuator, a value of -28.55db was chosen because the parallel resistors in each of two pi attenuators is a standard value. Further, calibration is only read at 10MHz. The graph at the right shows the actual performance of the attenuator I built. There is very little phase shift through the filter and the attenuation is very close to the -28.55db target. These values were obtained using the free Harbor Freight DVM and values were selected from among 10% 0805 smd resistors and leaded resistors.



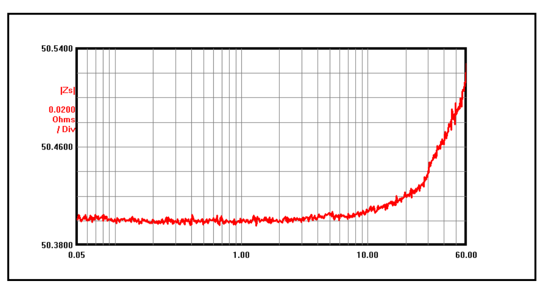
B. The AD8307 Module

The input impedance of the AD8307 is 1100 ohms. In parallel with 50 ohms this is about 48 ohms. The graph follows this impedance over most of the range of Yana. Thus the detector is also a good match to 50 ohms.

C. The SWR Bridge

The design of the bridge is standard and described in Hayward, Campbell, and Larkin, Experimental Methods of RF Design, Figure 7.41. I chose the transformer based upon measurements by Jack Smith, K8ZOA, of Clifton Laboratories. A great loss to us all, K8ZOA is now a silent key. DX Engineering has taken over Jack's products, but his web pages have disappeared: another great loss to us all.

D. The -10dbm Calibrator



The impedance of my calibrator is shown at the right. The match is extraordinarily good. I doubt that a different CMOS crystal oscillator would be any less of a match. A direct connection between the calibrator and Yana's detector should mean the waveform presented is not distorted, so calibration should be effective. Accidentally I had the calibrator connected by a strange cable combination and was obtaining weird results. When checked with a scope there was a huge amount of ringing on the square wave of the calibrator. Thus calibration was way off. So, it is important to keep the connection between Yana and the calibrator as direct as possible. Calibration obtained this way matched my sine wave comparison with my HP 8656.

E. Accessory Loads

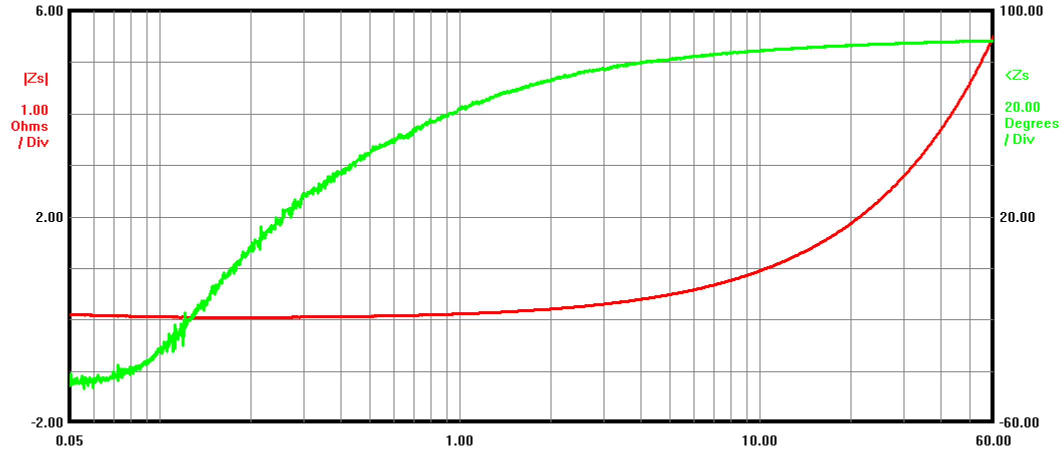
One quarter watt leaded resistors were used for the loads. Values were selected from 10% standard values using a Harbor Freight DVM. The loads were built on male pin headers which plug into an sma plug fit with a female pin header.

The additional lead length suggests that the loads will have an increasing reactive component as the frequency rises toward 70MHz. Even so, the results are impressive in the N2PK-VNA scans. If more than two loads are presented on the same graph, the errors are too small to see clearly, therefore, separate graphs are shown for each load. Given the inexpensive DVM, the results are surprising, so a graph for each load is shown.

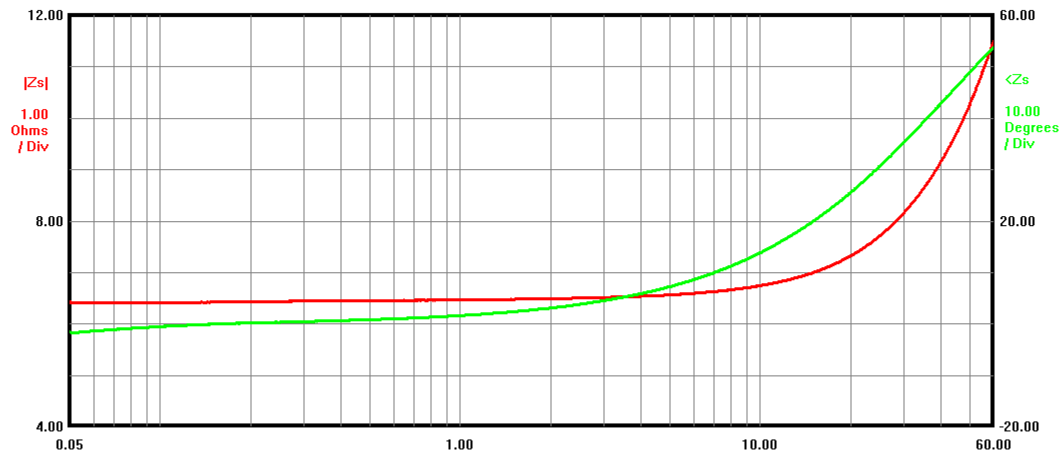
Because of the lead length, it is reasonable to assume that reactance should be positive and increasing with increasing frequency. There is a bit of a surprise for the 200 and 400 ohm loads. The reactance goes negative (capacitive) with increasing frequency. There is capacitance between the input and output because of lead length. I believe the resistors are spiral cut which would mean they are low Q inductors. It might be that for high resistance, the inter-turn capacitance dominates the very low Q of the inductor. I don't know the actual reason for the negative reactance.

More significant, the loads are high quality and useful for measurements. The most useful loads are 0 ohms (short) and 50 ohms.

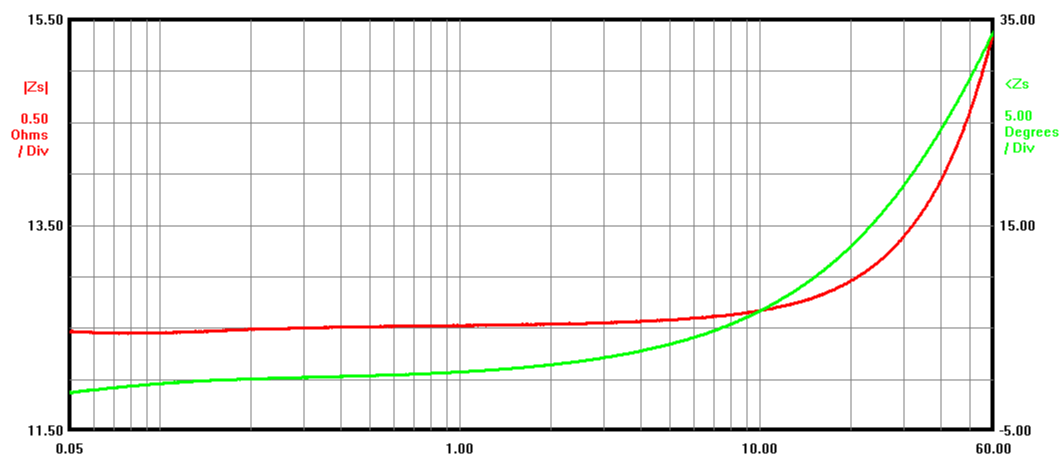
Zero Ohms



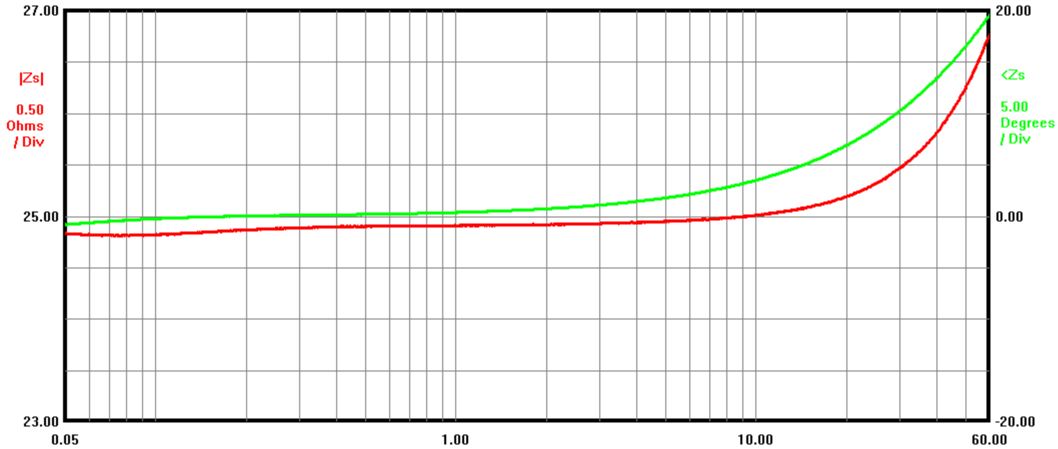
6.25 Ohms



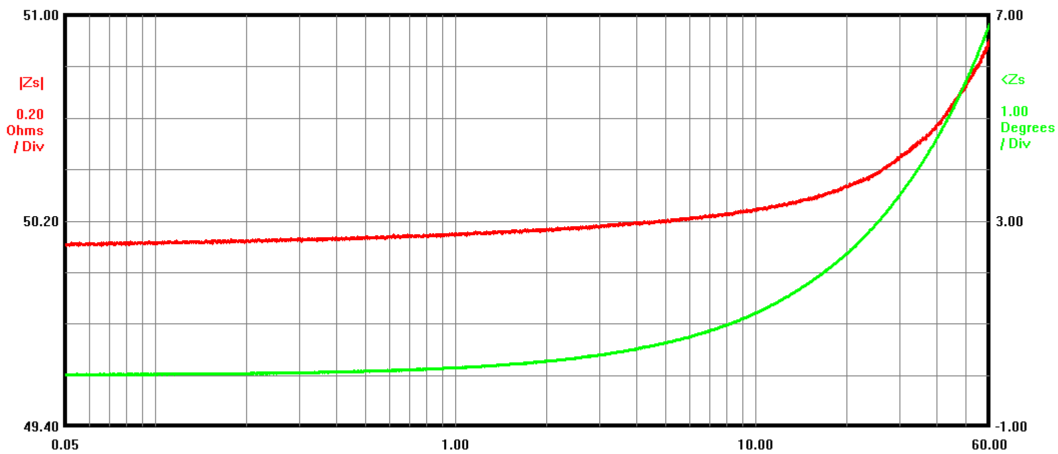
12.5 Ohms



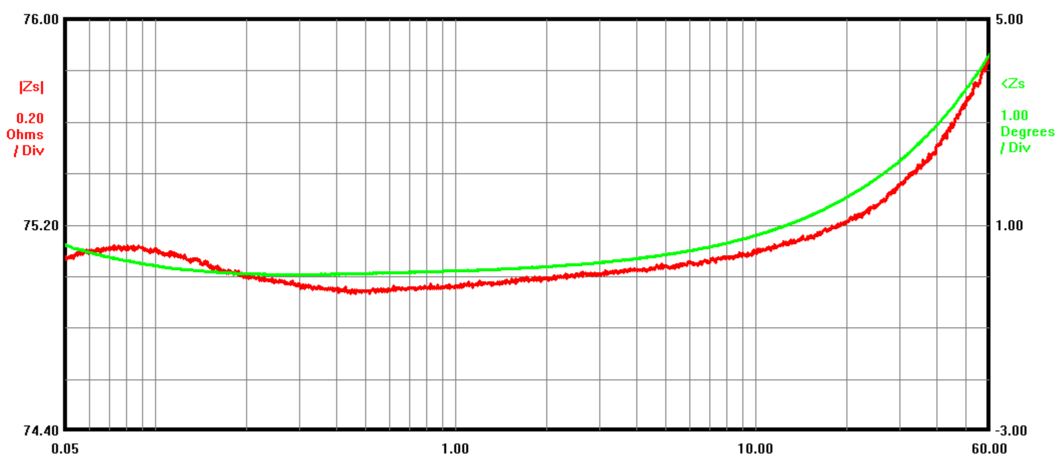
25 Ohms



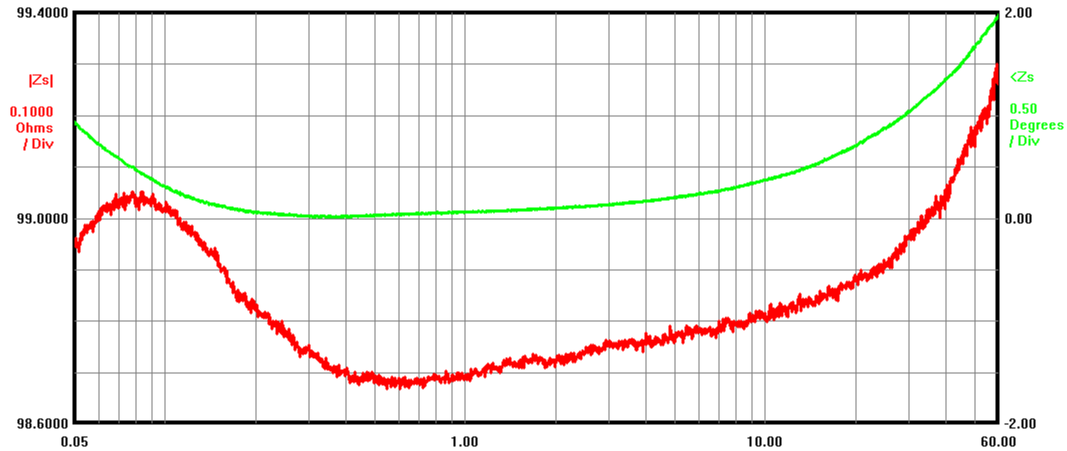
50 Ohms



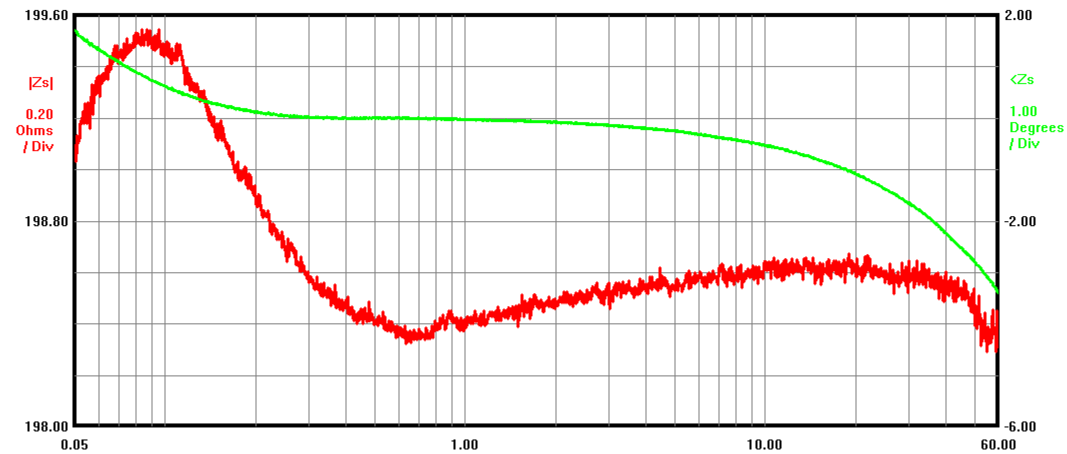
75 Ohms



100 Ohms



200 Ohms



400 Ohms