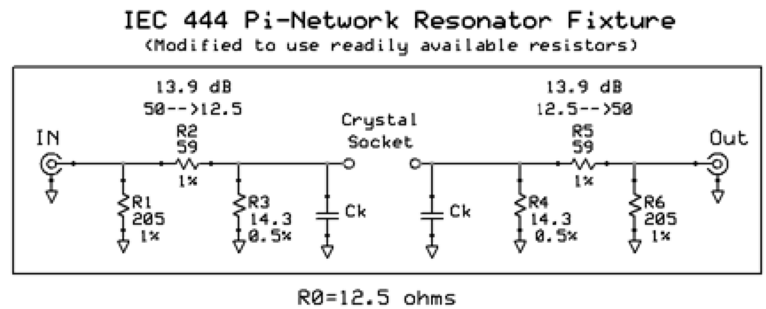
Attenuators and Test Fixtures

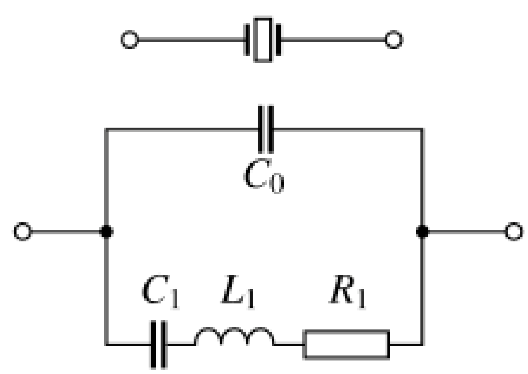
Test fixtures are used so that you can achieve repeatable results. Attenuators buffer some of the undesirable variations of testing and promote more consistent results. Attenuators come in various flavors with the more common configuration of a symmetrical Pi network of only two values and an input & output impedance of 50 Ohms for RF and 600 Ohms for audio. Attenuators can also provide impedance transformation in addition to attenuation. With A Nano VNA the attenuator can also adapt the measuring reference in the test fixture to be a different value from 50 Ohms as long as the new value is included inside the fixture at the measurement plane for the S-O-L calibration.

Let's take a look at the IEC-444 Xtal Fixture with the values shown in the original Series Fixture schematic. The IEC-444 specification requires the crystal to be tested at R_0 = 12.5 Ohms[1] and this is a series fixture.



I picked the crystal fixture to discuss because a crystal exhibits an extremely hi Q value[2] and wide variation in measurement values during a sweep. Sam Wetterlin's figure above can be implemented using the Series Fixture v2 09012024[3] or the Universal NanoVNA Test Fixture[4] with a change to the Load resister.

Some basic information about quartz crystals is shown below, along with a schematic[5].



f_s: series resonant frequency

$$f_s = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

f_p: parallel resonant frequency

$$f_p = \frac{1}{2\pi\sqrt{L_1\left(\frac{C_1 * C_0}{C_1 + C_0}\right)}}$$

Q: Q – factor

$$Q = \frac{2\pi f_s L_1}{R_1}$$ Typically from 10^4 to 10^6

R_1: Effective Series resistance typically 20 to 50 Ohms

The graph on the right shows the frequency plot with X on the vertical axis and frequency on the horizontal axis.

At low frequencies, below the series resonant frequency the crystal is capacitive and has a negative X value.

Between the series resonant frequency [a zero "0"] and the parallel resonant frequency [a pole "x"] the crystal is inductive with a +X value approaching an infinite positive value.

After the pole it again becomes an infinitely large negative capacitor [-X] and asymptotically approaches X = 0 at high frequencies.

And Δf is typically 2 to 3 KHz max at 10 MHz[6]
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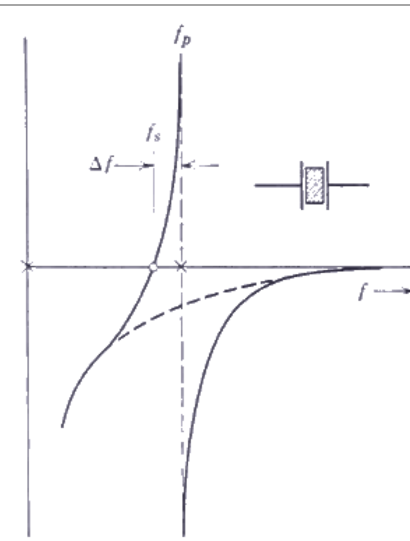

As you can see on the graph above, of the crystal frequency sweep, the measured values depart substantially from the 50+j0 the VNA expects to see or the 12.5 Ohms the internal fixture expects. Sam Wetterlin explains why these fixture resistor values have been chosen to improve the series fixture performance in the VNA Guide pg 5[1] and will not be repeated here.

Attenuators are normally characterized at low frequencies and the effects of stray inductance and capacitance are ignored. When used at RF frequencies it may be necessary to add small capacitances across the series resistor to flatten the response curve at higher frequencies. An example is the Miniature SMA Step Attenuator schematic in the zip file[8]. A gimmick capacitor is often used because of the small values required. A gimmick capacitor is just a twisted pair of insulated wires that may be trimmed shorter or twisted tighter to change the value. Compensating attenuators is beyond the scope of this paper.

Because this fixture translates the 50 Ohm input/output impedance to 12.5 Ohms it is necessary to change the internal fixture Load from 50 Ohms to 12.5 Ohms, if you want to put the S-O-L calibration internally in the fixture. This is not a standard value and we need to use two parallel resistors. The best that Resistor Finder[7] suggests are 75 Ohms and 15 Ohms and for the 12.5 Ohm value and there are 300 and 15 Ohms for the 14.3 Ohm parts.

If you have an application that requires a load impedance that is substantially different from 50 Ohms you can use some on line calculators to determine the proper resistors for the attenuation and load translation.

> Resistor Finder[7] - Finds a combination of two series or parallel connected resistors for a custom value. Returns a list of the best values found.
>
> Matching Pi Attenuator Calculator[9] - Calculates the resistor values, attenuation, minimum attenuation, 'impedance', reflection coefficient, VSWR and return loss of a matching Pi attenuator and includes the formulas that are used in the calculations.

If you have a need for more information relating to quartz crystals look at

> Quartz Crystal Parameter Calculator[10] - This online crystal parameter calculator calculates the series resonance frequency Fs (MHz), parallel resonance frequency Fp (MHz), and Q factor of a quartz crystal by entering the value of series resistance (Rs), series inductance (Ls), Series capacitance (Cs), and parallel capacitance (Cp).

IEC-444 Test fixture parts - Series Fixture - R_0 = 12.5 Ohms configuration

R1a, R6a	Thin Film Resistors - SMD 0805 1/8W 205 ohm 0.1% 25ppm	603-RT0805BRD07205RL
R2a, R5a	Thin Film Resistors - SMD 0805 1/8W 59 ohm 0.1% 25ppm	667-ERA-6AEB59R0V
R3a,R4a,R7a,R8a	Thin Film Resistors - SMD 0805 1/8W 15 ohm 0.1% 25ppm	603-RT0805BRD0715RL
R3b,R4b	Thin Film Resistors - SMD 0805 1/8W 300 ohm 0.1% 25ppm	667-ERA-6AEB301V
R7b, R8b	Thin Film Resistors - SMD 0805 1/8W 75 ohm 0.1% 25ppm	667-ERA-6AEB750V

Notes:

1. Sam Wetterlin, VNA Guide pg 5, https://web.archive.org/web/20181206052548/http://www.wetterlin.org/sam/SA/Operation/VNA_Guide.pdf
2. Q factor. A typical *Q* value for a quartz oscillator ranges from 10^4 to 10^6, …. The maximum *Q* for a high stability quartz oscillator can be estimated as $Q = 1.6 \times 10^7/f$, where *f* is the resonant frequency in megahertz https://en.wikipedia.org/wiki/Crystal_oscillator
3. http://www.k9ivb.net/NanoVNA/SeriesFixture_06102014.pdf
4. http://www.k9ivb.net/NanoVNA/Universal%20Test%20Fixture%20Schematic%20v1.1.pdf
5. https://en.wikipedia.org/wiki/Crystal_oscillator
6. Crystal Basics, CTS Application Note, https://www.mouser.com/pdfDocs/ctsappnote-crystal-basics.pdf?srsltid=AfmBOoo4_iI59CsQw-QIe2U3QIIsIKskR_Dx2DutBLYNRkB_hZuqjeAG
7. http://mustcalculate.com/electronics/resistorfinder.php?r=12.5&es=E96
8. QEX September/October 2021 pp 9-21 by Tom Alldred VA7TA. http://www.k9ivb.net/Miniature%20SMA%20Step%20Attenuator/Files/VA7TA_rev1.zip
9. https://chemandy.com/calculators/matching-pi-attenuator-calculator.htm
10. https://www.everythingrf.com/rf-calculators/quartz-crystal-parameter-calculator

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