How to Measure a Quartz Crystal

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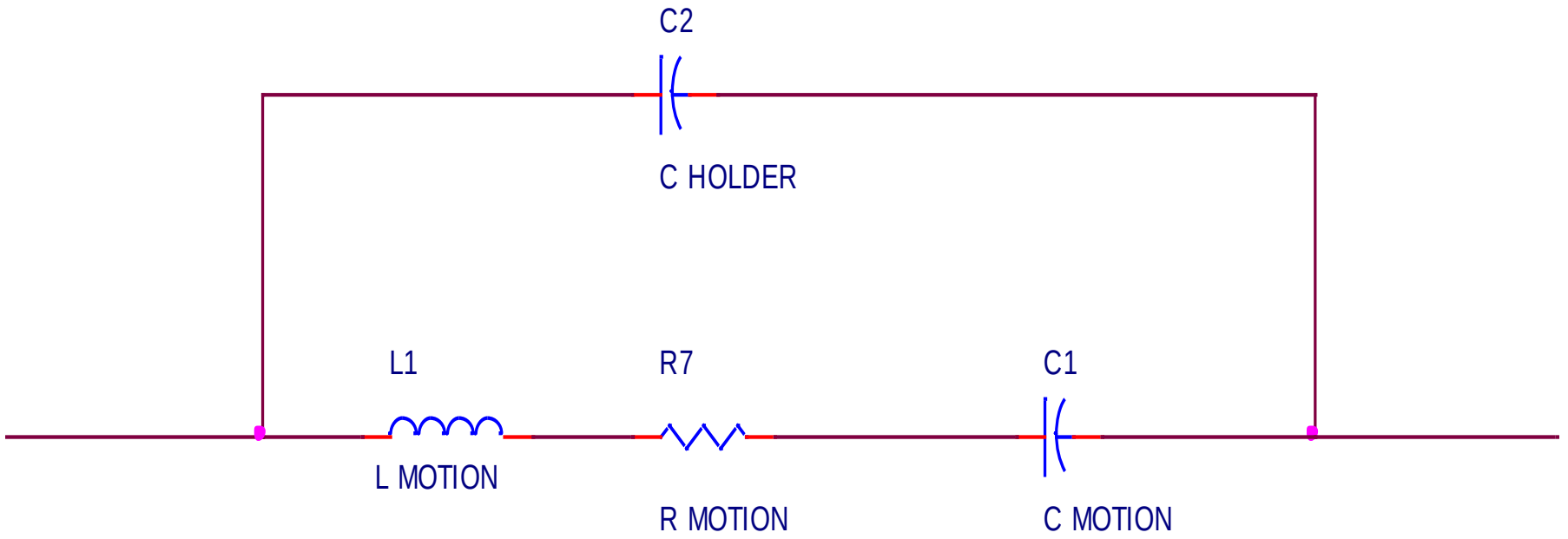
What does a Crystal Look Like

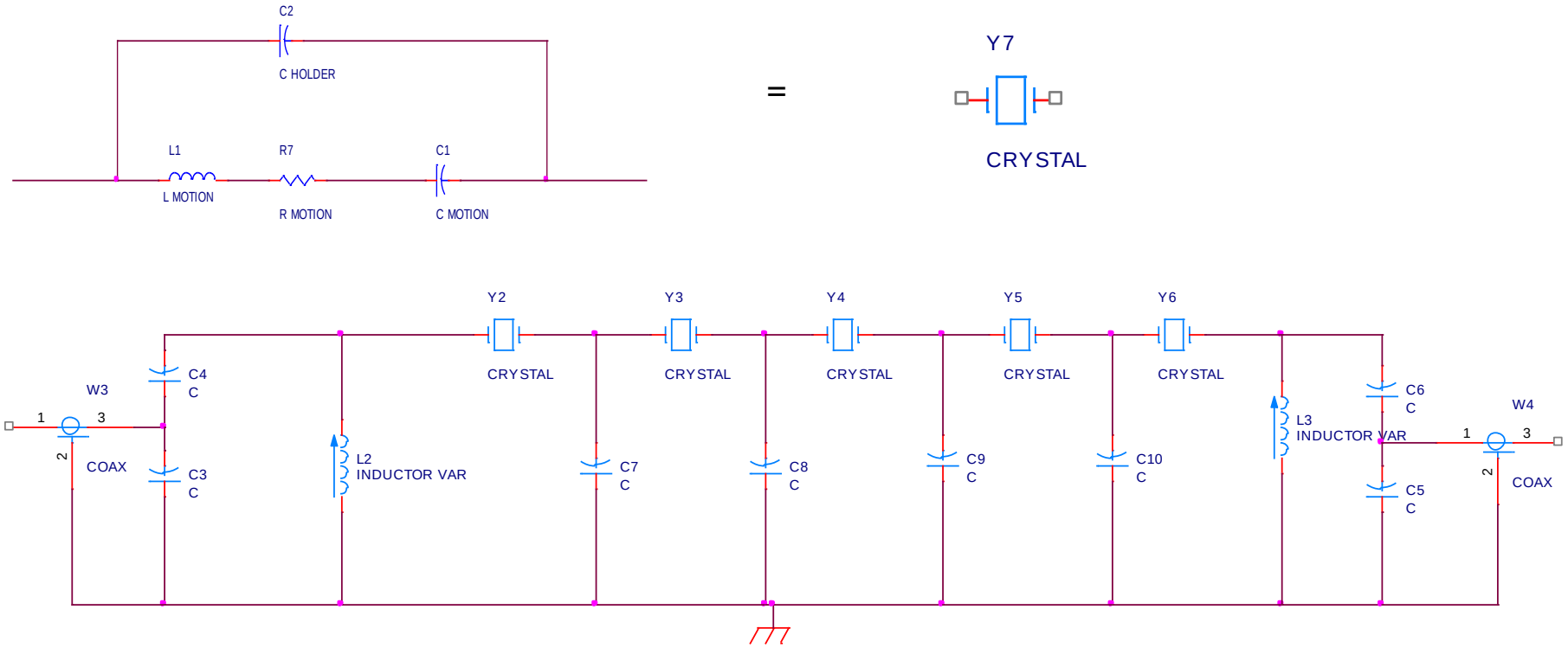


What do we REALLY need to Measure

- Four Basic Parameters

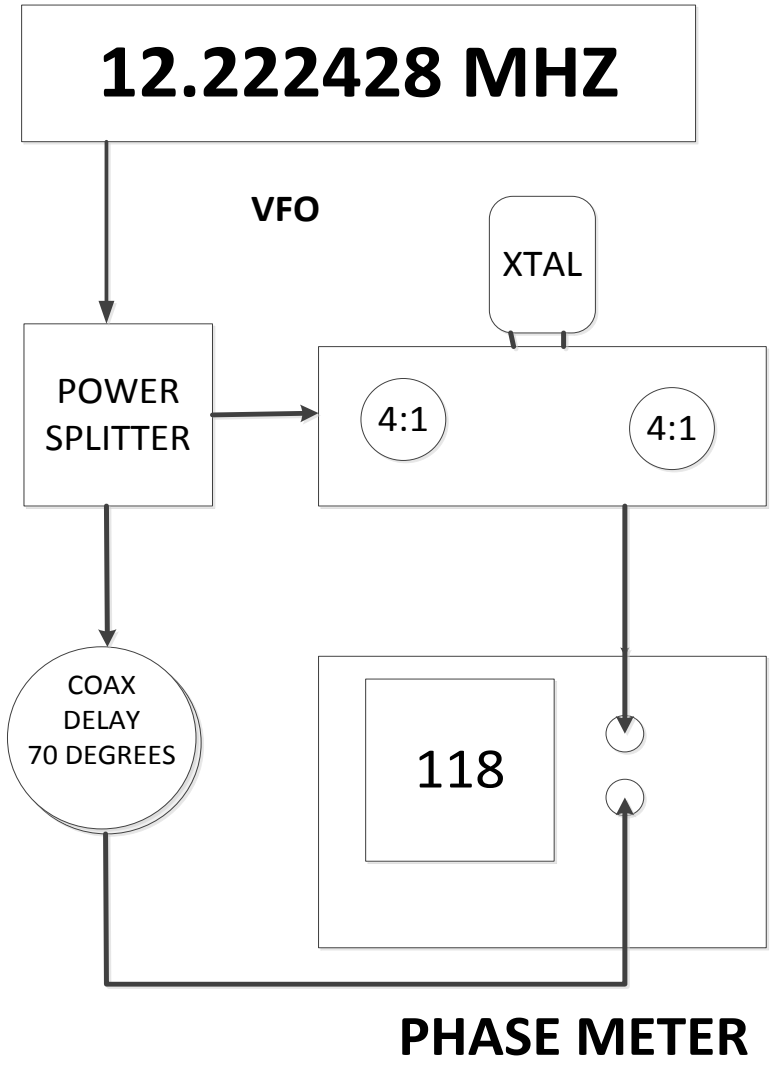
- Series Resistance
- Holder Capacitance (Plates or Deposited Metal on crystal)
- Motion Inductance Determines the Frequency
- Motion Capacitance Determines the frequency

Why do we need to measure all that ?

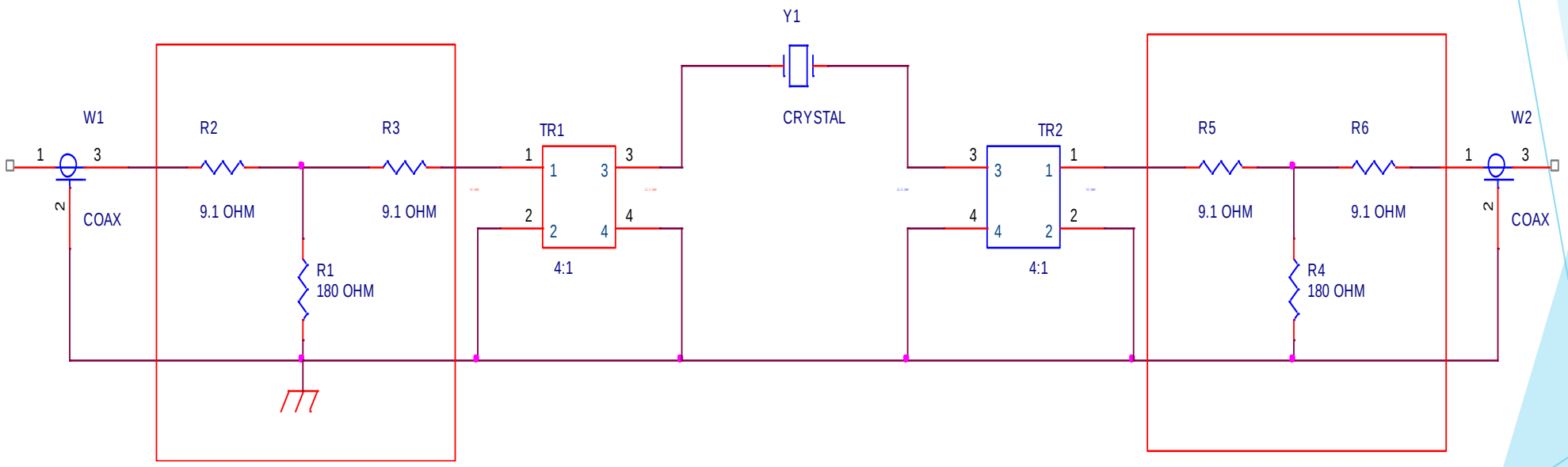


12.228 MHz SHELF FILTER

TEST SETUP


12.222428 MHZ
VFO
XTAL
POWER SPLITTER
4:1
4:1
COAX DELAY 70 DEGREES
118
PHASE METER

DUT SCHEMATIC



DUT Description

- 12.5 OHM Impedance
- 3 DB Pads to provide Impedance match

- Broad Band 4:1 ferrite Balun. Two windings #28 WW wire 14T
- 3DB pad T Configuration 9.1 Ohm and 180 Ohm

Power Splitter

- 6 DB Attenuation per port
- Less sensitive to load variations
- Trifilar windings forming a center tapped secondary

- Provides two paths 180 Degrees out of phase

Inside the DUT Box

VFO

- Signal Generator Needs 1 HZ resolution
- 0 to +10 DBM Output
- Using a VFO with Si570 chip

Phase Meter

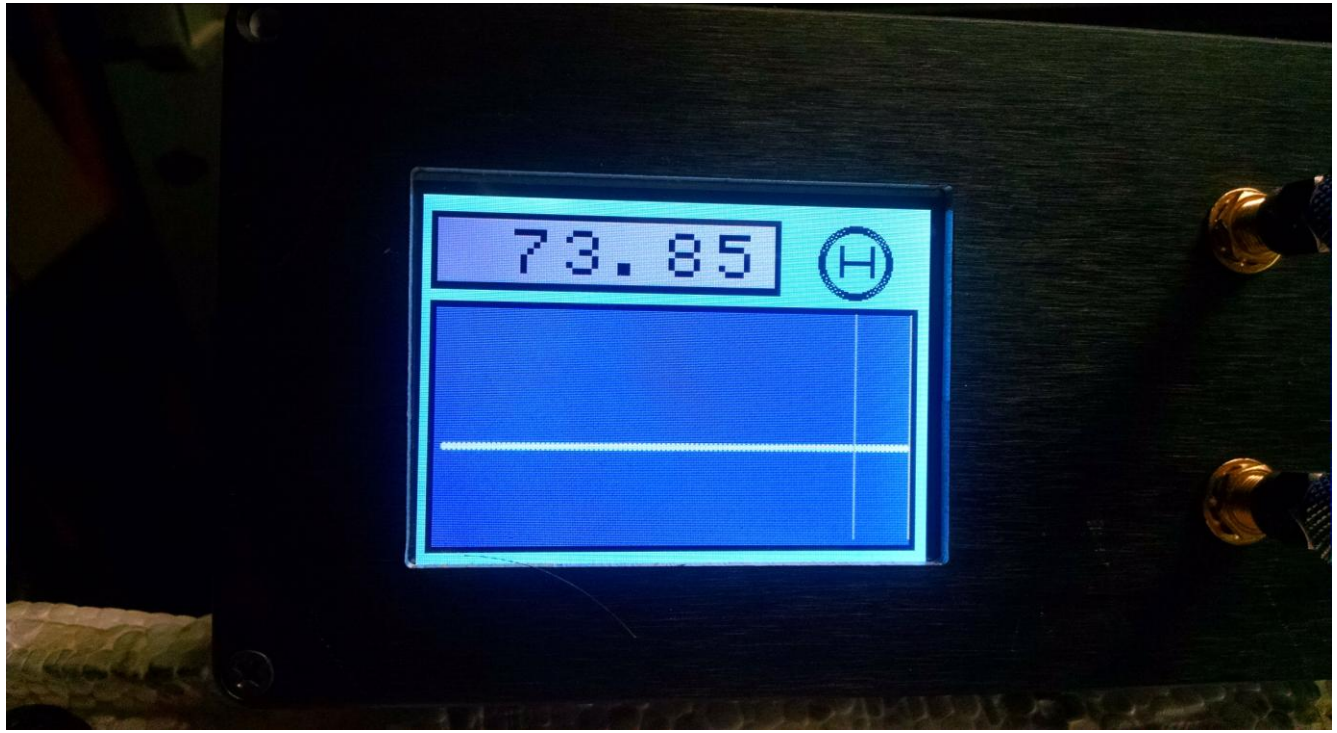
- Based on W1GHZ Ratiometer Project
- Works on Phase Differences between 20 and 160 Degrees
- 20’ of RG-58 provides about 70 degrees of phase shift
- Puts the phase differences in the active region of the meter
- Arduino Processor and TFT display

System Calibration

- Place a short in place of the crystal
- Set the VFO to the crystal's manufactured frequency. The actual crystal frequency may be +- several KHz either way.
- Note the phase angle on the phase meter, this will be 0 degrees reference
- Replace the phase meter with a milliwatt power meter or calibrated 50 ohm volt meter. Take a reading. This will be 0DB attenuation for measuring the series resistance.
- Install Crystal and reconnect the Phase meter.

Finding the Crystal's Resonate Frequency

- Adjust the VFO frequency until the Phase reading matches the reading with the short. This will be 0 Degrees or resonance of the crystal. In my case with the roll of coax I had in the shop, the phase difference was 73.85 degrees.

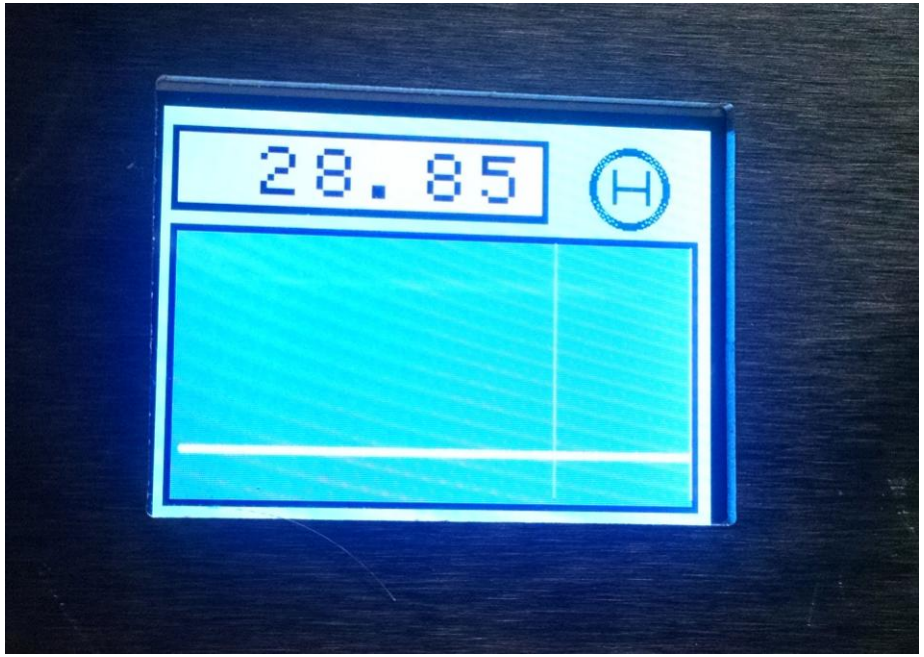


Measure Crystal Attenuation

- Reconnect the power meter and take a reading with the crystal at resonance. The maximum voltage (power) may be at a different point, but only the resonate voltage counts.
- Save this attenuation for later. My case the attenuation was 1.1DB
- Save the VFO frequency for later 12.222420 MHz was my reading

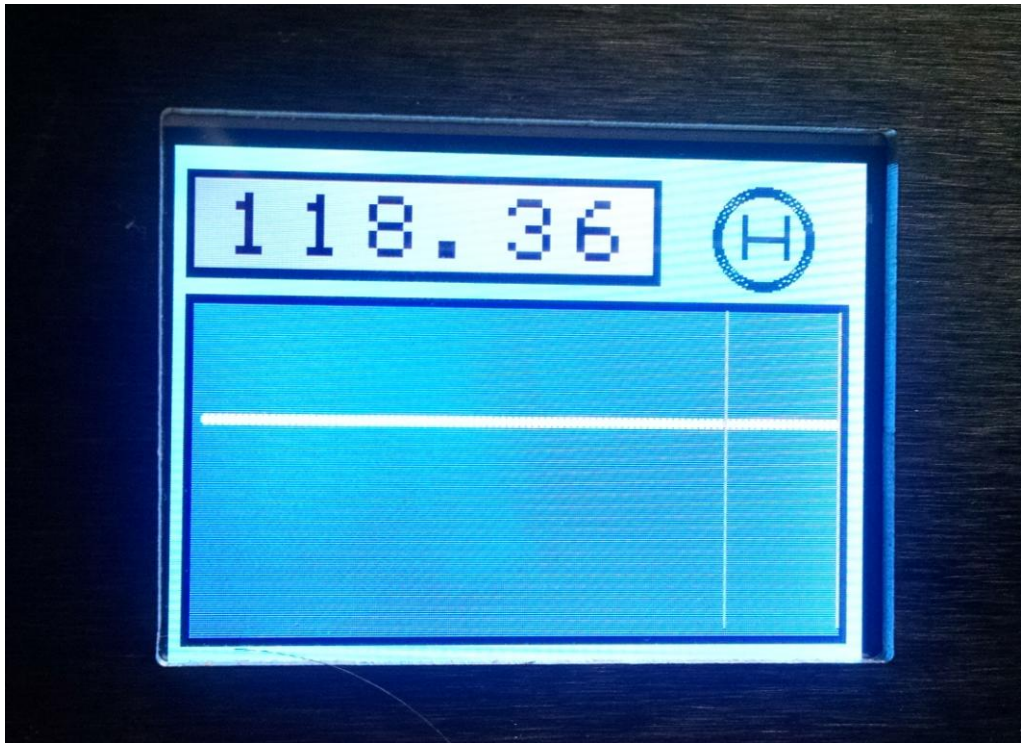
Measurement at - 45 Degree

- Reconnect the Phase Meter
- Adjust the VFO until the Phase is 45 Degrees lower than the reference phase. In my case 28 Degrees (73 – 45) Write down this Frequency



Go The Other Way

- Adjust Phase for + 45 Degrees 73+45 = 118
- Save this frequency



Numbers you need to know

- Tan (45) = 1
- System Impedance = 12.5 Ohm
- Attenuation 1.1 DB
- Fs = Center Frequency 12.222420 MHz
- F-45 = 12.222928 MHz
- F+45 = 12.222156 MHz
- Delta Frequency = 772 Hz

Motion Resistance

The relationship between attenuation and series resistance is:

$$R_M = 2R_L\left(10^{\frac{\alpha}{20}} - 1\right)$$

Where

R_M is the motional resistance
R_L is the source and load resistance seen by the crystal (a function of the test fixture)
α is the loss in dB

RM = 2 x 12.5 * [10^(1.1/20) -1]

RM = 3.539083 Ohm

REFF = 2RL + RM
REFF = 2X12.5 + 3.54 or 28.54 Ohms

Motion Values

$$C_M = \frac{\Delta f(\pm\vartheta)}{2\pi f_R{}^2 R_{EFF} \tan(\vartheta)}$$

CM = (772) / [2*3.1415 * 12222420 * 12222420 * 1]

CM = 2.92696E-14 Farads or .29 Femto Farads

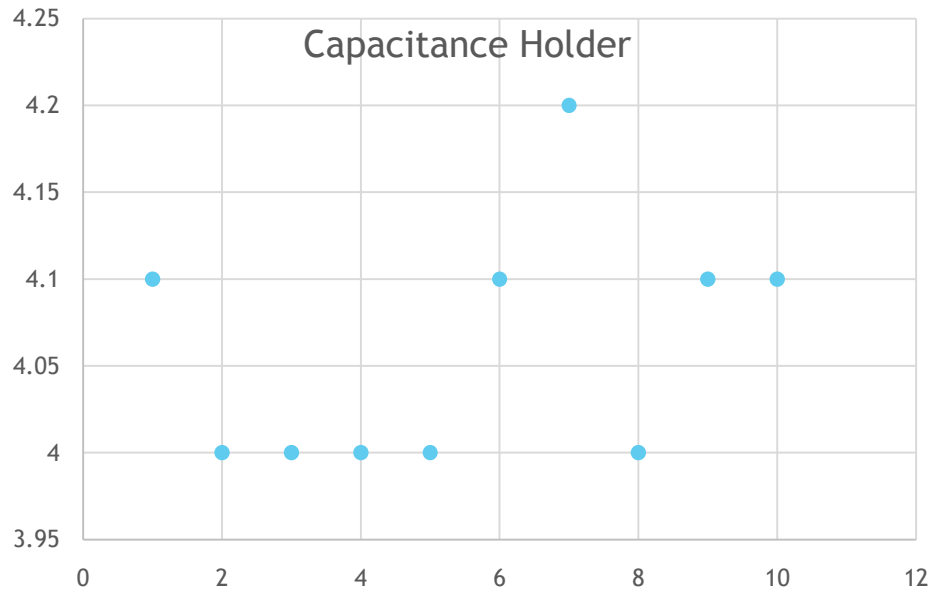
$$L_M = \frac{R_{EFF}}{2\pi\Delta f(\pm\varphi)} \tan(\vartheta)$$

LM = 28.54 / [2 * 3.14159 * 772]
LM = 0.005793075 or 5.79 mH

Last but Not Least

- Cp or Parallel Capacitance

- Measure in a LRC bridge. I made a holder for 4 crystals to measure in parallel
- Be sure to take in account of any fixture capacitance
- In my case Most of the crystals measured close to 4 pF



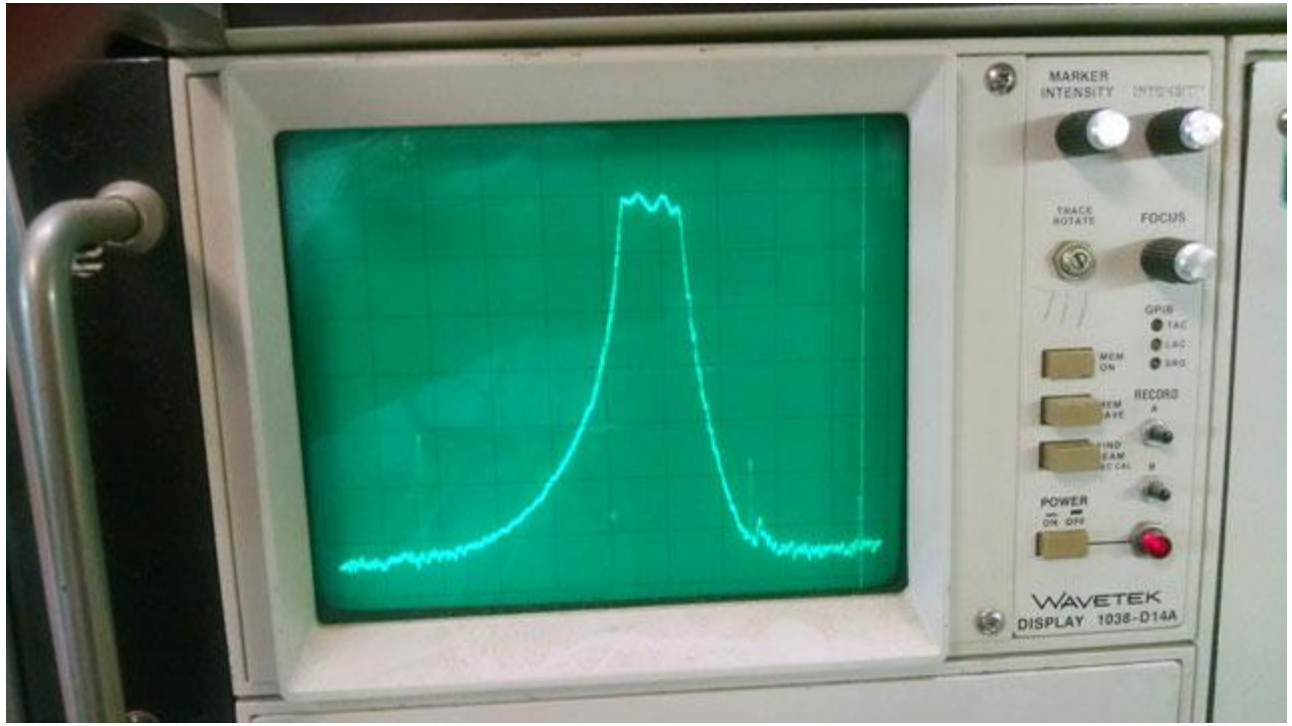
All Measurements In Place

- All four major parameters are now measured

- Sanity Check 1/(2 * 3.14259 * SQRT(LM * CM) Resonate Frequency
- 1 / (2 * 3.4159 * SQRT(0.005793075 * 2.92696E-14)
- Fcalculated = 12222420 Hz
- Fmeasured = 12222420 Hz

OK Now What

- Tune in next presentation on Lattice filters
- First sample built 5 KHz bandwidth with ~ 1DB ripple after tuning



Really Good Reference

- http://www.cliftonlaboratories.com/Documents/Crystal%20Motional%20Parameters.pdf
- Phase Meter W1GHZ.org Antenna ratiometer