NanoVNAs Explained: A Practical Guide to Nano Vector Network Analysers

Mike Richards, G4WNC
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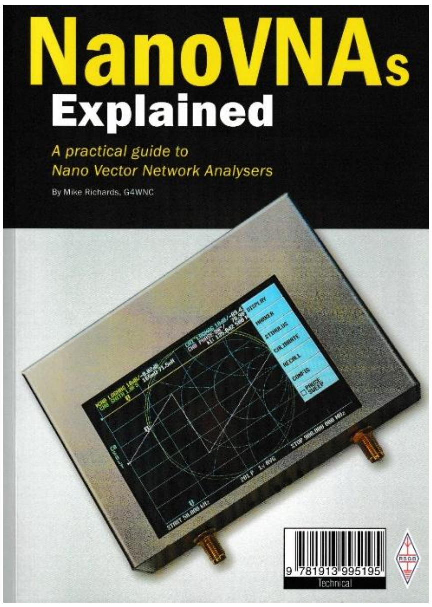

The NanoVNA, that little Vector Network Analyzer that has taken the amateur world by storm is an amazingly capable device. While perhaps it is not as precise or versatile as the professional devices costing thousands of dollars, it has become an almost indispensable piece of equipment on most every ham workbench. Yet, it seems that it is most commonly used to produce antenna and feedline SWR plots. As useful as that may be, the NanoVNA can go far beyond that. Mike Richards, G4WNC, together with the Radio Society of Great Britain, has the perfect guide to show off a world of measurements beyond the SWR curves.

The concise 122-page softcover book is divided into two parts. The first portion, entitled "NanoVNA Basics" describes the VNA internals, a bit on the hardware together with much more detail on the software. Especially useful are the discussions on what it can and cannot do – essentially the differences between this economical device and the professional instruments.

For anyone still contemplating the purchase of a NanoVNA, Richards makes sense of the various available versions. This is especially useful as the original NanoVNA created by edy555 was published on Github and has fostered numerous clones and copies, not all of which may be of the highest quality. It's important to purchase from a reliable source and know which version to get. In some circumstances a version 1 model may be preferred to version 2. At the time of writing, Richards notes that a version 3 model is in development and, thus, is not covered in this book. That version is now available at a heftier price than the earlier models. Information on version 3 may be found here:

https://nanorfe.com/nanovna-v3.html Unless you're doing microwave work, the version 3 device may be overkill.

Richards devotes considerable attention to calibration, its importance and methods. In some circumstances a rough & ready calibration may suffice – the kind where relative measurements or order of magnitude adjustments are being made. But in other cases, such as passive filter characterization, calibration should be more thorough. It becomes significant to perform the calibration at the ends of the test leads connected to the device under test so any capacitance or inductance those leads induce can be eliminated, or "zeroed out" of the resultant measurement.

Equally important is selecting the frequency range for particular calibrations. As a worst-case scenario, the NanoVNA may sample only 101 points across the selected frequency sweep. This sets the possibility that it could skip over an entire amateur band if you perform a scan from 10kHz to 1.5GHz, for example. Fortunately, Richards provides plenty of advice on selecting optimum sweep ranges for the various tests and on increasing the number of sample points beyond 101. He also stresses the value of using high quality calibration standards, noting that while it's easy to have a proper 50Ω load for the amateur HF bands, this becomes more of a challenge as the frequency increases since any resistive load is never purely resistive. It is a combination of an inductance in series with the capacitance and resistive elements. This is a reminder that nothing in life is simple.

On a personal note, I had been reluctant to update the firmware on my NanoVNA-H that I have had for a few years as I feared something would go wrong that I could not un-do and thus be left with a useless brick. After all, it met my needs running the 0.4.5-1 engineering level that it came with. The very detailed step-by-step instructions, however, convinced me to give it a try. Not only did the steps seem fool proof, but Richards claimed that it is impossible to brick the device, as the bootloader code is resident in Read Only Memory (ROM). So, I thought, "how could I fail." Well, I did.

I attempted to follow the steps and somehow ended up with a wiped microcontroller. It seems that a few changes conspired to result in my failure. First, under my Windows 11 system, the Windows Device Manager did not recognize the NanoVNA as expected. Secondly, the DfuSeDemo application needed to load the firmware has been deprecated by STMicroelectronics in preference to their STM32CubeProgrammer application. As documented by Richards, to successfully recover and upgrade my NanoVNA, I had to first open the case and short out the BOOT0 and VDD points on the board, a simple matter using hook test clips. Upon power-up this launches the update software that is in ROM and makes the device ready to accept an update even though the screen is blank and there is no indication that any software is running. Then I launched STM32CubeProgrammer on my Windows computer and updated my NanoVNA with the .bin firmware file instead of the .dfu file that's indicated in the book instructions. Firmware files are here: **https://github.com/DiSlord/NanoVNA-D/releases/** The STM32CubeProgrammer software is here: **https://www.st.com/en/development-tools/stm32cubeprog.html**

So, it seems that bricking really is impossible. And you can imagine my relief when my NanoVNA booted successfully after the update!

Richards devotes considerable attention, a full twelve pages, to the application NanoVNA Saver, available for Windows, Linux, Mac, and Raspberry Pi platforms. NanoVNA Saver supercharges the Nano. It offers greatly enhanced control and display options, all via USB cable attachment. Specifically, NanoVNA Saver allows you to combine multiple 101-point segments across a wider sweep range, like scanning a multiband antenna. This capability alone makes it worthwhile to sacrifice the handheld portability of the NanoVNA for greater precision. And if you've ever been put off by squinting at the tiny screen, you'll fall in love with NanoVNA Saver's display of beautiful large graphs. By default, it displays four at a time, which is useful in many situations. Incidentally, all of the plots in this review were captured from NanoVNA Saver.

The NanoVNA logs the individual measurements, the S parameter data, as entries in Touchstone files. These data may then be exported by NanoVNA Saver and imported into SimSmith, the free application by Edward Harriman, Jr., AE6TY. As Richards writes, "This is a simple task but it's not obvious to those that are new to the software." SimSmith is a versatile program for RF analysis. Harriman covers SimSmith at length in the Winter 2011, issue of *The QRP Quarterly*.

Speaking of Phillip Smith and his venerable Smith Chart, Richards offers a short tutorial on the chart together with a discussion on the numbering of the S or *scattering parameters*. For example, an S parameter of S21 indicates that the measurement was taken on port 2 using a signal applied from port 1. A reflection measurement is described at S11 where both the signal origin and the reflection measurement involves only port 1. It's only mildly confusing that the NanoVNA ports are numbered 0 and 1.

In the final portion of section 1, Richard details use of an Android mobile smartphone application to control and view data from a NanoVNA. I did not explore the mobile app.

Part 2 of the book is the "Practical Measurement Guide." Here Richards offers specific instructions for conducting tests on some sixteen tasks beyond measuring your feedline SWR. In my opinion, this is where the book really shines. As an introduction, he first cautions, "If the results look too good, they probably are!" He then goes on to show how markers attached to specific points of a measurement trace are useful. The NanoVNA provides six basic markers and a Delta marker to show the difference between any two standard markers. An option on the MARKERS – SEARCH menu will automatically locate the maximum or minimum values on a trace. And if the TRACKING box is selected a marker can be dynamic. As Richards writes, "This is ideal to use when you're adjusting a tuned circuit, antenna, etc."

As we saw with the firmware updating instructions, times change and so does firmware.   And the firmware changes since the time of publication may compromise the step-by-step procedures detailed by the author. For that reason I elected to run though an even handful of the more interesting measurement cases.

Passive Filter Measurement

When I built a Michigan Mighty Mite for the 2025 FDIM challenge, I noted that it had significant strong harmonic content. So, just for fun I built the "Chebyshev With A Zero" (CWAZ) low-pass filter designed by Jim Tonne, WB6BLD, and available from Mostly DIY RF.

First, Richards covers the need for a two-port calibration since we will be measuring both through loss and return loss. He emphasizes that the calibration must be made at the ends of the test leads, in my case that's at the ends of my two-foot SMA to BNC cables (although Richards prefers 12-inch cables).

Figure 1 shows the result of the scan of the filter. And I have some confessions to make. First, I found that the step-by-step menu operations on my NanoVNA with the latest firmware did not perfectly align with those steps documented by Richards. So I didn't follow them. Secondly, I selected all of the charts within the NanoVNA Saver application. It is simply way too convenient compared to doing that on the tiny NanoVNA screen. The application offers 21 different charts, though four fit comfortably on the display. These are selected using the diminutive "Display setup..." button on the bottom left-hand side of the window.

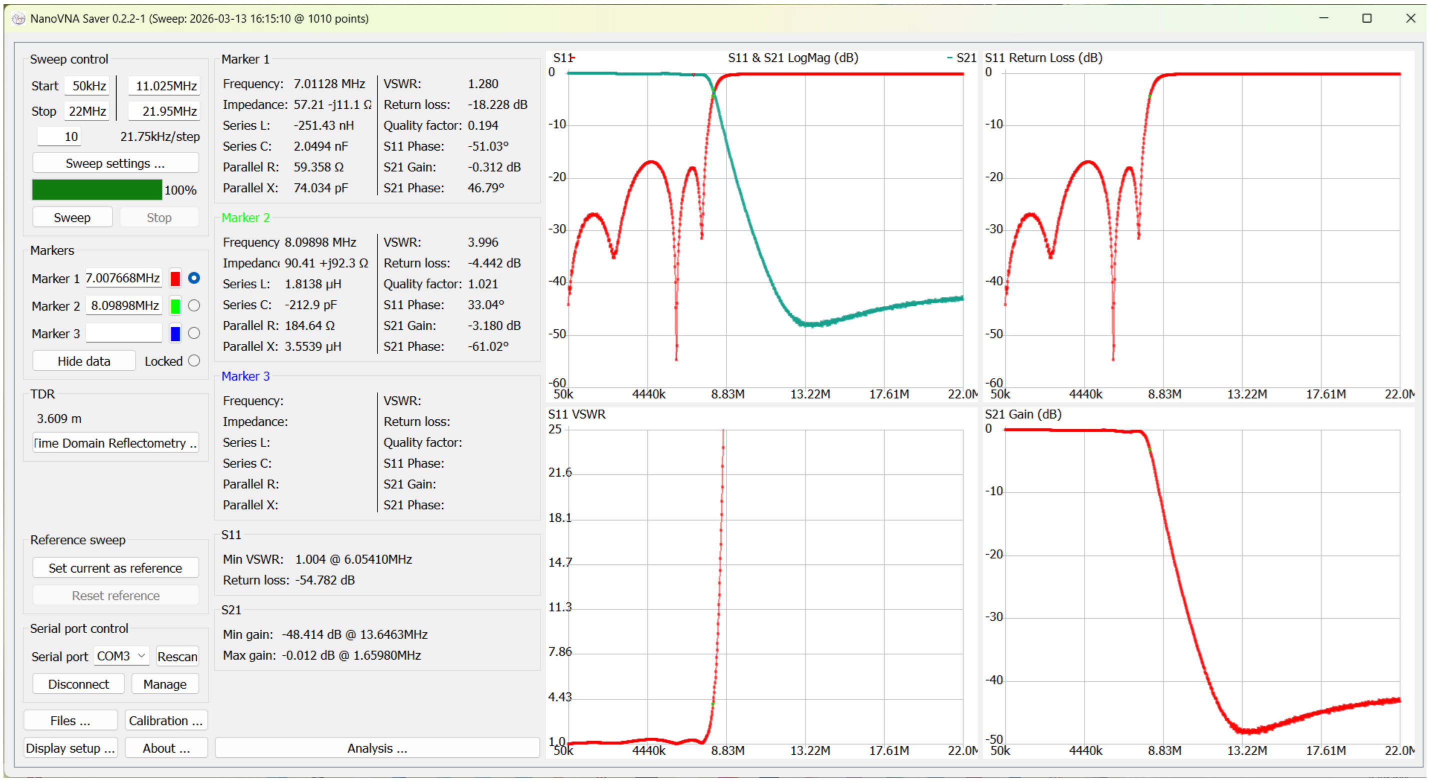

Figure 1
This figure presents four views of a CWAZ low pass filter sweep using the NanoVNA together with the NanoVNA Saver application recommended by author Mike Richards. The application offers twenty-one different charts using the scattering parameters logged by the NanoVNA sweep.

Attenuator Measurements

Next up was validating the attenuation of my little Pacific Antennas 41dB V2 attenuator. This device offers six steps of dB attenuation from -1,- 2,- 3, -5, -10, and -20 dB, or any combination thereof. First I charted each step individually and found them to be spot on. Then, as apparent in Figure 2, I set the attenuator to -35 dB and the chart shows the S21 gain in dB across 3 MHz to 30 MHz.

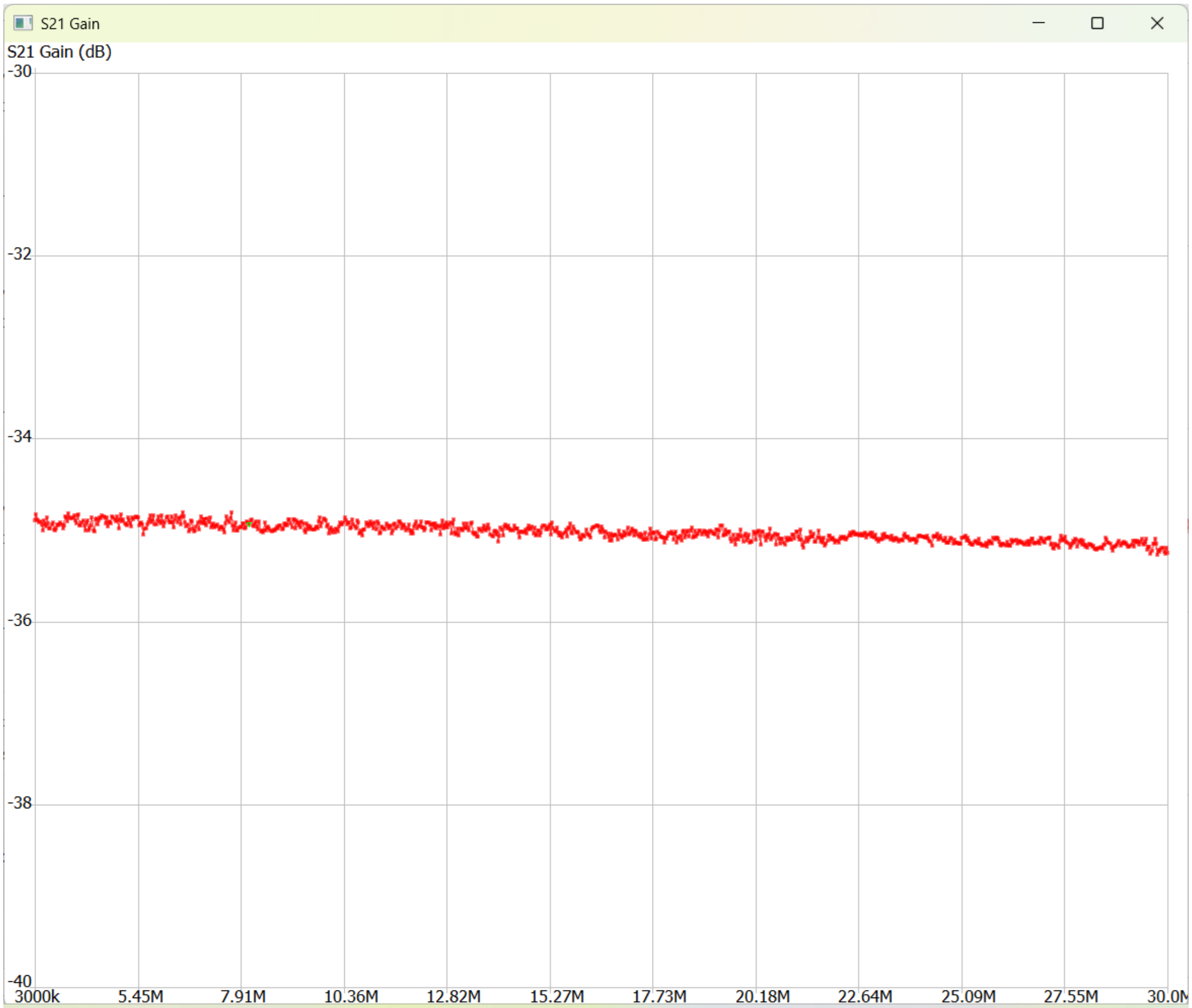

Figure 2
In this view, the NanoVNA swept my Pacific Antenna attenuator set to -35 dB showing an essentially flat response from 3 MHz to 30 MHz.

Crystal Resonance
The ability to measure the series and parallel resonance of crystals came as a complete surprise to me (and to be honest, I'm not sure when I'd need to do this). But this is totally cool from an educational perspective. Figure 3 shows a wide band scan of an FT-243 crystal (left around from my novice days and an HW-16). It shows the fundamental spike at 7.135 MHz along with the 3rd order harmonic at 21.405 MHz, and even a 5th order harmonic at about 35.69 MHz. That's pretty neat-o, but not the coolest part.

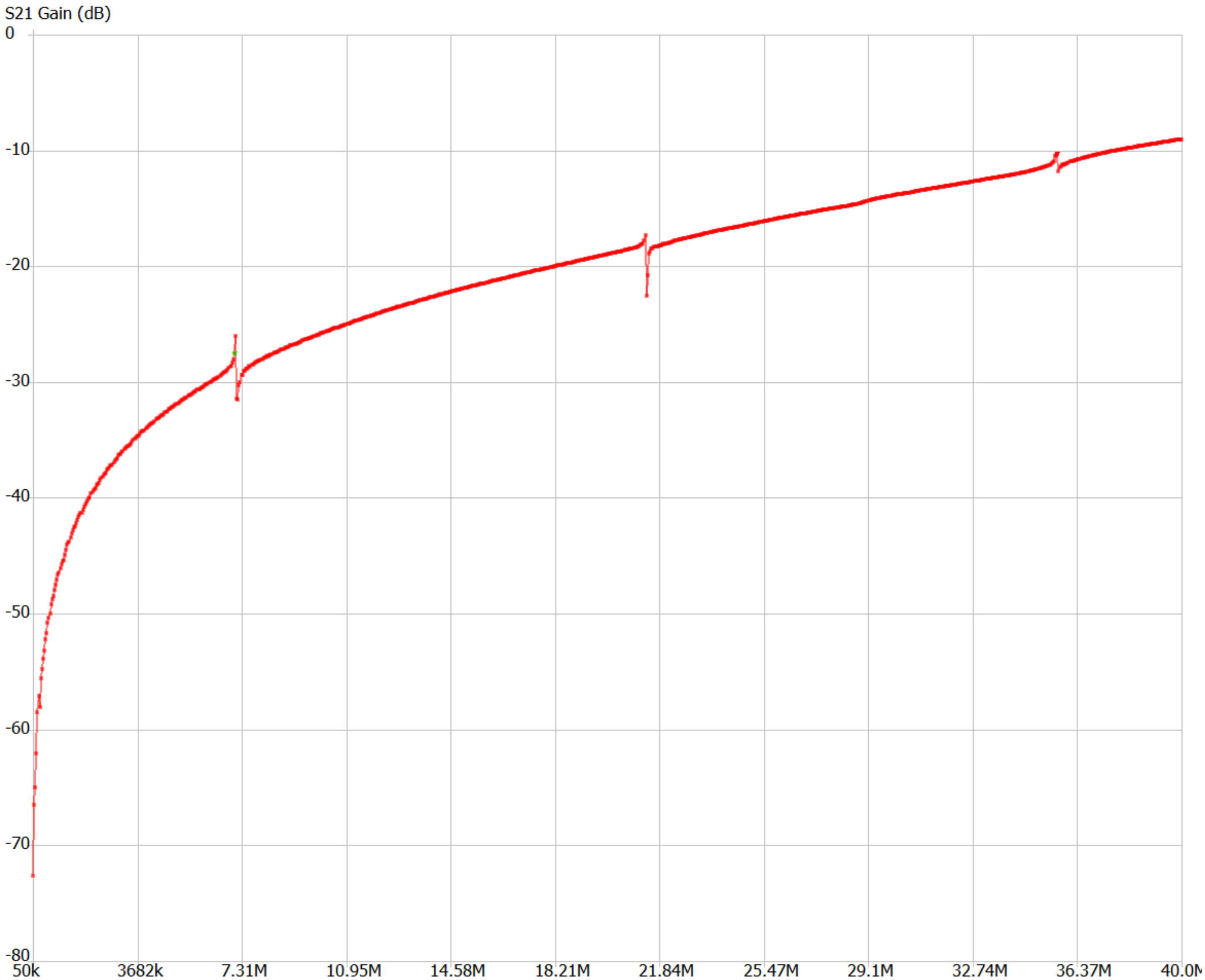

Figure 3
Sweeping a 7.135 MHz crystal from 50 kHz to 40 MHz shows the primary resonance along with 3rd and 5th order harmonic resonances. A narrower sweep on the 3rd harmonic could reveal if the resonance is sufficiently strong to be used for oscillation.

I next narrowed the sweep from 5 MHz to 9 MHz. As the Figure 4 chart more clearly shows, the positive peak is the series resonance, and the negative peak is the parallel resonance. According to Richards, measuring crystal characteristics is where the version 1 NanoVNA outperforms the version 2 Nano. The version 2 model uses a signal pulse rate of several kilohertz. Crystals, being electromechanical devices thus do not experience sufficient “settling time” after each NanoVNA version 2 pulse. The version 1 NanoVNA applies a continuous test signal and the crystal does not have the “settling” issue.

If I wished to use this crystal on its 3rd order harmonic on the upper end of the 15 meter band I would do another narrow sweep centered on that frequency to determine if the resonance is sufficiently strong to be useful.

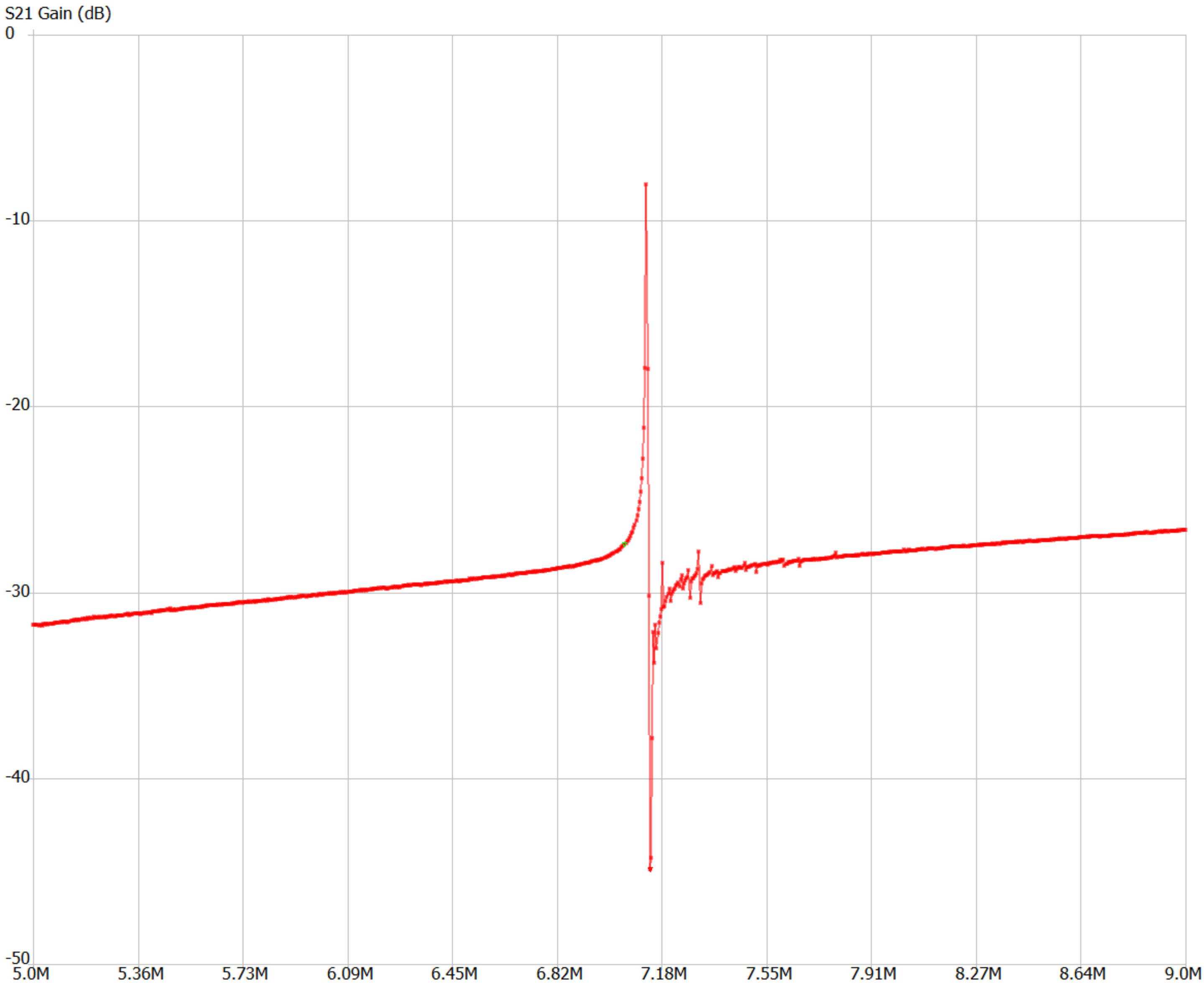

Figure 4
A narrow sweep of the same 7.135 MHz from 5 MHz to 9 MHz clearly shows the series resonance positive peak and the parallel resonance negative peak.

Measuring RF Feedline Loss
Except for feedline loss, every bit of power that leaves your ATU is radiated regardless of SWR. Therefore, it is beneficial to know that loss, the transmitted energy that becomes heat (thanks to the Conservation of Energy) in your feeder. The NanoVNA makes such a measurement relatively straightforward, if not easy. Richards suggests doing this with a sufficient length of coaxial cable that can reach the far end of the feedline that's in use. The alternative to the VNA is to excite the feedline with a calibrated signal generator and measure the signal strength at the opposite end with a calibrated level meter (like, who's going to have those pieces of equipment?).

To begin the process, it is required to calibrate the NanoVNA at the ends of the "test leads," even if one of those test leads is a lengthy run of coaxial cable. This moves the measurement plane out to each end of the feedline. When this is done, the S21 gain should be virtually flat as is illustrated by Figure 5. This is not a very exciting plot, and that's exactly as it should be.

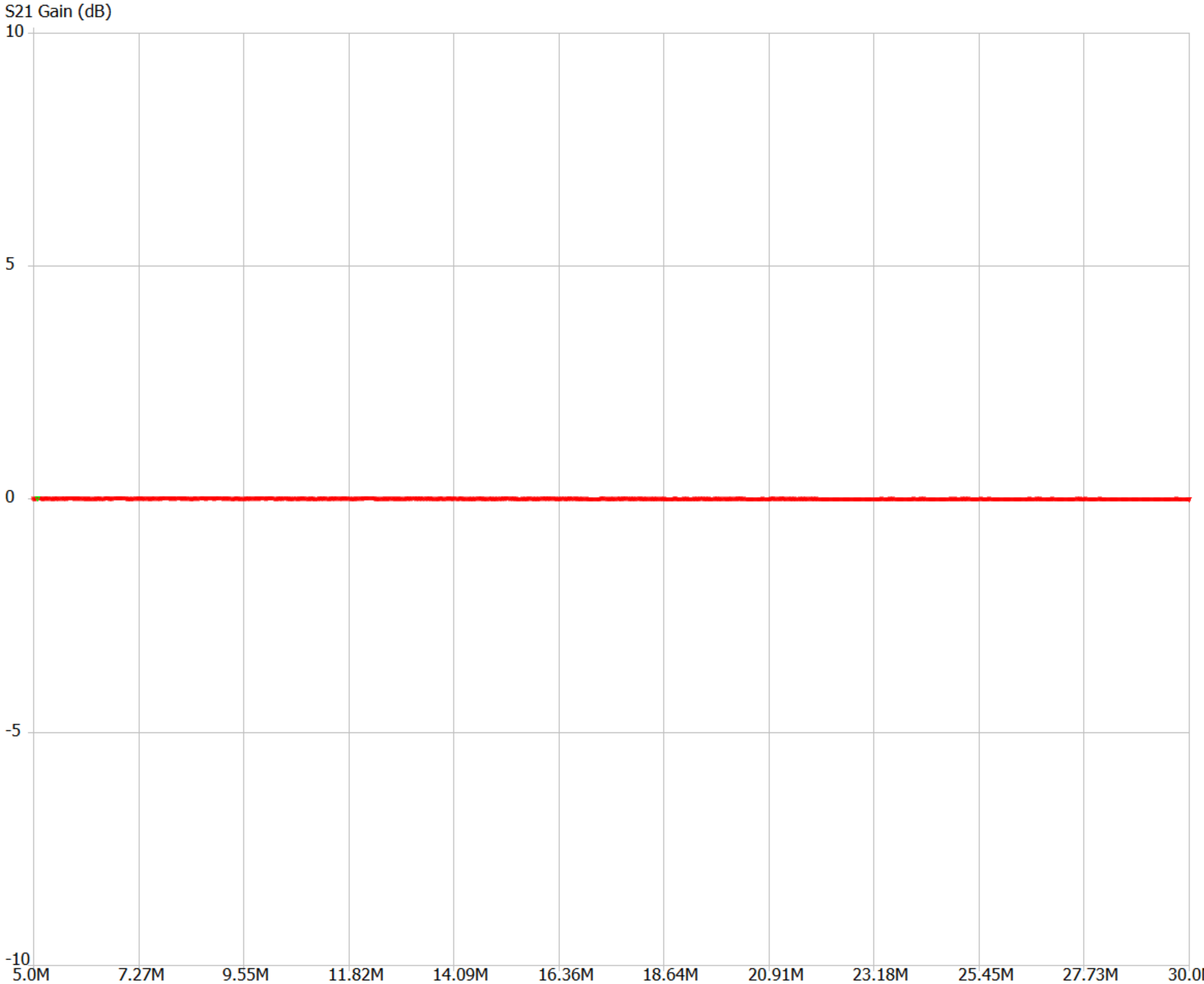

Figure 5
Measuring feedline loss requires careful and accurate calibration of the NanoVNA leads used to connect to each end of a coaxial cable. Including the leads moves the measurement plane out to their ends, essentially "zeroing out" any inductance or capacitance they may induce in the measurement signal. This graph shows a properly calibrated setup, ready to measure the actual feedline.

For my example, I next connected a 100-foot length of RG58 cable and swept it from 5 MHz to 30 MHz. The result is the S21 chart in Figure 6 and the results are as expected for a hamfest purchase of unmarked cable.

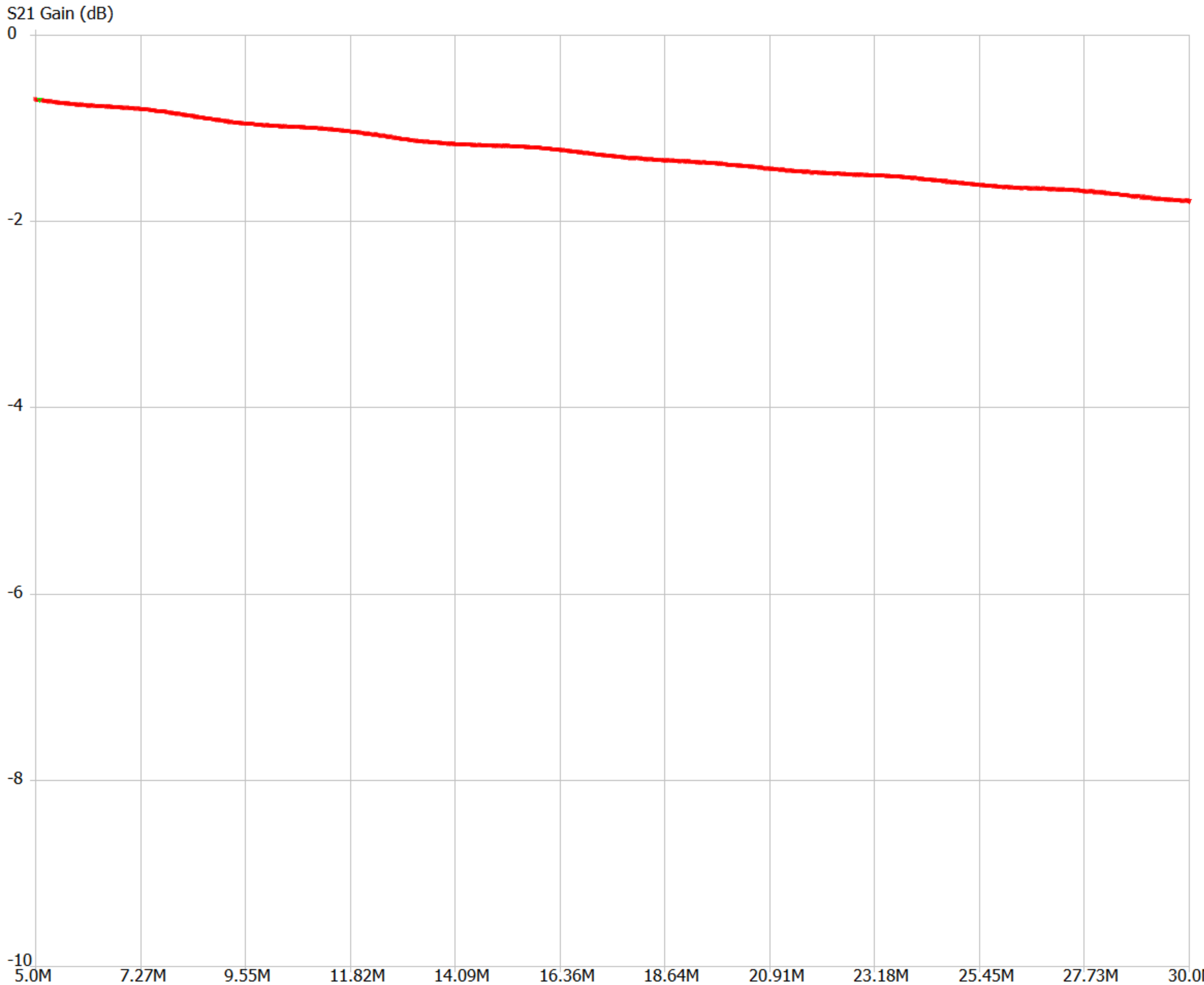

Figure 6
A 5 MHz to 30 MHz sweep of 100-feet of an RG58 cable shows loss steadily increasing as a function of frequency. This is as expected and accords well with published data for such cable.

Measuring and Cutting 1/4λ Stubs

A NanoVNA permits very accurate cutting of a 1/4λ stub without knowing the velocity factor of the cable. And it's incredibly simple. This involves only a single port 0 measurement and this is another case where it is very important to zero-out whatever test lead you are using to attach to the coaxial cable that is to be trimmed to length. Once the calibration is done, simply select the S11 phase chart and perform a sweep across the frequency range to be used with the stub.

Figure 7 shows my sweep of a cable connected to NanoVNA port 0 and open on the opposite end. At the 1/4 wave point, the reflected signal suddenly reverses phase. Placing a marker on the reversal point, I can see that it's at 10.9713 MHz. If I'm shooting for a 7.030 MHz stub, I would carefully start trimming the coax. With this proper calibration of the Nano I'm getting results out to four decimal places. That's probably better than I could ever do with a calculation based on the coax velocity factor and a tape measure.

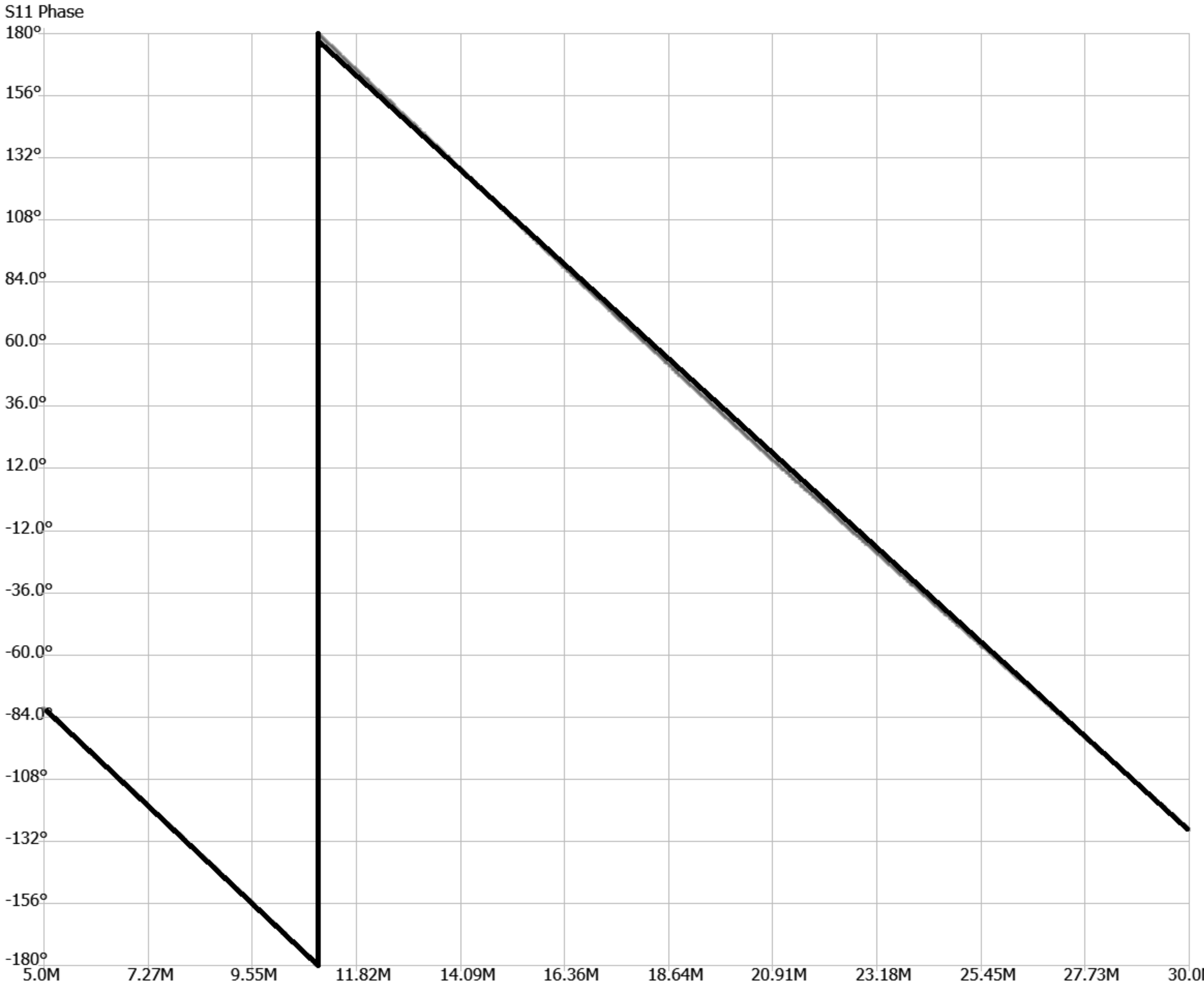

Figure 7
The NanoVNA excels when it comes to cutting 1/4 λ stubs. This chart shows the dramatic phase reversal at the 1/4 wavelength. In this case the frequency is 10.9713 MHz and in practice I would start carefully trimming the coaxial cable to reach the intended stub value.

The Rest of the Story
It's probably clear by now that I enjoy measuring things and learning more about RF. The five test scenarios above are a sample of the measuring capabilities that Richards details for the NanoVNA. Here are the others:

- Antenna Measurements
- Optimize ATU Settings
- Time Domain Reflectometry
- RF Switch and Relay Performance
- Active Filter Measurement
- Directional Couplers

- RF Taps
- Common Mode Chokes
- Baluns
- UNUNS
- Splitters/Combiners
- Cable Checker

In my opinion, *NanoVNAs Explained* is the missing manual for the NanoVNA. And while I have depended heavily on the NanoVNA Saver application to study the various measurements, I suspect that anyone already comfortable with navigating the menu options on the Nano would have little trouble following Richards step-by-step methods even if some procedures have changed slightly from the firmware 1.0.53 level that he used as the reference. Considering the vast amount of knowledge Richards packs into a mere 122 pages it is clear that his book is an essential resource. He demonstrates what can be done and takes the guesswork out of how to do it.

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