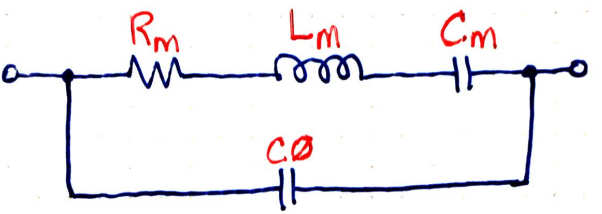
MEASURING CRYSTAL PARAMETERS WITH THE NANOVNA & MORE

A LOOK AT SEVERAL METHODS ...

THE BASIC CRYSTAL MODEL:



R_m = MOTIONAL RESISTANCE } Q

PARALLEL RESONANCE

L_m = MOTIONAL INDUCTANCE

C_m = MOTIONAL CAPACITANCE } SERIES RESONANCE

$C_\emptyset$ = HOLDER CAPACITANCE

- PARAMETERS NEEDED TO DESIGN FILTERS, ETC ...

EQUIPMENT USED:

- NANOVNA-H4 WITH DISLORD v1.0.39 F/W
- AADE L/C METER IIB
- DER EE DE-5000 LCR METER
- TEKTRONIX FCA-3003 FREQUENCY COUNTER
- 12 V POWER SUPPLY

- CUSTOM BUILT G3UUR TEST CIRCUIT
- HOMEMADE "THRU" TEST FIXTURE FOR VNA
  (50Ω THRU FIXTURE)

REFERENCE:

"CRYSTAL MOTIONAL PARAMETERS
A COMPARISON OF MEASUREMENT PROCEDURES"
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11 JUNE 2006

WE WILL COVER:

- MEASURING C0 - METERS OR NANOVNA
- MEASURING Rm - NANOVNA
- MEASURING Lm & Cm USING:
  - G3UUR METHOD - COUNTER
  - PHASE SHIFT METHOD
  - -3dB METHOD
  - SERIES/PARALLEL METHOD

} NANOVNA

MEASURE C0 – "HOLDER" CAPACITANCE

- TYPICALLY MEASURED WELL BELOW THE CRYSTAL FREQUENCY
  (SO THE MOTIONAL PROPERTIES DON'T INTERFERE)

L/C METER : 3.69pF
DE-5000 : 3.75pF
NANOVNA : 3.8 pF

$C0 = 3.747_p$

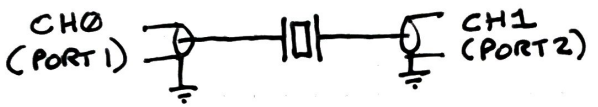
TIPS FOR USING THE NANOVNA ON CRYSTALS

- RUN SOME INITIAL "THRU" (S21) SCANS TO DETERMINE SERIES & PARALLEL RESONANCE
- CALIBRATE A SPAN THAT COVERS f_s & f_p AND STORE IT, AND...
- CALIBRATE A SPAN THAT JUST COVERS f_s TO GET GOOD RESOLUTION IN FREQUENCY
- USE THE HIGHEST # OF POINTS AVAILABLE

MEASURE R_M - MOTIONAL RESISTANCE

- MEASURE S21 OVER NARROW SPAN CENTERED ON f_s (SERIES RESONANCE FREQUENCY) f_R
  - TYPICALLY 10 kHz OR LESS

• SERIES-THRU METHOD:



① RECORD: S21 @ 0° PHASE

f_s @ 0° PHASE (f_R)

$$R_M = 2 \cdot R_L \cdot \left(10^{\frac{-S21}{20}} - 1\right)$$

S21 = −0.60 dB

f_s = 18.723225

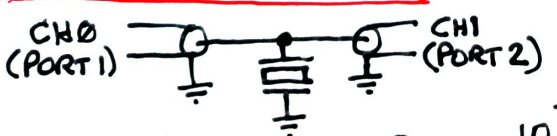
$R_L = 50\,\Omega$ IN THIS CASE

(USE −S21 TO MAKE EXPONENT POSITIVE)

② COMPUTE R_M

$R_M = 7.152\,\Omega$

• SHUNT-THRU METHOD:

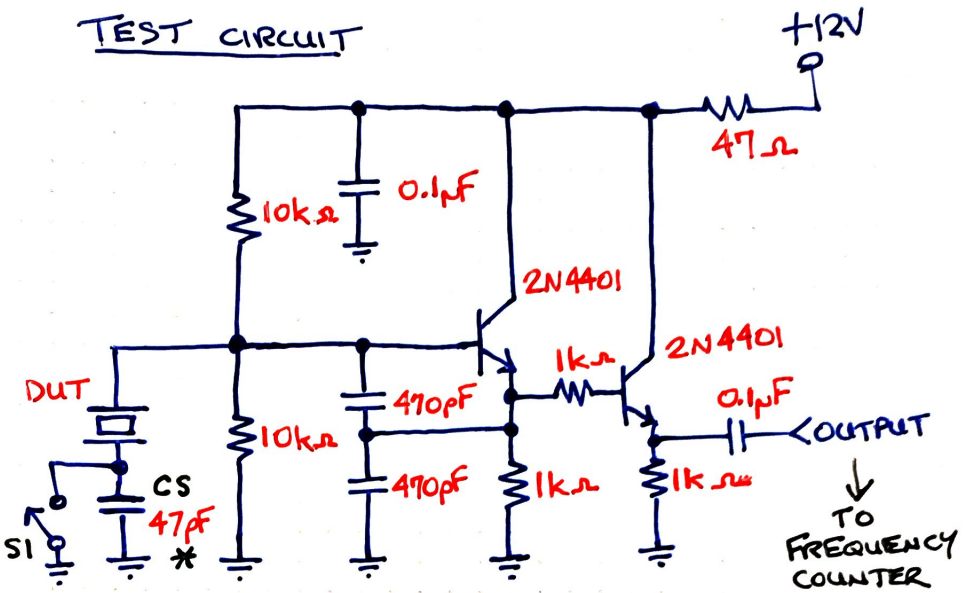


$$R_M = \frac{10^{\frac{S21}{20}} \cdot R_L}{2 \cdot \left(1 - 10^{S21/20}\right)}$$

G3UUR METHOD FOR C_M & L_M

W2AEW (5)

TEST CIRCUIT



MEASURE: f_{GND} WITH SWITCHED CLOSED

f_{OPEN} WITH SWITCH OPEN

CALCULATE:

$$\Delta f = f_{OPEN} - f_{GND}$$

$$C_M = \frac{2(CS + C\varnothing) \cdot \Delta f}{f_{GND}}$$

$$L_M = \frac{1}{(2\pi f_{GND})^2 \cdot C_M}$$

$f_{GND} = 18.72384$ MHz

$f_{OPEN} = 18.72661$ MHz

$\Delta f = 2770$ Hz

$C_M = 15.02$ pF

$L_M = 4.81$ mH

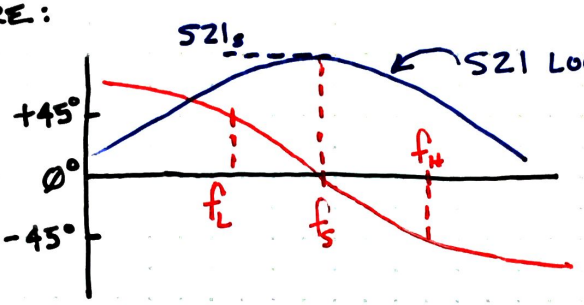
* TYP 27-56pF MEASURE IT ACCURATELY

PHASE SHIFT METHOD

SETUP: - SPAN ≈ 5-10kHz AROUND f_s
- S21 LOG MAG
- S21 PHASE

(OPTIONAL S11 LOG MAG + SMITH)

MEASURE:



f_s = FREQUENCY @ 0°

f_L = FREQUENCY @ +45°

f_H = FREQUENCY @ -45°

$S21_s$ = LOG MAG @ 0°

MEASURED

f_s = 18.723200

f_L = 18.721475

f_H = 18.724900

$S21_s$ = -0.60dB

CALCULATE:

$$R_M = 2 \cdot R_L \left(10^{\frac{-S21_s}{20}} - 1\right)$$

$$R_{EFF} = 2 \cdot R_L + R_m$$

$$\Delta f = f_H - f_L$$

$$C_m = \frac{\Delta f}{2\pi f_s^2 \cdot R_{EFF}}$$

$$L_m = \frac{R_{EFF}}{2\pi \Delta f}$$

CALCULATED

R_M = 7.152Ω

R_{EFF} = 107.152

Δf = 3.425kHz

C_m = 14.51fF

L_m = 4.98mH

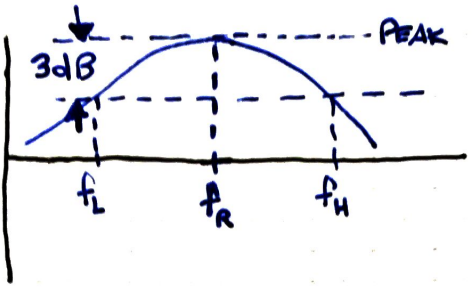
(R_L = LOAD ON EITHER SIDE OF XTAL)
50Ω IN THIS CASE

3dB METHOD

W2AEW

SETUP: - SPAN ≈ 5-10kHz AROUND f_R (PEAK OF S21)
- S21 LOG MAG
- S21 PHASE

MEASURE:



f_L & f_H = FREQUENCIES WHERE S21 IS 3dB BELOW PEAK (f_R)

NOTE: S21 ≠ 0dB @ f_R

COMPUTE:

$f_S = 18.723200$

$$\Delta f = f_H - f_L$$

$$Q = \frac{f_R}{\Delta f} = \frac{2\pi f_R L_M}{R_{EFF}}$$

$$L_M = \frac{Q \cdot R_{EFF}}{2\pi f_R}$$

$$C_M = \frac{1}{(2\pi f_R)^2 L_M}$$

RESULTS

f_L = 18.721350
f_H = 18.724825
Δf = 3.475kHz
Q = 5389
L_M = 4.91mH
C_M = 14.72 fF

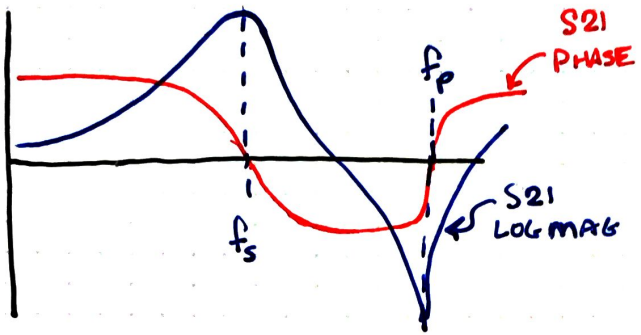
NOTE: SEE PREVIOUS PAGE FOR R_M & R_{EFF} CALCULATION

SERIES / PARALLEL METHOD

W2AEW

SETUP: - SPAN TO SHOW SERIES & PARALLEL RESONANCE (PEAK + DIP)
TYPICALLY 50 - 150 kHz

- S21 LOG MAG & PHASE



MEASURE: f_s = SERIES RESONANCE
f_p = PARALLEL RESONANCE

f_s = 18.123250
f_p = 18.761500

NOTE: MAY NEED TO SPAN TIGHTER AROUND EACH FOR GOOD RESOLUTION

COMPUTE:

$$C_M = \left(\frac{f_p}{f_s} - 1\right) \cdot 2 \cdot \left(C0 + C^*_{STRAY}\right)$$

C_M = 15.31 fF

$$L_M = \frac{1}{(2\pi f_s)^2 \cdot C_M}$$

L_M = 4.72 mH

* C_{STRAY} = CAPACITANCE OF FIXTURE

Summary of Results

$R_m = 7.152\ \Omega$

$C_0 =$	3.69 pF	AADE L/C METER
	3.75 pF	LCR METER
	3.80 pF	NANOVNA

METHOD	C_M (fF)	L_M (mH)
G3UUR	15.02	4.81
PHASE SHIFT	14.51	4.98
-3dB	14.72	4.91
SERIES/PARALLEL	15.31	4.72