OPERATION AND SERVICE MANUAL

RQCM

RESEARCH QUARTZ CRYSTAL MICROBALANCE

MAXTEK, INC.

OPERATION AND SERVICE MANUAL

RQCM
RESEARCH QUARTZ CRYSTAL MICROBALANCE

P/N 603800

S/N _____

MAXTEK, INC.

WARRANTY

Maxtek, Inc. warrants the product to be free of functional defects in material and workmanship and that it will perform in accordance with its published specification for a period of (twenty-four) 24 months.

The foregoing warranty is subject to the condition that the product be properly operated in accordance with instructions provided by Maxtek, Inc. or has not been subjected to improper installation or abuse, misuse, negligence, accident, corrosion, or damage during shipment.

Purchaser's sole and exclusive remedy under the above warranty is limited to, at Maxtek's option, repair or replacement of defective equipment or return to purchaser of the original purchase price. Transportation charges must be prepaid and upon examination by Maxtek the equipment must be found not to comply with the above warranty. In the event that Maxtek elects to refund the purchase price, the equipment shall be the property of Maxtek.

This warranty is in lieu of all other warranties, expressed or implied and constitutes fulfillment of all of Maxtek's liabilities to the purchaser. Maxtek does not warrant that the product can be used for any particular purpose other than that covered by the applicable specifications. Maxtek assumes no liability in any event, for consequential damages, for anticipated or lost profits, incidental damage of loss of time or other losses incurred by the purchaser or third party in connection with products covered by this warranty or otherwise.

DISCLOSURE

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WARNING

Only properly trained personnel should attempt to service the RQCM.

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1   GENERAL DESCRIPTION

The RQCM is designed for many types of research applications where QCM (Quartz Crystal Microbalance) measurement is desired. Included with each instrument is a Windows™ based software package that allows the user to configure the RQCM, setup multiple experiments, log data with real-time graphing and review results from previous experiments.

The QCM portion of this system accurately measures crystal frequency and crystal resistance for up to three crystals simultaneously. The software uses this data to derive various physical parameters of the deposited film and/or the liquid or gas environment at the surface of the crystal. The heart of the system is a high performance phase lock oscillator (PLO) circuit that provides superior measurement stability over a wide frequency range (3.8 to 6.06 MHz, or 5.1 to 10 MHz). The circuit also incorporates adjustable crystal capacitance cancellation reducing error caused by the parasitic capacitance of the crystal, cable and fixture. Capacitance cancellation is essential for accurate measurements of lossy (soft) films.

Data collection from external sources is accomplished with an optional Data Acquisition Card, which provides three temperature inputs (RTD, Thermocouple and Thermistor) as well as five scalable analog inputs. As for example, the user can combine the potential and current outputs of a potentiostat with the mass, frequency and crystal resistance data of the QCM.

Control of external instruments and peripheral devices is accomplished with an optional input/output card. Each remote I/O card provides eight remote inputs and eight relay outputs. The functions of the inputs and outputs are defined in the RQCM's software with some typical uses including the control of pumps, heaters, valves, instrument initiation, etc.

1.1   FEATURES

1.1.1   VERY WIDE FREQUENCY RANGE

The RQCM supports a wide frequency range from 3.8 to over 6 MHz. It will support both 5 and 6 MHz crystals; and with a low limit of 3.8 MHz it will support 1.2 MHz of frequency shift on a 5MHz crystal. A frequency range of 5.1 to over 10 MHz is also available.

1.1.2   SUPPORT FOR VERY LOW Q, HIGHLY DAMPED, CRYSTALS

The RQCM will reliably lock to crystals with resistance of 5 KΩ or less. In most cases it will maintain lock up to a resistance of 10 KΩ or more. It will support crystal oscillation in highly viscous solutions of more than 88% glycol in water.

1.1.3 DIRECT REAL-TIME MEASUREMENTS OF CRYSTAL FREQUENCY, MASS, AND RESISTANCE

The RQCM accurately measures crystal frequency, mass, and resistance. The software uses this data to derive various physical parameters of the deposited film or media at the surface of the crystal.

1.1.4 MULTIPLE CRYSTAL MEASUREMENT CHANNELS

The RQCM can be configured for up to three crystal measurement channels. All channels are measured simultaneously.

1.1.5 ELECTRODE CAPACITANCE CANCELLATION

The total quartz crystal impedance includes a shunt capacitance (due to the capacitance of the crystal electrodes, cable and holder) in parallel with the series resonant arm. The total current through the crystal is the sum of the current through the shunt capacitance plus the current through the series resonant arm. The physical motion of the crystal is reflected in the values of the L, R and C in the series arm of the crystal only, and therefore we want to subtract out or otherwise cancel the current through the shunt electrode capacitance.   The Crystal Measurement Card includes a method of canceling the electrode capacitance insuring that the measured crystal current does not include the current through the electrode capacitance and therefore is essentially the current through the series resonant arm of the crystal only.

1.1.6 "AUTOLOCK"

When the PLO loses lock, the VCO (Voltage Controlled Oscillator) is ramped up to the maximum frequency at which time it is automatically reset to the minimum frequency and a new scan is initiated.

To insure that the VCO ramps up in frequency, a small amount of quadrature current is injected into the current to voltage buffer whenever the PLO is unlocked. This current is equivalent to a shunt capacitance of about 1.5 pfd. As soon as lock is detected, the quadrature current is turned off.

1.1.7 CRYSTAL FACE ISOLATION

The Crystal face is galvanically (transformer) isolated from earth ground. The Crystal Face connection allows the crystal face to be easily connected to an external voltage or current source such as a potentiostat.

1.1.8 FULLY INTERGATED COMPUTER SOFTWARE

Computer software is included with each RQCM, allowing the user to set up, graph and log frequency and resistance of the crystals from a computer. It also allows the setup, graphing and logging of temperature and analog data – if the hardware is installed.

1.1.9 INPUTS AND OUTPUTS CAPABILITY

As an option, the RQCM can be outfitted with an I/O Card. This card provides eight remote discrete inputs and eight relay outputs. These I/O's can be used to monitor or control external instruments and peripheral devices.

1.1.10 DATA ACQUISITION CAPABILITY

To support the simultaneous logging and display of additional analog information, such as voltage, current, or temperature, the RQCM can be outfitted with an optional Data Acquisition Card. This card supports three types of temperature sensors (RTD, Thermocouple and Thermistor) as well as five scalable analog inputs.

1.2 CHARACTERIZING THE CRYSTAL MEASUREMENT

1.2.1 FREQUENCY ERRORS

The first thing we want to know regarding the performance of the crystal measurement is "What is the magnitude of the frequency error we can expect from the crystal measurement portion of the RQCM?"

In any oscillator and sensing crystal system, the error in the frequency measurement, is a function of both the oscillator and the sensing crystal. The same is true for phase locked loops. Any phase error will introduce a frequency error and this frequency error will be inversely proportional to the sensing crystal's Q. These errors are over and above any change in crystal frequency due to stress or temperature changes.

There are four important parameters that determine the frequency error of the PLO and sensing crystal system or indeed, any oscillator and sensing crystal system. The first two, the zero phase error and the electrode capacitance cancellation errors, are characteristics of the PLO. The second two are characteristics of the crystal, the Q of the crystal and the conductance (1/resistance) of the crystal.

1.2.2 FREQUENCY ERROR DUE TO PHASE ERROR

Given some finite zero phase error, the resulting frequency error depends on the sensing crystal's Q, the higher the Q, the lower the error. For phase errors below 10 degrees the frequency error is 0.087 PPM per degree for crystals with a Q of 100,000. Thus a one degree phase error in the PLO results in a 0.44 Hz frequency error for a 5MHz crystal with a Q of 100,000. For a 5 MHz crystal with a Q of 10,000, the error is 10 time greater or 4.4 Hz per degree.

$$\text{Frequency Error/deg} = df/f = PI/(360*Q)$$

1.2.3 FREQUENCY ERROR DUE TO IMPERFECT CAPACITANCE CANCELLATION

The effect of imperfect electrode capacitance cancellation can also be viewed as an equivalent phase error. This error is directly proportional to crystal resistance.

The equivalent phase error due to a non-zero shunt capacitance equal to 1 pfd is one degree for a crystal with a series resistance of 556 Ω. Since the equivalent phase error is proportional to the crystal resistance, a 1-pfd residual capacitance error will result in a 10-degree equivalent error for a sensing crystal with a resistance of 5.56 KΩ.

Polar Plot of Crystal Conductance
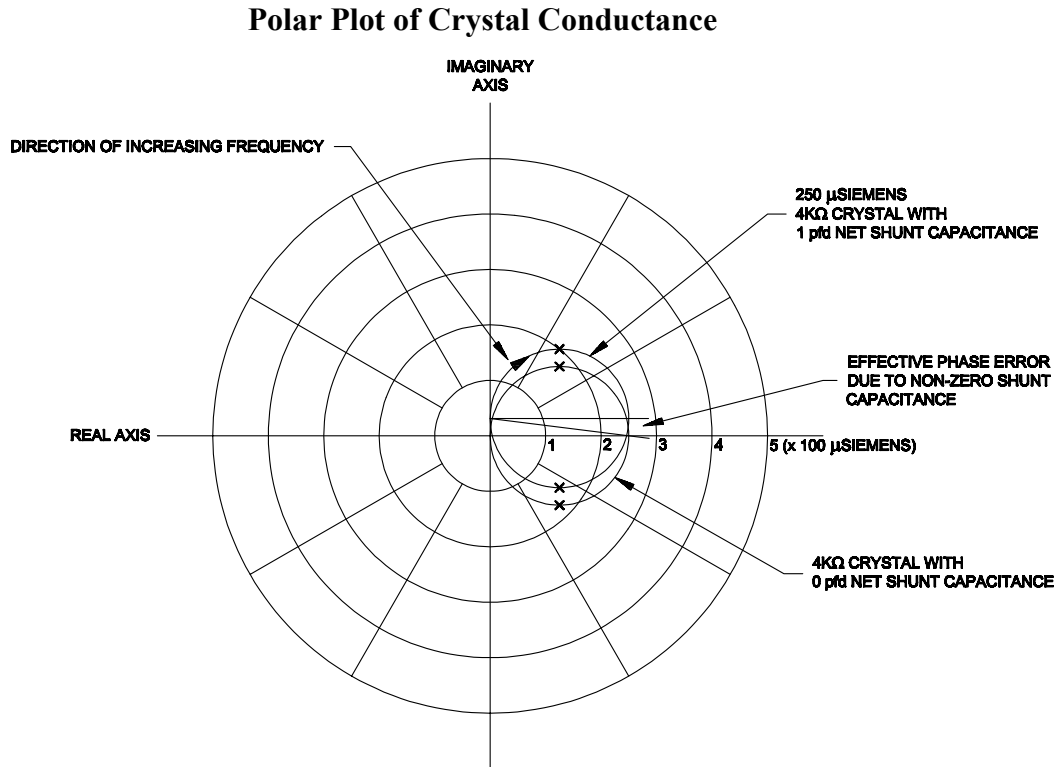
Figure 1 Equivalent Phase Error Due to Imperfect Capacitance Cancellation

1.3   SPECIFICATIONS

1.3.1   CRYSTAL MEASUREMENT

Crystal measurement channels:	One standard, three maximum.
Frequency range:	3.8 to 6.06 MHz, or 5.1 to 10 MHz
Frequency resolution:	0.03 Hz @ 6.0MHz
Mass resolution:	<0.4 ng/cm^2 (0.014 Å Aluminum)
Capacitance compensation range:	40 to 200 pfd
Achievable capacitance cancellation:	± 0.3 pfd
Crystal resistance range:	5 Ω to 5.0 KΩ
Phase angle accuracy:	± 2 degrees
Phase angle stability:	± 0.5 degrees
Frequency error vs. phase error and crystal Q:	Q= 100,000 0.087 ppm per degree Q=10,000 0.87 ppm per degree Q=1,000 8.7 ppm per degree
Measurement update rate:	From 0.5 to 20 updates/sec
Operating temperature range:	0 to 50°C
Operating temperature range for stated stability:	20 ± 10°C
Controls:	Reset Switch Capacitance Adjustment Trimmer, Course and Fine
Indicators:	Green "Lock" LED Red "Unlock" LED Yellow "Sweep Rate" LED
Crystal Drive Voltage, open circuit:	125 mV RMS
Crystal Drive Source Impedance:	20 Ω ± 1%
Crystal Power:	200 microwatt, maximum
Crystal Face Isolation:	Transformer, ± 200 VDC maximum

1.3.2   DATA ACQUISITION ANALOG CARD (OPTIONAL)

1.3.2.1   Analog Inputs

* Note: Except where noted. All specifications @ 25°C. All specifications are within 90 days of calibration.

Number of channels:	5
Resolution:	16 bits (see Section 10.1)
Selectable range:	0-5V, 0-10V, ± 5V, ± 10V
Zero offset:	± 2mV
Gain accuracy:	± 0.01% (± 0.02% for ±5V & ±10V)
Gain non-linearity:	< 2 LSB
Single ended input impedance:	1 MΩ
Differential input impedance:	2 MΩ
Input protection:	± 200V
Common mode range:	± 200V
Common mode rejection:	70 dB up to 200 Hz

1.3.2.2   Thermocouple Input

Type:	Type "T" thermocouple
Temperature range:	0 to 371°C
Accuracy:	± 2°C + sensor error

1.3.2.3   RTD Input

Type:	100 Ω Thin film platinum
Temperature range:	0 to 600°C
Accuracy:	± 4°C + sensor error

1.3.2.4   Thermistor Input

Type:	100 KΩ
Temperature range:	0 to 150°C
Accuracy:	± 0.5°C + sensor error

1.3.3   I/O CARD (OPTIONAL)

Number of Discrete Inputs:	8, ground true 4.7KΩ pulled up to 5V
Number of Discrete Outputs:	8, SPST relays, 120VA, 2 A max.

1.3.4   COMMUNICATIONS

RS-232 serial port standard.

RS-485 serial port optional.

IEEE-488 optional.

1.3.5   FRONT PANEL INDICATORS

Communication Status LED's

System Ready LED

1.3.6   POWER REQUIREMENTS

100, 200, 220, 240 VAC @ 50/60Hz, 25 W

1.3.7   PHYSICAL

Size: 4" H (including feet) x 13" W x 9 ¾" D
Weight: 7 lbs.
Shipping Weight: 10 lbs.

1.4   ACCESSORIES

Part Number	Description
172205	CHT-100 Crystal Holder, Teflon®, SMB Connector
173205	CHC-100 Crystal Holder, CPVC, BNC Connector
184204	CHK-100 Crystal Holder, Kynar®, SMB Connector
603211	DB25S to Terminal Strip for Passive I/O Card
603212	DB37S to Terminal Strip for Data Acquisition Card
828007	Cable, SMB Plug-SMB Plug,1' length, RG174A/U coax
888023	Adapter, BNC Male to SMB Jack
803081	Power Cord
803312	Capacitance Tuning Tool

Refer to Maxtek Price List for more accessories and other products.

1.5   OPTIONAL CARDS

Part Number	Description
603208	Crystal Measurement Card
603209	Data Acquisition Card
603210	Passive I/O Card

2 UNDERSTANDING AND SETTING UP A CRYSTAL MEASUREMENT CHANNEL

The RQCM can have up to three independent crystal measurement channels. Each channel has a crystal input, three status LED's, fine and course capacitance adjustments, a reset switch and a crystal face connection. Refer to Figure 2.

2.1 FRONT PANEL DESCRIPTION

2.1.1 LOCK INDICATOR

The green, Lock LED is **on** when the frequency is locked on a crystal's resonant frequency.

2.1.2 UNLOCK INDICATOR

The Red, Unlock LED will be **on** whenever the frequency is not locked on a crystal.

2.1.3 SWEEP RATE INDICATOR

The Yellow, Sweep Rate LED flashes each time the frequency ramp is reset to its low starting point. In normal operation, the sweep light will only flash while adjusting the capacitance compensation. The Sweep LED will not light when locked on a crystal.

2.1.4 RESET SWITCH

The Reset switch should be pressed while adjusting the capacitance compensation. This switch forces the VCO to its lowest frequency independently of the Integrator output. The Reset switch also forces the Lock LED on, thus turning off the quadrature current injection which is require for proper capacitance cancellation adjustment. The equivalent of about 1.5 pfd of capacitance is added as quadrature current to insure that the VCO ramps up in frequency when not locked onto a crystal. The quadrature current is turned off as soon as a lock is detected.

2.1.5 CRYSTAL CONNECTOR

The SMB connector labeled Crystal provides connections to the crystal. When used with a Maxtek crystal holder, the center pin connects to the crystal's rear electrode, and the connector housing connects to the crystal's front electrode.

2.1.6 CRYSTAL FACE CONNECTOR

The Crystal Face connector provides a connection to the crystal's front electrode when used with a Maxtek crystal holder. When this connection is not used, the crystal face electrode is grounded. When the mating connector is inserted, the crystal face electrode is disconnected from ground allowing a potential to be applied. For example, you can connect the crystal face electrode to the working electrode of a potentiostat for electrochemical experiments.

CHANNEL 1

RESET BUTTON
(WHEN PRESSED, BRINGS THE FREQUENCY TO ITS MINIMUM AND TURNS ON THE LOCK INDICATOR. THIS BUTTON MUST BE DEPRESSED WHILE ADJUSTING THE CAPACITANCE CANCELLATION.)

FINE CAPACITANCE
(USED TO TUNE OUT SMALL CAPACITANCE)

COURSE CAPACITANCE
(USED TO TUNE OUT LARGE CAPACITANCE)

CRYSTAL CONNECTOR
(PROVIDED FOR CONNECTIONS TO THE CRYSTAL. THE CENTER PIN CONNECTS TO THE REAR ELECTRODE AND THE CONNECTOR HOUSING CONNECTS TO THE FRONT ELECTRODE - CRYSTAL FACE)

FREQUENCY SWEEP RATE INDICATOR (YELLOW)
(WHEN FLASHING, INDICATES THE CRYSTAL CAPACITANCE IS UNDER COMPENSATED.)

UNLOCK INDICATOR (RED)

LOCK INDICATOR (GREEN)

CRYSTAL FACE CONNECTOR
(PROVIDED FOR CONNECTION TO AN ELECTROCHEMICAL INSTRUMENT TO MAKE THE CRYSTAL FACE THE WORKING ELECTRODE.)

RESET

FINE

CAPACITANCE

COARSE

CRYSTAL

SWEEP

UNLOCK

LOCK

CRYSTAL FACE
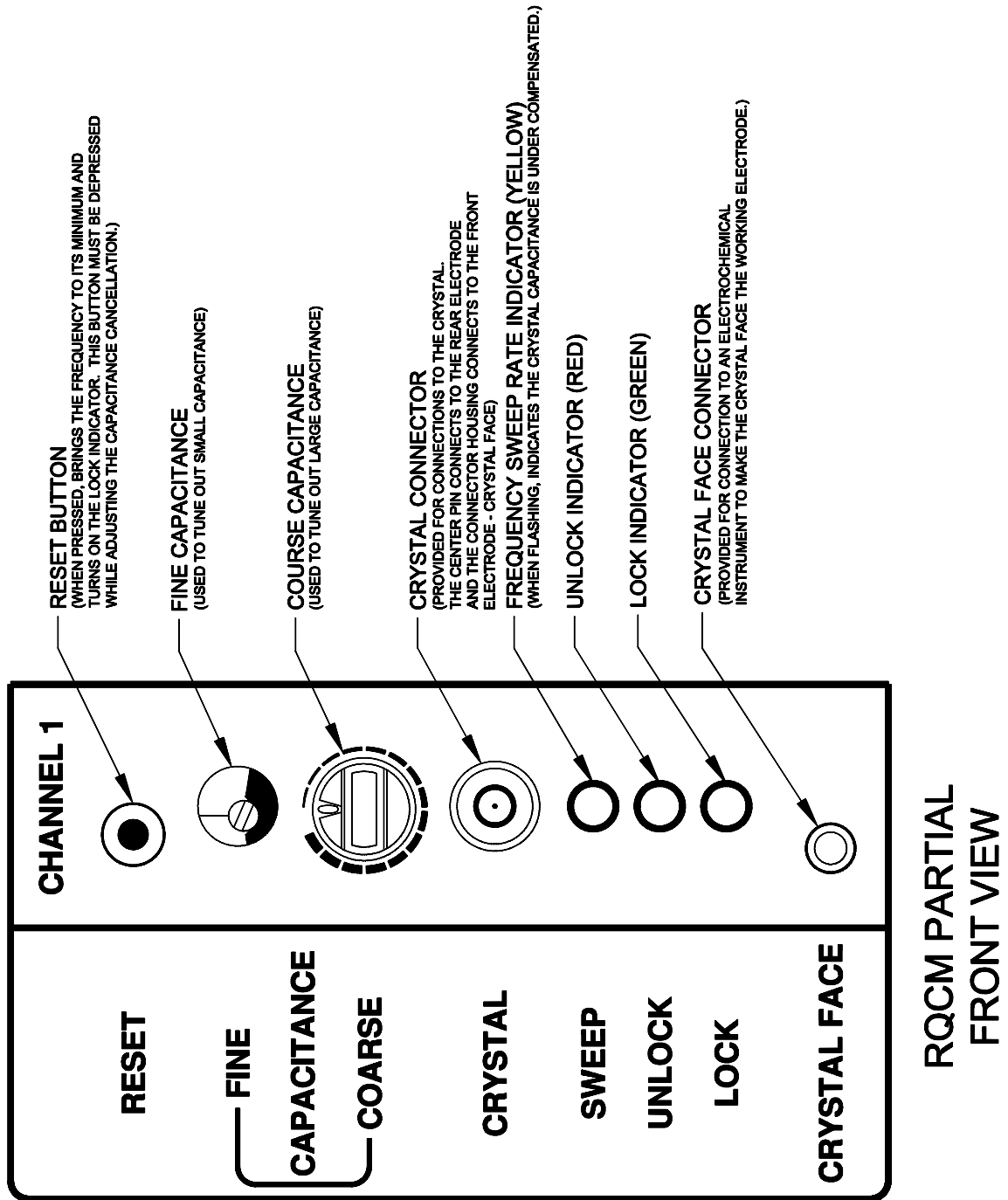
RQCM PARTIAL FRONT VIEW

Figure 2 Crystal Channel Description

2.2 GENERAL DESCRIPTION OF THE CRYSTAL MEASUREMENT

The Maxtek Phase Lock Oscillator (used on the Crystal Measurement Card) was developed specifically to support the use of the quartz crystal microbalance in the measurement of lossy films and in liquid applications. In addition to accurately tracking the frequency of heavily damped crystals, the RQCM also tracks the crystal's resistance. This provides additional information in the study of lossy films and/or viscous solutions.

The PLO utilizes an internal oscillator referred to as a Voltage Controlled Oscillator (VCO) to drive the crystal. The crystal current is monitored and the frequency of the oscillator is adjusted until there is zero phase between the crystal voltage and current. Assuming that the crystal's electrode capacitance has been effectively cancelled, this point of zero phase between the crystal current and voltage is the exact series resonant point of the crystal. The magnitude of the current at this point is directly proportional to the crystal's conductance. This current is monitored by the RQCM and displayed as crystal resistance. The PLO contains a phase detector that continuously monitors the phase difference between the crystal's current and voltage. At frequencies below the crystal's resonant frequency the current leads the voltage and the phase goes to 90 degrees as the frequency separation continues to increase, see Figure 12. Above the resonant point the current lags the voltage and the phase go to minus 90 degrees. As the frequency increases through the resonant frequency, the phase goes from plus 90 through 0 to minus 90. It is interesting to note that the phase angle is 45 degrees when the VCO frequency is one half of the crystal's bandwidth above or below the crystal's resonant frequency.

The output of the phase detector is fed into an integrator. The integrator accumulates the phase error such that any positive phase error causes the integrator output to climb; a negative phase causes the integrator output to fall. With zero phase error the Integrator output holds steady.

The integrator output is connected to the VCO. Thus, if the VCO frequency is initially below the crystal resonant frequency, the phase will be positive, producing a positive output at the phase detector. This causes the Integrator output to climb, which causes the VCO frequency to increase. When the VCO frequency matches the resonant frequency of the crystal the phase will decrease to zero, the phase detector output will go to zero, the Integrator output will hold steady and the VCO frequency will be "locked" to the crystal's resonant frequency.

If the crystal's resonant frequency moves up or down, a phase difference between the crystal voltage and current will develop, producing a phase detector output. The non-zero phase detector output will drive the Integrator output up or down until the phase is zero once again, thus keeping the VCO frequency locked to the crystal's resonant frequency.

Once the frequency of the VCO is locked to the series resonant frequency of the crystal, the in-phase component (at zero phase error, there is no out of phase component) of the crystal current is demodulated to a DC voltage. This voltage is amplified and converted into resistance value which the RQCM outputs to the computer.

2.3   NORMAL OPERATION

The RQCM comes set up for operation with a Maxtek cable and crystal holder. If a Maxtek cable and crystal holder is being used, then no initial adjustments should be needed.

During normal operation with a crystal installed and connected to the oscillator, the green Lock LED will be on and the frequency output will reflect the crystal resonance. The red Unlock LED will be off.

If the Unlock LED is on, the Sweep Rate LED should slowly flash. Continuous sweeping of the frequency range indicates that the crystal's resonant frequency is outside of the PLO's frequency range or the crystal's conductance is below the conductance threshold.

No flashing of the Sweep Rate LED when the Unlock LED is on can mean one of two things. First, if the VCO frequency is sitting at its low limit, it means the electrode capacitance is over compensated. Second, in some cases, even though the crystal conductance has fallen below the threshold necessary to indicate lock, the internal signals are still sufficient to keep the VCO locked to the crystal. In that case, the PLO really is locked and the VCO frequency will be sitting at the crystal frequency somewhere between its minimum and maximum frequencies.

If the VCO frequency is sitting at its low limit, press and hold the Reset switch and adjust the fine capacitance trimmer a few degrees clockwise (not more than ten) until the Sweep LED begins to flash.

2.4   CHECKOUT

Connect the DB9S computer cable to the RS-232/RS-485 port located on the rear of the RQCM. Connect the other end of the cable to the computer serial port. If you have the IEEE-488 communication option, install the proper cable.

Refer to Section 9.1 to install, setup and run the RQCM software.

Connect the crystal holder, with a crystal installed, to the SMB connector labeled Crystal by means of the 12-inch SMB coaxial cable.

Observe the AC voltage setting on the rear panel. Make sure it is set for your local line voltage. Plug one end of the power cord to a power outlet and plug the other end into the rear of the RQCM.

Refer to Figure 3, and Figure 5 for complete system connections.

Switch the front panel power switch to **on**.

Start the RQCM Application program. Note that you may have to set the RQCM address and select the correct COMM port in the Setup Menu in order for the RQCM to communicate with your PC. Click on the View Status button to bring up the Status Screen.

On the RQCM front panel, the green, Lock, LED should be on. On the computer Status Screen, the frequency should indicate the correct crystal frequency and the resistance should indicate something between 5 Ω and 15 Ω for an uncoated polished crystal in air.

Check the capacitance cancellation by pressing and holding the Reset switch. The green, Lock LED should light. Keeping the Reset switch pressed, adjust the fine capacitance trimmer clockwise by about 5 degrees.   The yellow, Sweep LED should flash. Back the trimmer counterclockwise to the point where the Sweep LED just stops flashing. The capacitance cancellation should be checked and readjusted every time the environment of the crystal and holder is changed. I.e. if the crystal and holder are moved from air to liquid or liquid to air, the capacitance cancellation should be checked and readjusted.

Remove the crystal. The red, Unlock, LED should light. The green, Lock, LED should go off. The Sweep Rate LED should not flash. If the Sweep Rate LED flashes the capacitance is under compensated. Reinstall the crystal in the holder and repeat the process until it is perfectly compensated (Sweep LED not flashing when the crystal is removed). Refer to Section 5 for more details on adjusting the capacitance cancellation.

Record the frequency and resistance using an uncoated 5 MHz polished crystal in air after adjusting for the capacitance. If you are using Maxtek 1" Polished, 5 MHz Gold Electrode Crystal, the frequency should be between 4.976 to 5.020 MHz, and the resistance should be between 5 to 15 ohms. Next, submerge the crystal holder into room temperature water and adjust for capacitance. The frequency change should be about -650 Hz and the resistance change should be about +364 ohms from the readings in air.
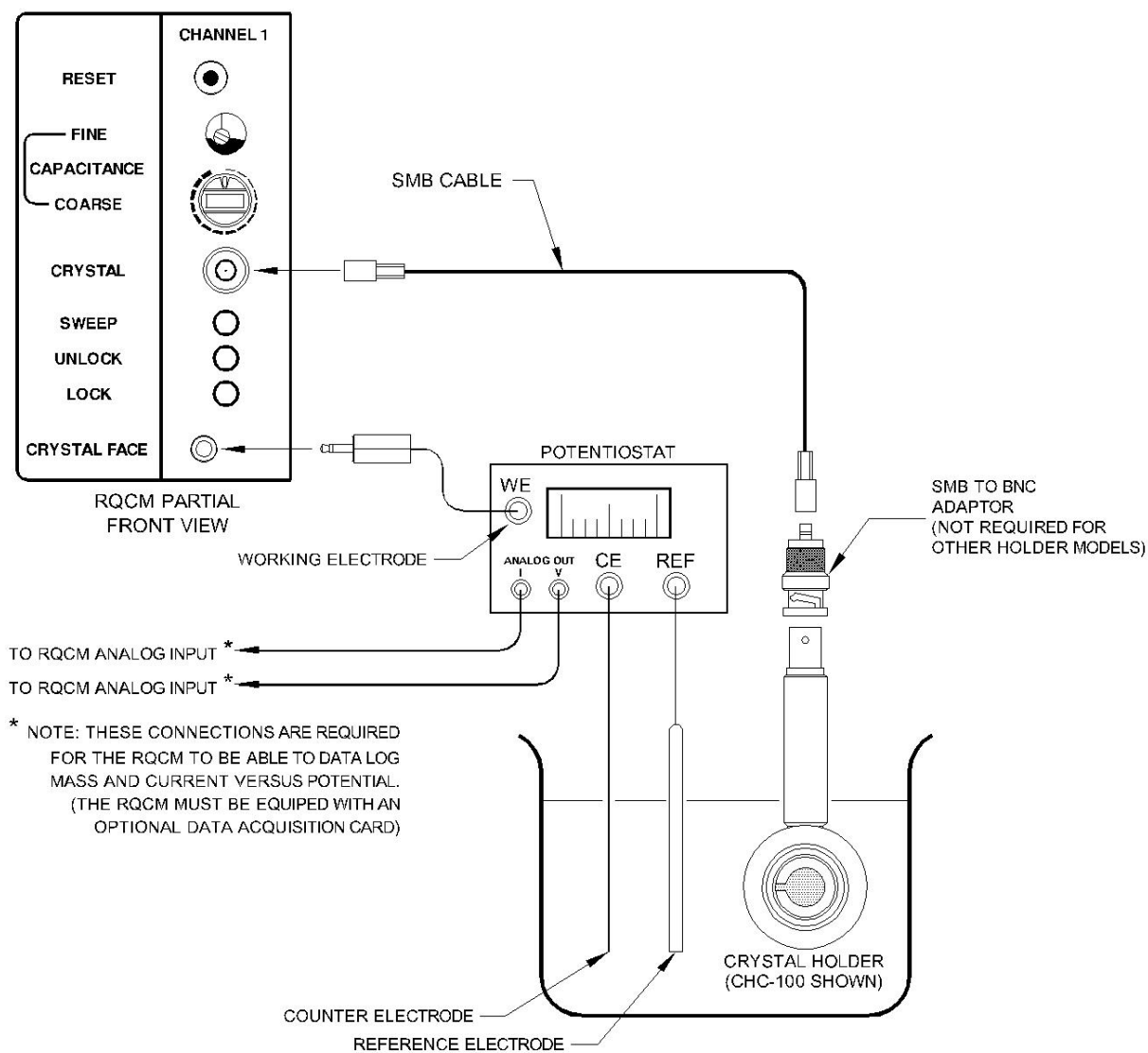
Figure 3 Typical System Connections
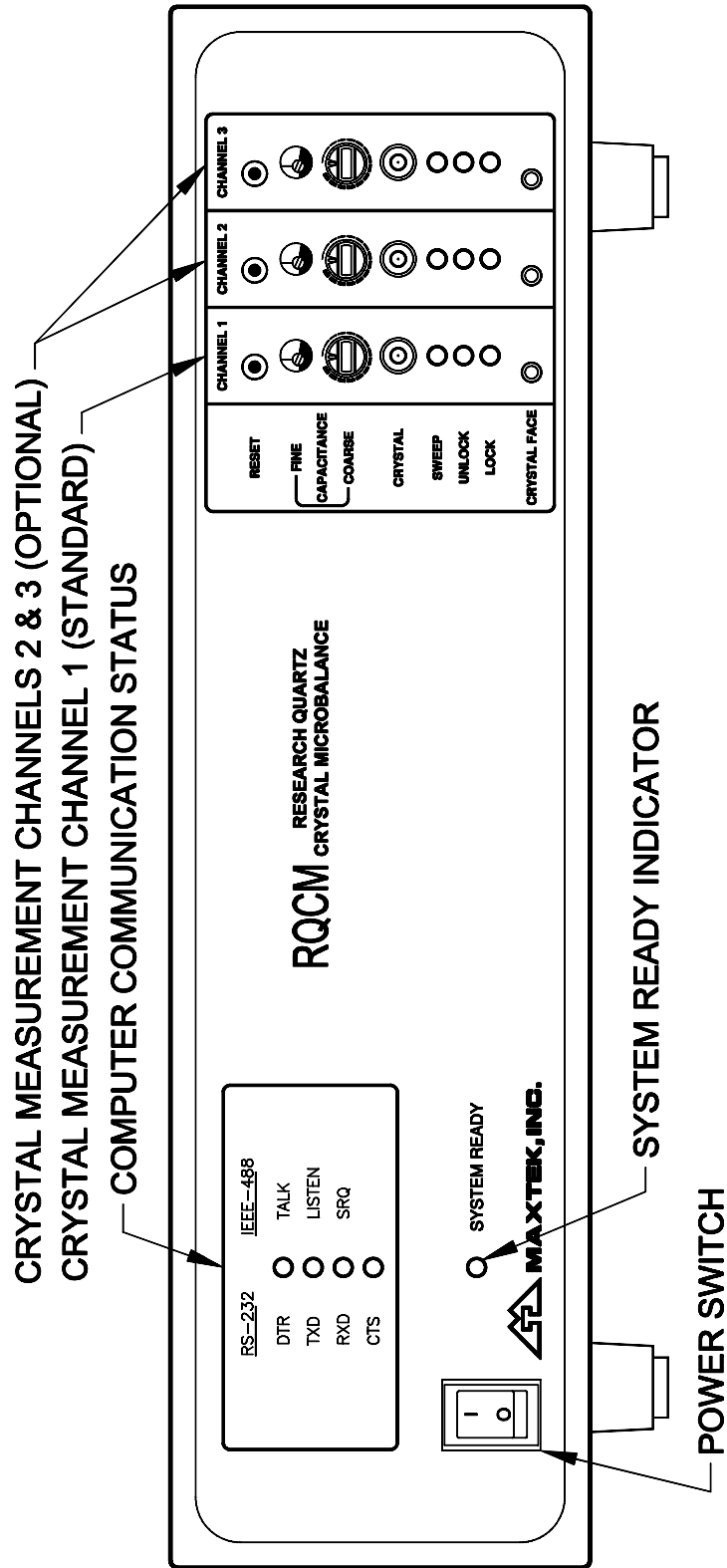
Figure 4 RQCM Front Panel
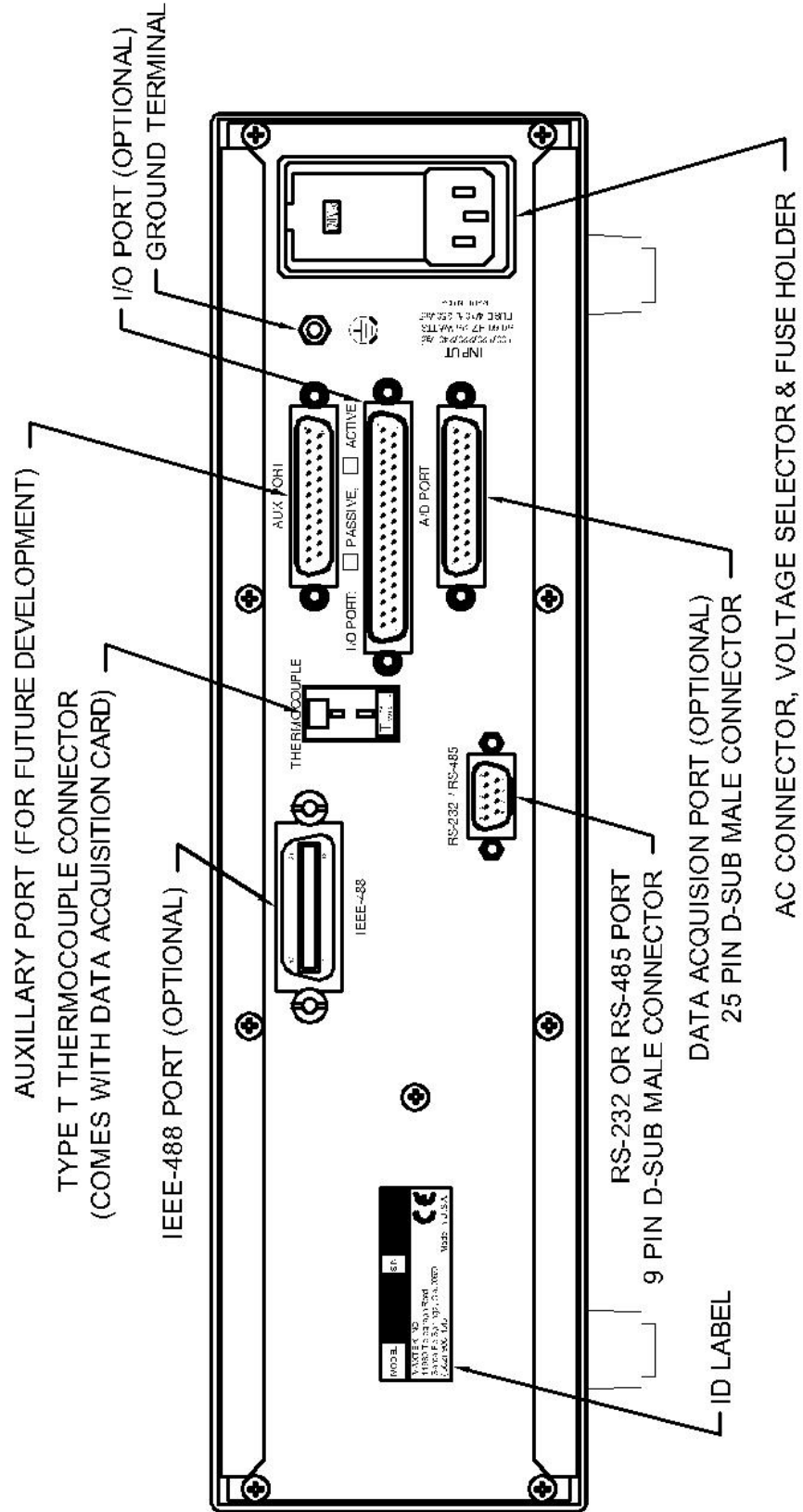
Figure 5 RQCM Rear Panel

3 CRYSTALS AND HOLDERS

An essential part of the RQCM system is the sensing crystal. The sensing crystal, the crystal holder and the connecting cable must be orientated and connected correctly in order for the RQCM to work properly. This is especially true if you design your own crystal or holder.

If you have purchased a Maxtek crystal, holder and cable, the installation is simple. Follow the instructions below.

If you plan to build your own crystal or holder or cable, see Section 3.4.

3.1 1 INCH DIAMETER CRYSTALS

Figure 6 below shows Maxtek 1" electrode patterns. The left figure shows the front electrode (also called sensing electrode) with an extended electrode that wraps around the edge of the crystal and extends into a semicircle shown in the top half of the right figure. The lower half of the right figure shows the rear electrode (also called contact electrode).

This configuration allows electrical contacts be made to both front and rear electrodes from the same side of the crystal.
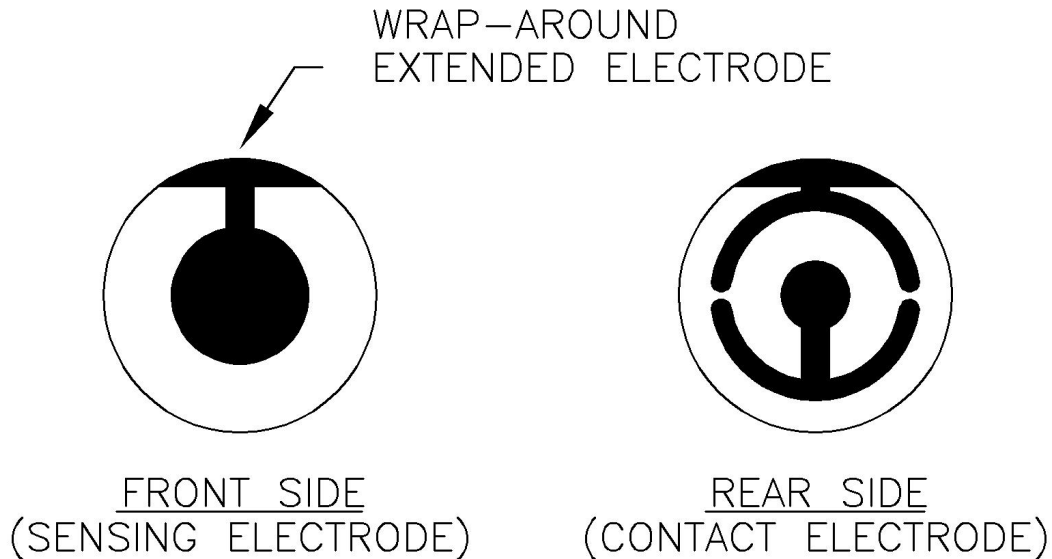
Figure 6 Maxtek 1-Inch Diameter Crystals

The figure below shows a Maxtek 1" diameter as seen from the front side.
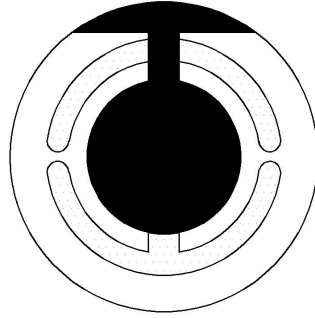
MAXTEK 1" CRYSTAL
AS SEEN FROM FRONT SIDE

3.2 CRYSTAL HOLDERS

Figure 7 shows a Maxtek CHC-100 Crystal Holder (without a crystal, the crystal retainer and the retainer cover. It has a cavity for 1-inch diameter crystal. Inside the cavity there are two pogo pins providing connections to the crystal's front and rear electrodes. Note the locations of the pogo pins. These pins are internally connected to the BNC connector (SMB Jack for CHT-100 and CHK-100 holders) via an internal coaxial cable.
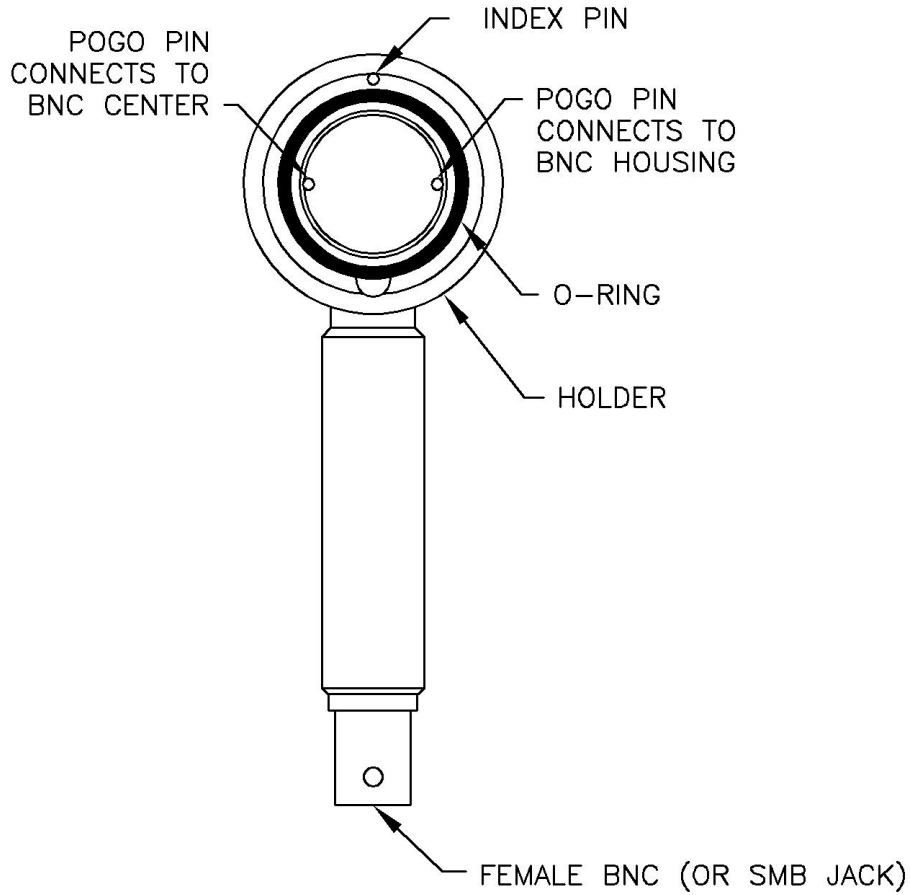
Figure 7 CHC-100 Crystal Holder

3.3 HOW TO INSTALL A CRYSTAL IN A CRYSTAL HOLDER

1. Identify the Front and Rear Sides of the crystal. See Section 3.1.

2. Clean & Dry the Probe / Holder cavity, then insert the Crystal with the Front Side (Sensing Electrode) exposed. The "Wrap-Around Extended Electrode" MUST be in the 60º region as in Figure 8 below.
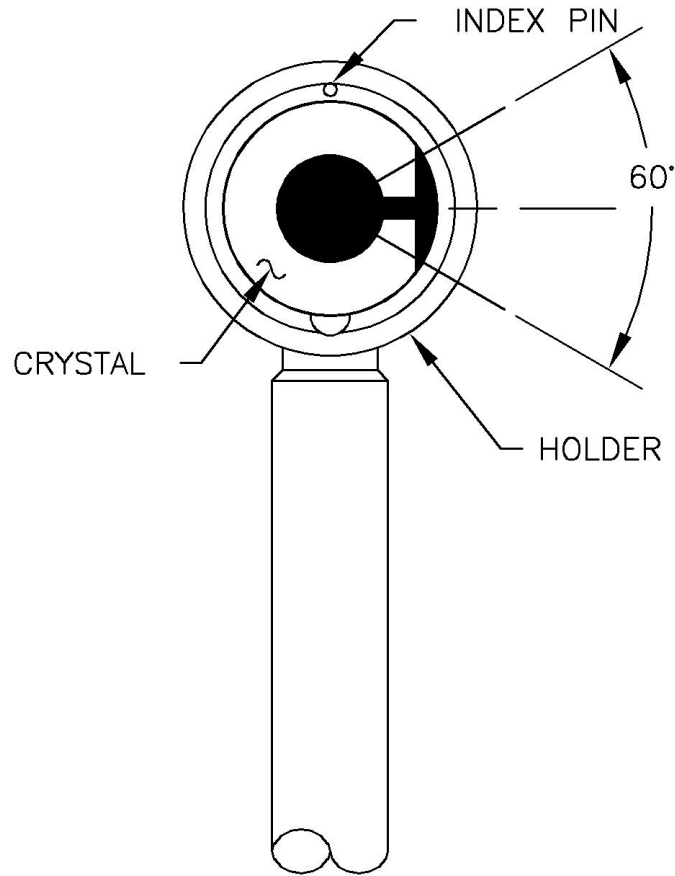
Figure 8 Crystal Installation

3. Place the Retainer Ring over the Crystal, with the Notch mating to the Index Pin.

4. Mount and turn the Retainer Cover approximately ¼ turn. Then with a gloved-finger or cotton swab *gently* press the Retainer Ring down at the Notch to make sure that it stays mated to the Index Pin. Finish tightening the Cover until it's snug.

3.4   CONSIDERATIONS FOR BUILDING YOUR OWN HOLDER

You MUST consider the following aspects when you build your own crystal or holder.

The holder must be designed as such when a crystal is installed in it, the crystal's front electrode (sensing electrode) is connected to the housing (shell) of the SMB Crystal Connector on the RQCM (see Section 2.1.5); and the rear electrode is connected to the center pin of the SMB Crystal Connector.

The crystal should only be clamped, as close as possible, near the edge of the crystal to avoid damping of the crystal oscillation.

The holder clamping mechanism should have a positive stop to avoid stress of over clamping of the crystal.

If the crystal is to be used in conductive fluid or conductive gas, the rear electrode must be sealed from the conductive environment to avoid electrical short between the electrodes. The electrodes should be designed so the rear electrode and the electrodes contacts can be sealed. Only the front electrode should be exposed.

The connecting cable must be coaxial all the way, from SMB on the RQCM, on up to the crystal. The shield of the coaxial must connect to the front electrode and the center conductor must connect to the rear electrode of the crystal. In addition, the coaxial cable must be free of kinks, knots, etc. to avoid unbalanced capacitance in the cable. Note that a one-foot of well balance RG174A/U coaxial cable has approximately 29 picofarads.

The total capacitance of the crystal, the crystal holder and the cable must be within the RQCM's capacitance compensation limits (between 40 and 200 pfd).

4 ELECTRICAL DESCRIPTION OF THE QUARTZ CRYSTAL

Figure 9 shows the equivalent circuit of a quartz crystal. The circuit has two branches. The motional branch, which contains the L, R & C, is the branch that is modified by mass and viscous loading of the crystal. The shunt branch, which contains the lone Cs element, represents the shunt capacitance of the crystal electrodes and any cable and fixture capacitance.
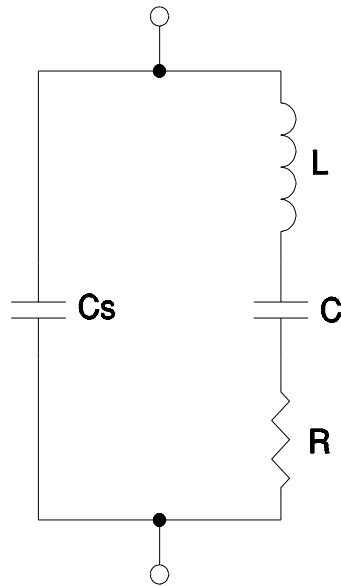
Figure 9 Crystal Equivalent Circuit

Because a crystal's impedance is minimum at resonance it is convenient to characterize a crystal in terms of admittance. Admittance is the inverse of impedance, $(Y = 1/Z)$, thus the admittance reaches a maximum at resonance. While impedance is proportional to the voltage developed across a device when it is subjected to a current, the admittance is proportional to the current through the device when it is subjected to a voltage.

 At any frequency the admittance of a quartz crystal is a complex value that can be expressed in terms of magnitude and phase or in terms of a real and imaginary value. The relationship of these two representations is shown in Figure 10.
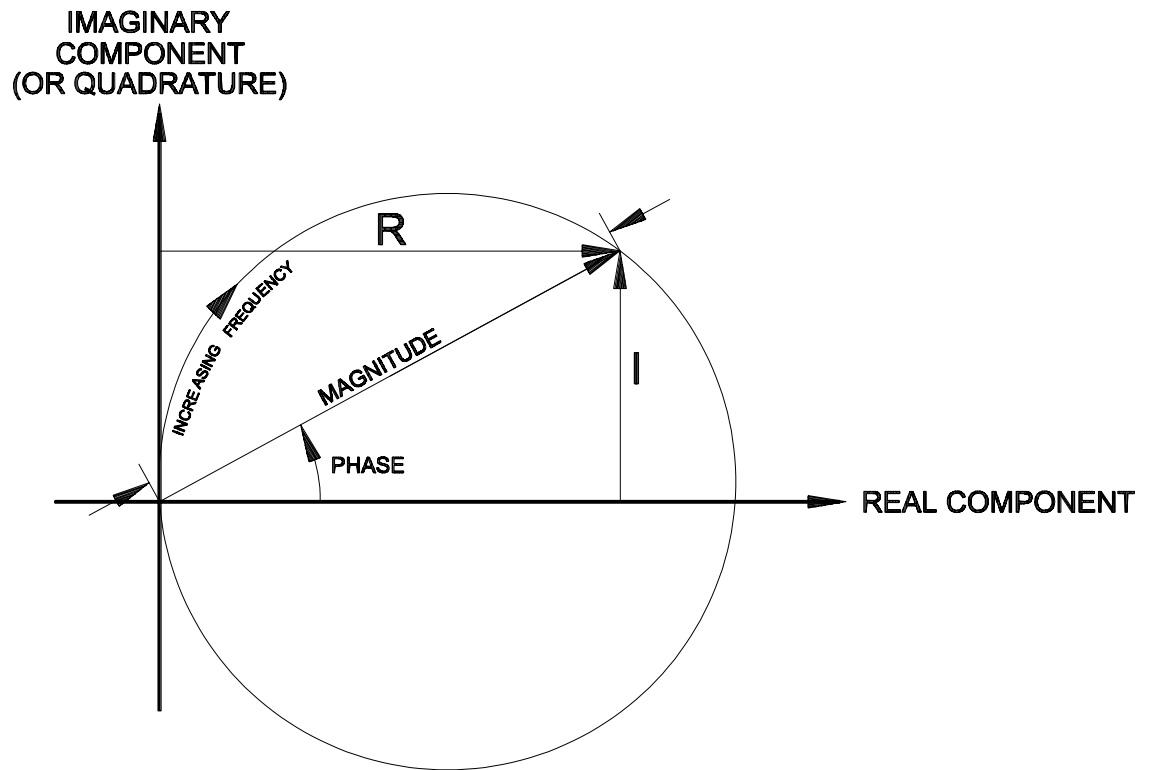
Figure 10 Polar Plot of Crystal Admittance

Figure 11 shows the conductance in terms of magnitude and phase, while Figure 12 shows the same information in terms of the imaginary and real part of the conductance.

```
REF LEVEL    /DIV      MARKER 4 987 964.000Hz
0.0          20.000E-3 MAG(UDF)      115.64E-3
0.0deg       30.000deg MARKER 4 987 964.000Hz
                       PHASE(UDF)    3.877deg
```
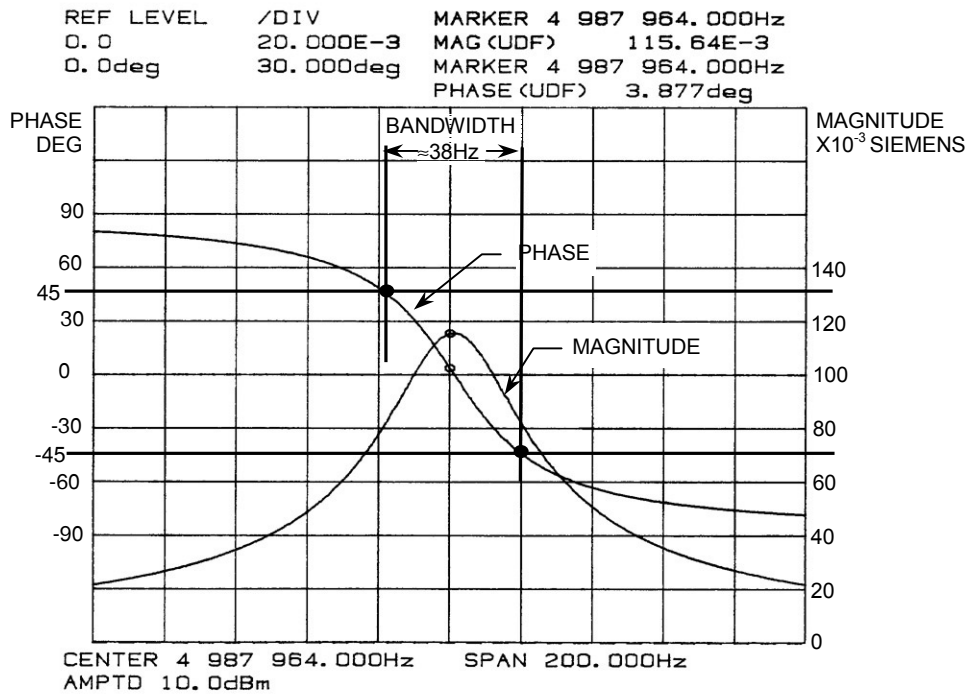
Figure 11 Admittance vs. Frequency, Magnitude and Phase of High Q Crystal


```
REF LEVEL    /DIV      MARKER 4 987 964.000Hz
0.0          20.000E-3 REAL(UDF)     114.94E-3
0.0          20.000E-3 MARKER 4 987 964.000Hz
                       IMAG(UDF)     -5.8860E-3
```
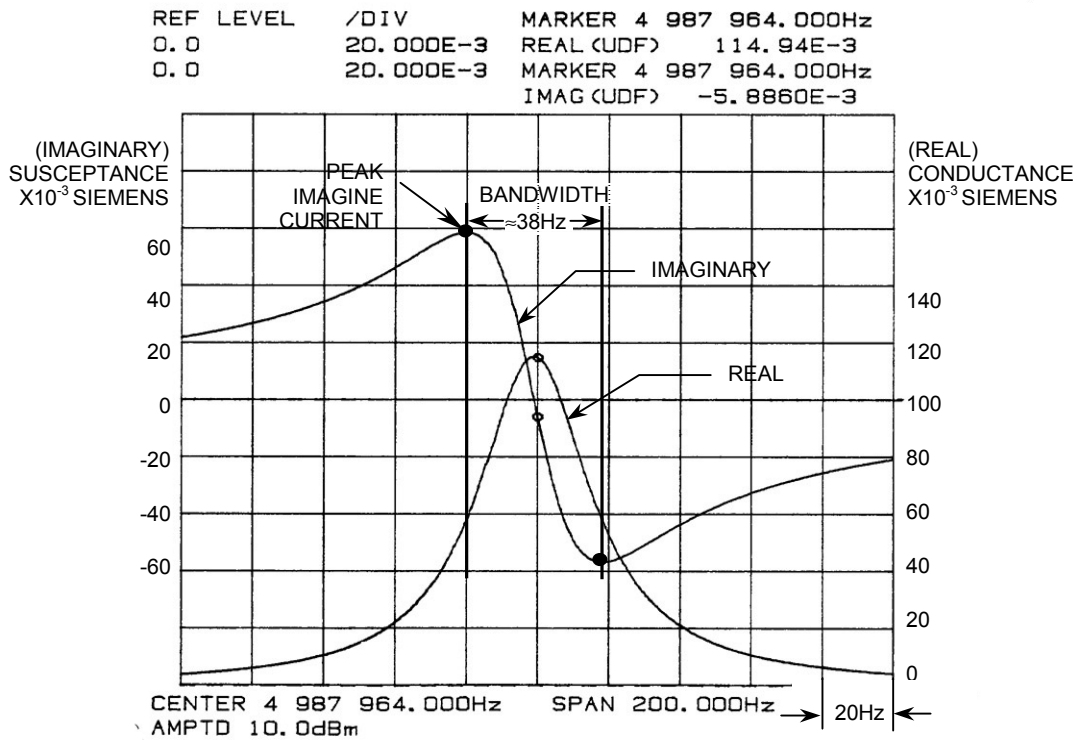
Figure 12 Admittance vs. Frequency, Real and Imaginary Components of High Q Crystal

RQCM – RESEARCH QUARTZ CRYSTAL MICROBALANCE

When the above complex conductance is plotted in polar coordinates, one obtains a circle as shown in Figure 13. The vector V indicates the magnitude and phase of the crystal current divided by the applied voltage. The real part of the conductance is indicated by the vector R and the imaginary part is indicated by the vector I.

```
FULL SCALE 200.00E-3      MARKER 4 987 966.500Hz
PHASE REF 0.0deg          MAG(UDF)      115.66E-3
REF POSN 0.0deg           PHASE(UDF)  -0.092deg
```

OSCILLATOR
LOCK POINT

OSCILLATOR
PHASE ERROR
OF 15 DEGREES

FREQUENCY = 4.987966 MHz
RESISTANCE = 8.6Ω
BANDWIDTH $\approx$ 38Hz
Q $\approx$130,000

ZERO PHASE
ERROR LOCK POINT
TRUE SERIES RESONANCE

```
CENTER 4 987 964.000Hz     SPAN 200.000Hz
AMPTD 10.0dBm
```
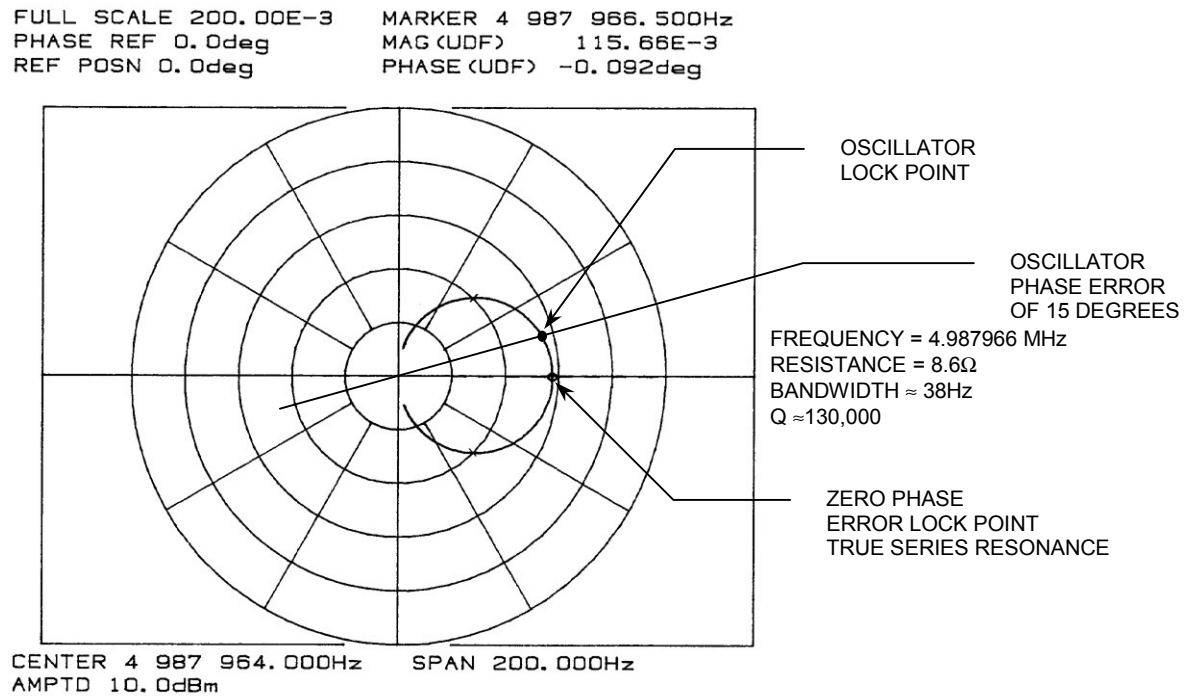
Figure 13 Polar Admittance Plot of High Q Crystal

```
FULL SCALE 2.5000E-3      MARKER 4 986 414.000Hz
PHASE REF 0.0deg          MAG(UDF)     1.5215E-3
REF POSN 0.0deg           PHASE(UDF)   13.518deg
```

FREQUENCY = 4.986414 MHz
RESISTANCE = 657Ω
Q = 1,700

CRYSTAL MEASURED IN GLYCEROL AND WATER SOLUTION.
FROM AIR TO SOLUTION:
RESISTANCE CHANGED FROM 8.6Ω TO 657Ω
FREQ. CHANGED FROM 4.987966 TO 4.987414 MHz
Δf = -526 Hz

CIRCLE TOP
4.984964 MHz

TRUE SERIES RESONANCE
4.986414 MHz

EFFECTIVE PHASE ERROR

CIRCLE BOTTOM
4.987914 MHz

BANDWIDTH = BOTTOM – TOP (CIRCLE)
= 4.987914 – 4.984964 MHz
= 2,950 Hz

```
CENTER 4 986 314.000Hz    SPAN 20 000.000Hz
AMPTD 10.0dBm
```

Figure 14 Polar Admittance Plot of Low Q Crystal

```
REF LEVEL    /DIV         MARKER 4 986 314.000Hz
0.0          200.00E-6    REAL(UDF)    1.3851E-3
0.0          200.00E-6    MARKER 4 986 314.000Hz
                          IMAG(UDF)    363.72E-6
```

(IMAGINARY)
SUSCEPTANCE
X10^{-3} SIEMENS

IMAGINARY

(REAL)
CONDUCTANCE
X10^{-3} SIEMENS

REAL

```
0.8                                              140
0.6
0.4                                              140
0.2                                              120
0                                                100
-0.2                                             80
-0.4                                             60
-0.6                                             40
-0.8                                             20
                                                 0
CENTER 4 986 314.000Hz    SPAN 20 000.000Hz
AMPTD 10.0dBm                          2 KHz
```
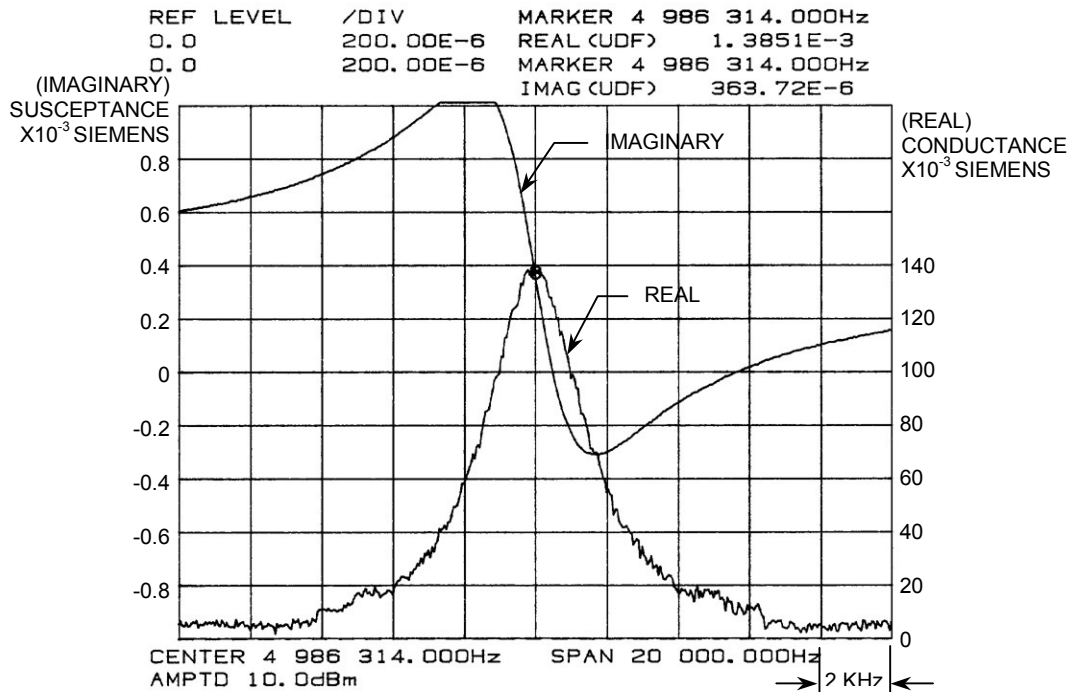
Figure 15 Admittance vs. Frequency, Real and Imaginary Components of Low Q Crystal

The conductance of the L, R & C series arm creates the circle in the polar plot with its center on the real axis. The effect of the shunt capacitance conductance is to offset the circle vertically. Figure 14 shows a heavily loaded crystal in which the offset is obvious. It is the imaginary (quadrature) current through the shunt capacitance that creates the

offset. The RQCM provides a mechanism for canceling out the imaginary current effectively putting the center of the crystal back on the real axis. The true series resonant frequency of the crystal is then the point where the conductance circle crosses the real axis. This is the frequency at which the inductive and capacitive impedance's in the L, R & C branch cancel out and the crystal looks like a pure resistance of value R.
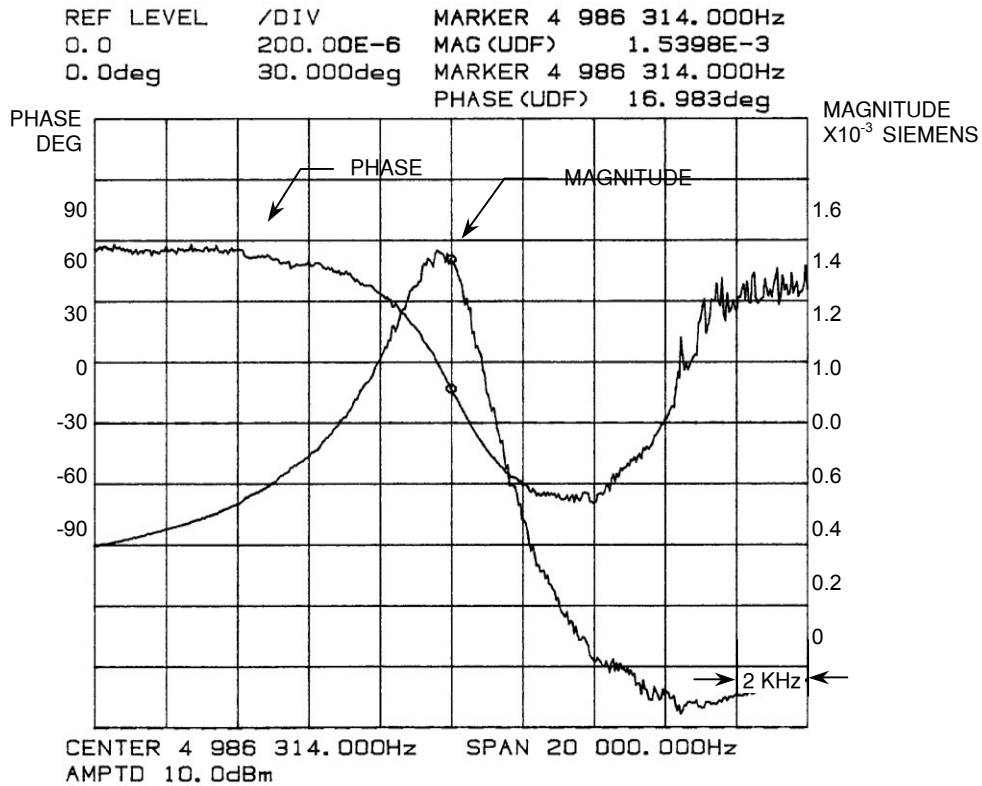
Figure 16 Admittance vs. Frequency, Magnitude and Phase of Low Q Crystal

FULL SCALE 200.00E-3   MARKER 4 987 966.500Hz
PHASE REF 0.0deg   MAG(UDF)   115.66E-3
REF POSN 0.0deg   PHASE(UDF) -0.092deg

CRYSTAL BANDWIDTH

CENTER 4 987 964.000Hz   SPAN 200.000Hz
AMPTD 10.0dBm
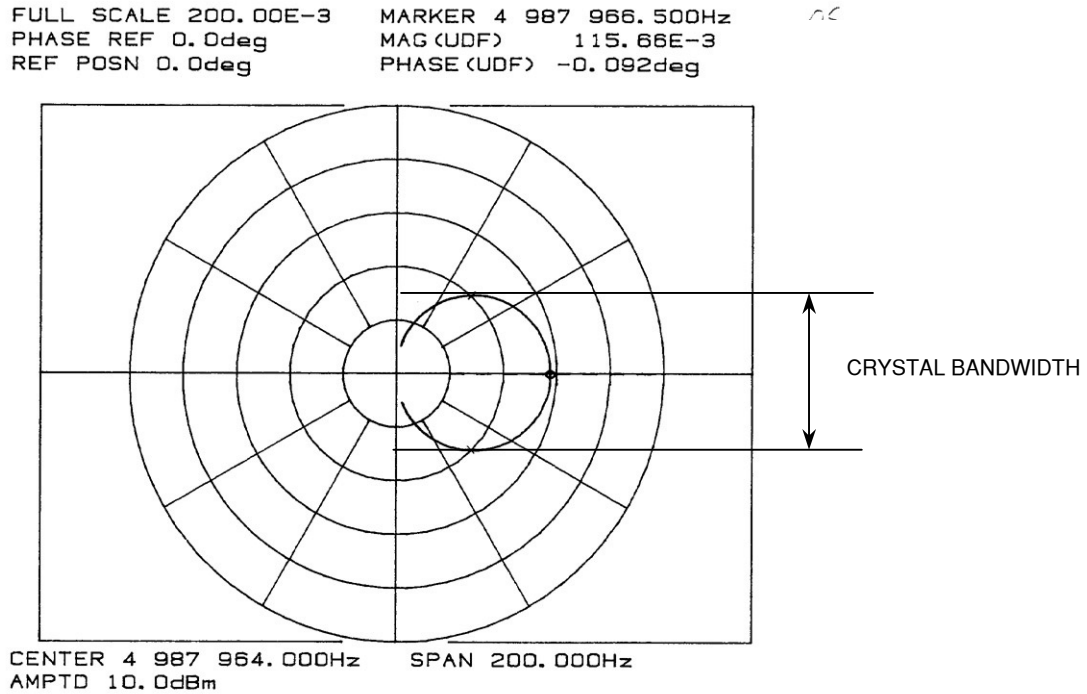
Figure 17 Non-zero Phase Lock

Figure 17 shows the result of a non-zero phase lock. Note that the frequency difference between the top of the conductance circle and the bottom is equal to the bandwidth of the crystal. For a high Q, (high conductance, low resistance) crystal, the bandwidth is very narrow and small errors in phase lock angle are insignificant. For a low Q crystal the bandwidth can be quite large and small phase errors can result in significant frequency errors. See the equations in the error discussion section.

5   ADJUSTING THE CAPACITANCE CANCELLATION

Proper adjustment of the Capacitance Cancellation is critical in obtaining accurate results with high resistance crystals. See Section 6. The cancellation adjustment should be performed with the crystal holder and crystal in the measurement environment. For instance, if liquid measurements are to be made, insert the crystal and its holder into the liquid where the measurement will be made.

With the crystal and holder in the measurement environment, press and hold the Reset switch. Pressing and holding the Reset switch forces the VCO to its minimum frequency, turns on the Lock LED, and turns off the quadrature current injector. Forcing the VCO to its minimum frequency insures that the crystal is being driven at a frequency far from its resonant frequency where its impedance is essentially due only to the shunt electrode capacitance. With the quadrature current injector turned off, the measured current is due only to the net shunt capacitance. The measured net shunt capacitance is the capacitance of the cable, holder and crystal electrodes minus the compensation capacitance. If the capacitance is under compensated, the phase of the measured current leads the voltage, (a phase angle of plus 90 degrees). If the capacitance is over compensated, it lags the voltage, (a phase angle of minus 90 degrees).

The Yellow Sweep LED is used to determine whether the crystal capacitance is over compensated or under compensated. The Sweep LED flashes whenever the crystal capacitance in under compensated.

If the Sweep LED is not flashing, turn the fine compensation clockwise until it begins to flash then back up until it just stops. If it is flashing, turn the fine adjustment counter clockwise until it just stops flashing. This is a very fine adjustment. Go back and forth until you are sure you are right on the edge. The sensitivity of the fine adjustment is approximately 0.05 pfd per degree. In situations where the crystal resistance is very high (over 1 KΩ) a net capacitance of over 0.5 pfd can result in a significant frequency error so try to get this adjustment to within a couple of degrees. Remember to keep the Reset switch depressed while making this adjustment.

5.1   ADJUSTING CAPACITANCE CANCELLATION TRIMMER & SWITCH

Setting up the capacitance cancellation is fairly straightforward. The thing to remember is that there are two adjustments, a course (rotary switch) and a fine (capacitor trimmer) with the total compensation capacitance being the sum of the two. The trim capacitor has no stops so it's not obvious when it is at its minimum or its maximum.

The fine adjustment capacitor has circular, rotor plates that mesh into fixed stator plates. The capacitance is at a maximum when the plates are fully meshed and a minimum when rotor plates are above the stator plates and not meshed. As the capacitor is rotated clockwise it goes through a full cycle from maximum to minimum and back to maximum. Or, depending on where you start it may go first toward a minimum, then to a maximum and then back toward a minimum. To avoid confusion, we always want to be turning clockwise as we approach the desired capacitance and we want the capacitance to be decreasing.

The coarse adjustment is a rotary switch. Like the fine adjustment, it goes from its minimum to its maximum, then back to its minimum capacitance value in a full rotation. The difference is that it has 16 positive stops. Observe the "V" notch on the switch (Figure 18). The coarse adjustment is at its minimum capacitance when the "V" notch is pointing straight upward (zero position). The capacitance is increased with each stop as the switch is rotated clockwise. It reaches maximum capacitance at the 15th stop – one stop before returning to the zero position.

If you bought a Maxtek crystal holder and cable with your RQCM then you should not have to change the course adjustment. Connect the cable and crystal holder to the SMB connector labeled Crystal but don't install a crystal.

If the Sweep LED is flashing, press and hold the Reset button and then turn the fine trimmer counter clockwise until it just stops flashing. Go back and forth a few times to get a feel for the point where the Sweep LED just stops flashing. Release the Reset button and the Sweep LED should begin to flash again.

Install a crystal. The PLO should lock. Even so, press and hold the Reset button and again adjust the fine trimmer to the point where the flashing just stops. The capacitance cancellation adjustment is now perfect. Remember to check this adjustment whenever the crystal holder is moved or changed to a new environment.

If you could not find the proper zero capacitance point using the fine trimmer alone, then we have found the following approach which is best for adjusting the coarse rotary switch.

First adjust the fine trimmer so that it is 50% meshed and the rotor plates are below the shaft. You can see these plates through the oversize adjustment hole. See Figure 18. Next connect a cable and crystal holder, if you haven't already done so. Don't install the crystal at this point.
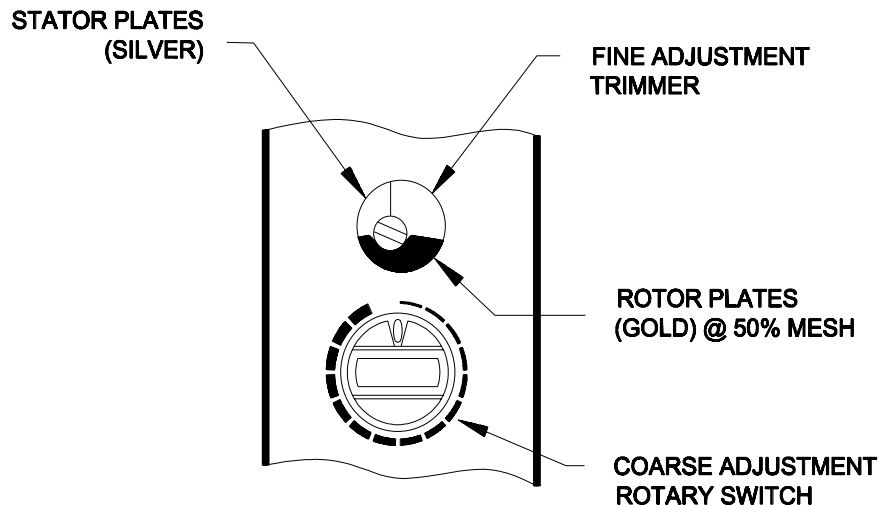

Figure 18 Capacitance Adjustments

Set the course rotary switch to its minimum. Do not press the Reset button, now rotate the course switch clockwise while watching the Lock and Unlock LED's. The green, Lock, LED will come on when the capacitance is grossly out of adjustment. Continue turning the course switch clockwise until the Unlock LED comes on. The adjustment is getting close.   Press and hold the Reset button, continue to turn the course switch clockwise. At each stop observe the yellow, Sweep, LED, at some point it will begin to flash. If you continue to turn clockwise the Sweep LED will cease flashing, but this is not the point you want. Back off one stop so the flashing begins again. The course adjustment is now complete.

Install a crystal into the holder. Now depress and hold the Reset button. Slowly adjust the fine trimmer clockwise until the flashing of the Sweep LED just stops. The capacitance compensation adjustment is now complete. Release the Reset button and assuming the crystal is not dead or out of range, the RQCM will lock on it.

5.2   WORKING WITH VERY LOW Q CRYSTALS

Very low Q crystals require very close adjustment of the compensating capacitance to insure a successful lock. To adjust the compensation capacitance one pushes the Reset button and adjusts the capacitance to the point where the Sweep LED just ceases to flash. With very low Q crystals, the PLO may not lock upon release of the Reset button. The Unlock LED will be on and the Sweep LED will be flashing. This is normal. Even so it may be possible to lock on the crystal by slowly adjusting the fine capacitance counterclockwise until the Sweep LED again ceases to flash. Lock is evidenced by the Lock LED turning on or by a crystal resistance of less than 10 KΩ.

Once lock is achieved the true series resonant point can be found by adjusting the capacitance for minimum resistance. The limits of the crystal bandwidth can be determined by adjusting the capacitance and reading the maximum frequency and the minimum frequency just before the PLO loses lock.

6 FREQUENCY ERRORS DUE TO IMPERFECT CAPACITANCE CANCELLATION

There are two reasons that proper capacitance cancellation is so important with high resistance crystals.

The first is that to a first approximation, the frequency error resulting from a given phase error is proportional to the bandwidth of the crystal. The bandwidth of the crystal is proportional to the crystal's resistance. A ten-ohm crystal might typically have a bandwidth of 42 Hz, while a one thousand-ohm crystal will have a bandwidth of 4,200 Hz. A five thousand-ohm crystal will have a bandwidth of 21,000 Hz. Since the frequency error for a given phase error is proportional to the bandwidth, a phase error that would result in a 0.5 Hz frequency error in a ten ohm crystal will cause a 50 Hz error in a one thousand ohm crystal and 250 Hz error in a five thousand ohm crystal.

The second reason is that the effective phase error caused by a non-zero net quadrature current is inversely proportional to the real current, which is inversely proportional to the crystal resistance. In other words, the effective phase error is proportional to the crystal resistance. For instance, a net unbalance of 1 pfd leads to an effective phase error of 0.02 degrees for a ten ohm crystal, but it leads to a 2 degree error for a one thousand ohm crystal and a 10 degree error for a five thousand ohm crystal.

Examples:

A ten-ohm, 5 MHz crystal will have a Q (Quality Factor) of about 120,000. The bandwidth is equal to the crystal frequency divided by Q. Thus, the bandwidth of this crystal would be about 42 Hz. To a first approximation, near zero phase, the frequency error per degree of phase error is given by the following formula,

$$\text{Frequency Error} = -\tfrac{1}{2}(\text{Phase Error, in radians})(\text{Bandwidth})$$

Or,

$$\text{Frequency Error} = -(1/(2*57.3))(\text{Phase Error, in degrees})(\text{Bandwidth})$$

For the above ten-ohm crystal, the frequency error caused by a one-degree phase error is 42/114.6 or approximately 0.37 Hz. For a one thousand-ohm crystal, one degree of phase error results in a 37 Hz error and for a ten thousand-ohm crystal the frequency error is 370 Hz per degree of phase error.

Now, the effective phase error caused by a non-zero quadrature (imaginary) current is given by the following formula,

$$\text{Effective Phase error} = \arctan(\text{imaginary current/real current})$$

And since current is proportional to conductance,

$$\text{Effective Phase error} = \arctan(\text{imaginary conductance/real conductance})$$

The conductance of a one picofarad capacitor at 5 MHz is 31.4 microsiemens. The conductance of a ten-ohm crystal at resonance is 100 millisiemens.

Effective Phase error = arctangent ((31.4e-6)/(100e-3)) = 0.018 degrees

In other words a one picofarad capacitance unbalance will result in an effective phase error of only 0.018 degrees when measuring a ten-ohm crystal. However, when measuring a one thousand-ohm crystal the effective phase error will increase to 1.8 degrees and it will increase to 9 degrees when measuring a five thousand-ohm crystal.

Combining these two errors we can get an idea of the magnitude of the frequency error caused by imperfect capacitance cancellation.

For a 10 Ω crystal a one picofarad capacitance imbalance results in a 0.018 degree phase error and a 0.0067 Hz frequency error.

For a 100 Ω crystal, the phase error is 0.18 degrees and the frequency error is 0.67 Hz. For a 1000 Ω crystal, the phase error is 1.8 degrees and the frequency error is 67 Hz. For a 5000 Ω crystal, the phase error is 9 degrees and the frequency error is 1,635 Hz.

A two picofarad capacitance imbalance will result in approximately twice the above error.

Frequency Error vs. Crystal Resistance
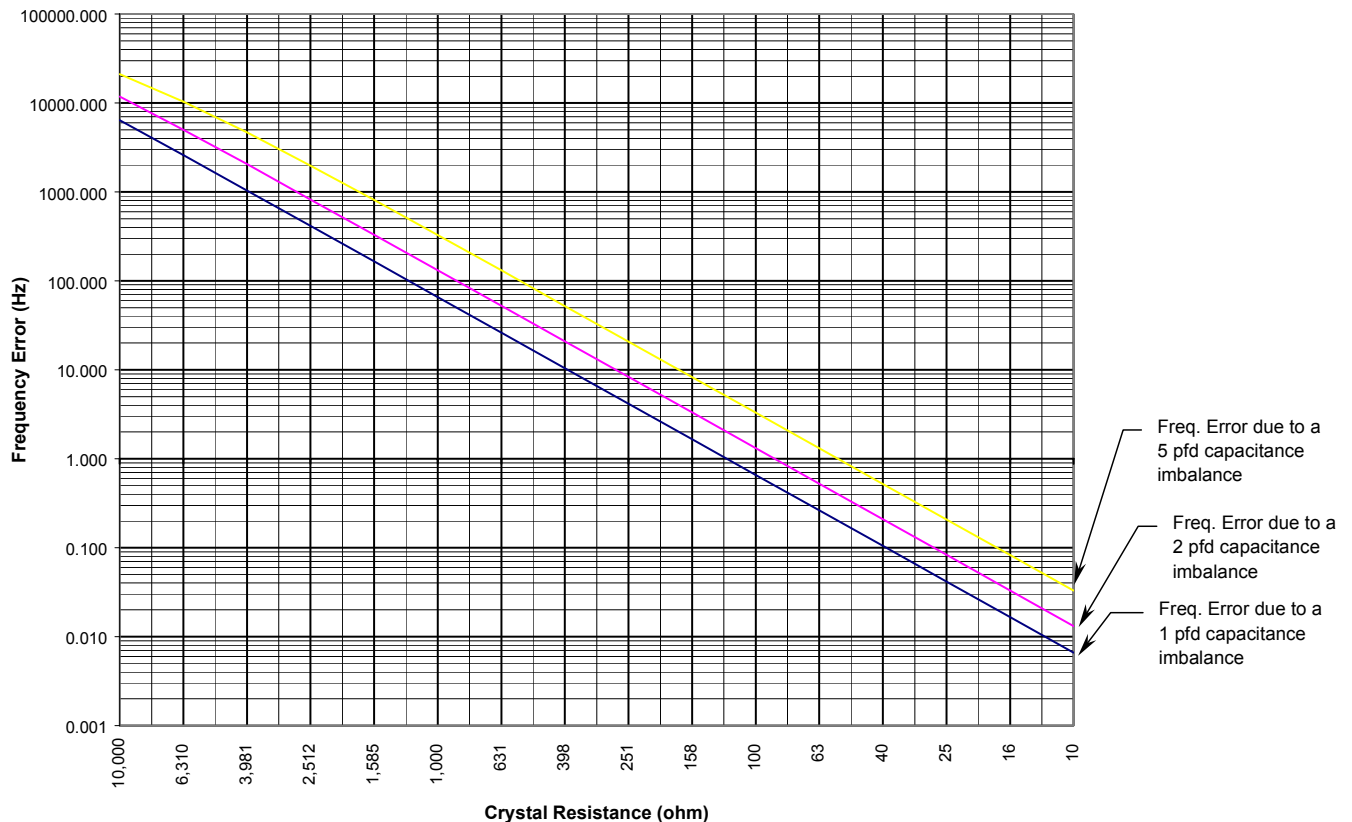
Figure 19 Frequency Error Due to Imperfect Capacitance Cancellation

7   CALCULATING CRYSTAL POWER

Crystal power can be calculated as follows:

Crystal power, $P_{cry} = i^2 * R_{cry}$

Crystal current, $i = V_{oc}/(R_s + R_{cry})$

Hence, $P_{cry} = i^2 * R_{cry} = [V_{oc}/(R_s + R_{cry})]^2 * R_{cry}$

Where:

V_{oc} = Open Circuit crystal drive voltage = 125 mV

R_s = Crystal drive source resistance = 20 ohms

R_{cry} = Crystal resistance value in ohms

Examples:

1.   Crystal Resistance = 80 ohms

$P_{cry, in watts} = [0.125/(20 + 80)]^2 * 80 = 1.25E^{-4}$ watts or 125 μW

2.   Crystal Resistance = 4000 Ω

$P_{cry, in watts} = [0.125/(20 + 4000)]^2 * 4000 = 3.87E^{-6}$ watts or 3.87 μW

Crystal Power vs. Crystal Resistance
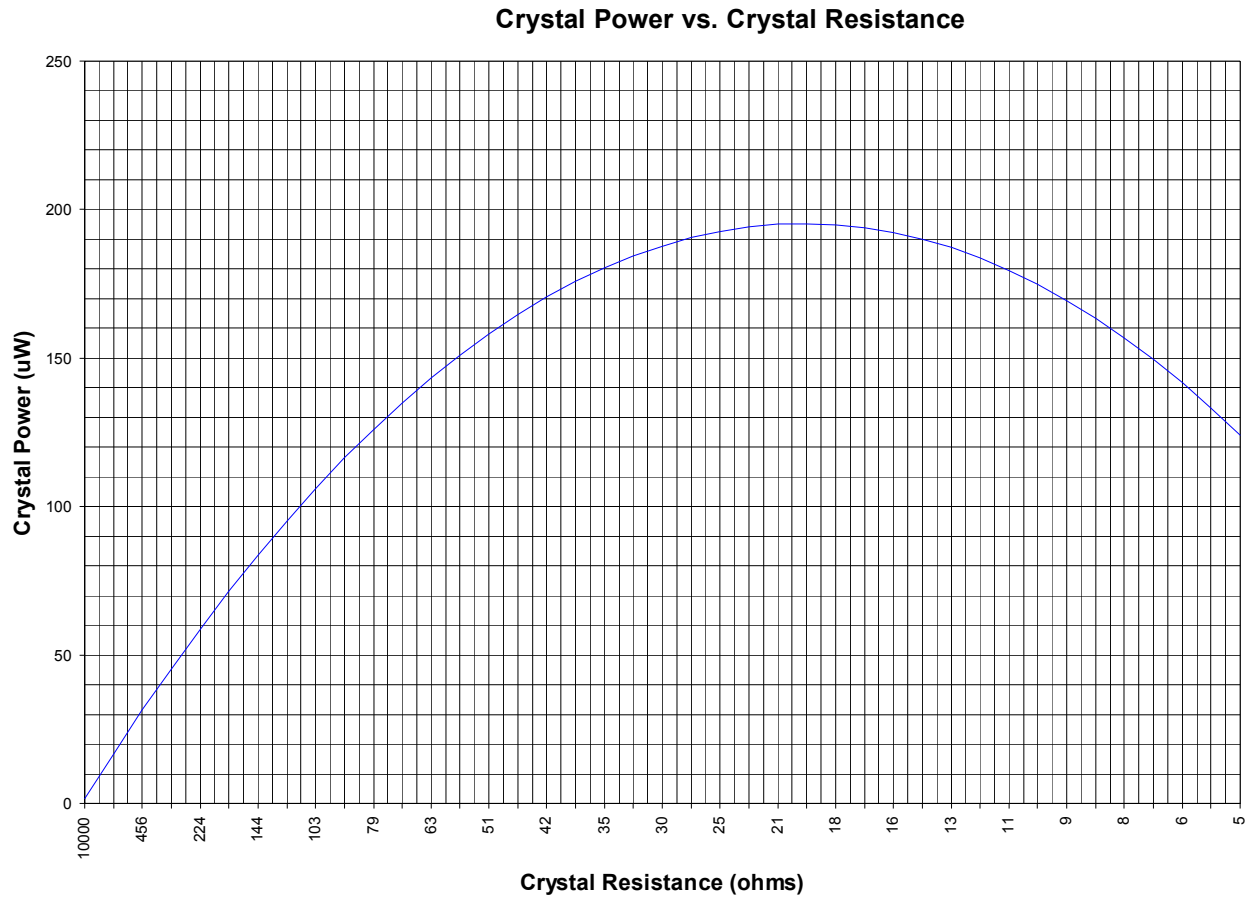
Figure 20 Crystal Power Dissipation vs. Crystal Resistance

8 FILM THICKNESS CALCULATION

Early investigators noted that if one assumed that the addition of material to the surface produced the same effect as the addition of an equal mass of quartz, the following equation could be used to relate the film thickness to the change in crystal frequency.

$$TK_f = \frac{N_q \cdot \rho_q}{\rho_f \cdot f^2}\left(f_q - f\right) \quad (1)$$

where:

N_q= Frequency constant for an "AT" cut quartz crystal vibrating in thickness shear (Hz x cm).

N_q = 1.668 x 10^5 Hz x cm.

ρ_q = Density of quartz g/cm^3.

f_q = Resonant frequency of uncoated crystal.

f = Resonant frequency of loaded crystal.

Tk$_f$= Film thickness.

ρ_f = Density of material g/cm^3 .

This equation proved to be adequate in most cases, however, note that the constant of proportionality is not actually constant because the equation contains the crystal frequency which of course changes as the film builds up. Because the achievable frequency change was small enough, the change in scale factor fell within acceptable limits.

Improvements in sensor crystals and oscillator circuits resulted in a significant increase in achievable frequency shift. Low cost integrated digital circuits became available allowing a significant increase in basic instrument accuracy. As a result of the above two factors, the frequency squared term in the scale factor became a significant limitation on the measurement accuracy.

If the period of oscillation is measured rather than the frequency, 1/period can be substituted for frequency resulting in the following equation.

$$TK_f = \frac{N_q \cdot \rho_q}{\rho_f}\left(\tau - \tau_q\right) \quad (2)$$

where:

τ= Period of loaded crystal (sec.)

τ_q= Period of uncoated crystal (sec.)

Note: Units of are cm/sec.

Note that the constant of proportionality in this equation is constant. This approach was demonstrated to be a significant improvement over frequency measurement and was widely adopted.

The original assumption that the addition of a foreign material to the surface of the crystal produced the same effect as that of the addition of an equal mass of quartz was of course, questionable and indeed work with crystals heavily loaded with certain materials showed significant and predictable deviation between the actual measured film thickness and that predicted by equation 2. Analysis of the loaded crystal as a one dimensional composite resonator of quartz and the deposited film led to the equation below:

$$TK_f = \left(\frac{\rho_q}{\rho_f}\right) \cdot N_q \cdot \left(\frac{\tau}{\pi R_z}\right) \cdot \arctan\left[R_z \tan\pi\left(\frac{\tau - \tau_q}{\tau}\right)\right] \qquad (3)$$

where:

R_z is referred to as the Acoustic Impedance Ratio and is obtained by dividing the acoustic impedance of quartz by the acoustic impedance of the deposited film.

This equation introduces another term into the relationship which is the ratio of the acoustic impedance of quartz to the acoustic impedance of the deposited film. The acoustic impedance is that associated with the transmission of a shear wave in the material. Note that if the acoustic impedance ratio is equal to one, quartz on quartz, equation 3 reduces to equation 2.

Although the above equation still involves a number of simplifying assumptions, its ability to accurately predict the film thickness of most commonly deposited materials has been demonstrated.

The basic measurement is period, which can be thought of as a measurement of equivalent quartz mass. The actual film mass on the crystal is then found by applying the acoustic impedance correction factor.

When the thickness indication is zeroed, the initial equivalent quartz mass and the initial corrected film mass are stored. For each subsequent measurement the new corrected total film mass is calculated, and the film mass deposited since the thickness was zeroed is determined by subtracting the initial corrected film mass from the total corrected film mass.

The film thickness on the crystal is calculated by dividing by the film mass by the material density.

9   COMPUTER INTERFACE

Three different interfaces are available to connect the RQCM hardware to your computer.

The RQCM system comes standard with an RS-232 serial interface. Both RS-485 and IEEE-488 interfaces are available as options. Currently the RQCM does not offer a Universal Serial Bus (USB) interface. However, you can use an inexpensive RS-232 to USB adaptor if your computer does not have an RS-232 port available. Refer to the RQCM Data Logging on-line help for more details.

9.1   COMPUTER INTERFACE SOFTWARE

Your RQCM software is supplied on a CD. Extensive on-line help makes a hardcopy manual unnecessary.

9.2   RECOMMENDED MINIMUM COMPUTER CONFIGURATION

- Pentium III 500 MHz PC

- 24 MB of RAM. (This is in addition to the Operating System requirements.)

- 35 MB of hard disk space. (Additional free hard disk space is required for data storage.)

- CD-ROM drive

- Microsoft Windows 9x/ME/NT4 (SP3 or later)/2000.

9.3   SOFTWARE INSTALLATION

Follow the instruction below to install the software on the computer.

1. Insert the RQCM Software CD into the CD-ROM drive.

2. If your system supports the auto-run feature, installation begins automatically.

3. If your system does not support the auto-run feature, click Start, Run, then enter X:\setup, where X is the CD-ROM's drive letter.

4. Follow the instructions in the windows as they appear.

9.4   CREATING YOUR OWN SOFTWARE

Although the RQCM includes a comprehensive Windows™ based interface program, some users may find it necessary to create their own interface program. This section describes the various computer interfaces and the protocol of the RQCM

There are three types of computer interfaces offered. The RQCM comes standard with an RS-232 serial interface. Both RS-485 and IEEE-488 interfaces are available as options.

9.5   RS-232 SERIAL INTERFACE

The standard RS-232 serial interface of the RQCM allows one RQCM to be connected to any other device with an RS-232 serial interface. The RS-232 interface port is the D9P

connector on the rear panel of the RQCM. The pin layout is shown in Figure 21 and Table 1 lists the pin signal assignments, including a definition of whether the signal is an input or an output of the RQCM.

The RQCM acts as DTE, and accordingly the 9-pin connector has 'plug' pins. It can be used with a DCE or a DTE host cable connection providing the sense of the RxD/TxD data lines and the control lines is observed. Pin 2 'TxD' transmits data from the RQCM to the host; pin 3 'RxD' receives data from the host. Pin 7 'CTS' is a control output signal, and pin 8 'RTS' is a control input signal.

In this implementation, pin 7 'CTS' means what is says, namely, this is an output control line, and when the RQCM asserts this control line 'true' the host can transmit to the RQCM. On the other hand, pin 8 'RTS' is not quite what it may seem because this is a signal input to the RQCM, and it is intended that the host should assert this line 'true' only when the RQCM is allowed to transmit data to the host. The RQCM does not generate an RTS 'request-to-send' as such for the host PC, so the host should assert pin 8 true whenever the RQCM is allowed to transmit to the host, without being asked to do so.

The RQCM's RS-232 port is automatically set up to operate with the following specifications:

19200 Baud, 8 Bit data, No Parity, 1 Stop bit
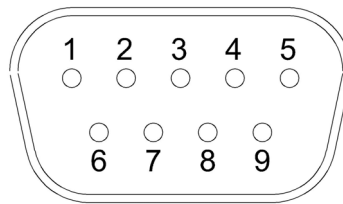
Figure 21 D9S DTE Rear-panel RS-232 socket connector

Pin	Signal			
Number	RS-232		RS-485	
1	Not used		Rx-	Input
2	Tx	Output	Rx+	Input
3	Rx	Input	Tx+	Output
4	Not used		Tx-	Output
5	GND		GND	
6	Not used		CTS-	Input
7	CTS	Input	CTS+	Input
8	RTS	Output	RTS+	Output
9	Not used		RTS-	Output

Table 1 D9 Rear Panel RS-232/RS-485 Connector Pin Assignments

9.6 RS-485 SERIAL INTERFACE

The optional RS-485 serial interface of the RQCM allows connection of up to 32 separate devices equipped with RS-485. The RS-485 serial interface is also ideal in electrically noisy environments and in applications where long cables are required. The RS-485 port of the RQCM is the same D9P connector on the rear panel used for RS-232. The pin layout is shown in Figure 21 and Table 1 lists the pin signal assignments, including a

definition of whether the signal is an input or an output of the RQCM.

The RQCM's RS-485 port is automatically set up to operate with the following specifications:

19200 Baud, 8 Bit data, No Parity, 1 Stop bit

9.7   IEEE-488 PARALLEL INTERFACE

The optional IEEE-488 interface provides the RQCM with the ability to communicate with computers and other devices over a standard IEEE-488 interface bus. The IEEE-488 interface, also known as GPIB or HPIB, provides an eight bit parallel asynchronous interface between up to 15 individual devices on the same bus. This means that one computer equipped with an IEEE-488 interface card can communicate with up to 14 RQCMs or other devices.

The pin layout of the IEEE-488 port is shown in Figure 22 and Table 2 lists the pin signal assignments, including a definition of whether the signal is an input or an output of the RQCM.

The RS-232 serial port can still be used with IEEE-488 installed. However, since both interfaces use the same input and output message buffers, they should not be used at the same time. This will result in communication errors.
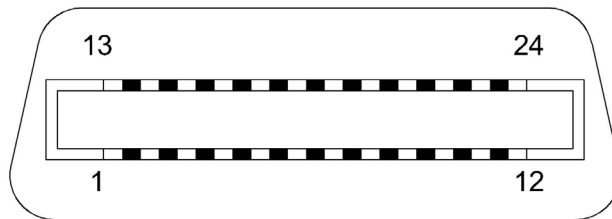
Figure 22 IEEE-488 Connector

Pin Number	Signal
1	DATA I/O 1
2	DATA I/O 2
3	DATA I/O 3
4	DATA I/O 4
5	End Or Identify
6	Data Valid
7	Not Ready For Data
8	Data Not Accepted
9	Service Request
10	Interface Clear
11	Attention
12	Shield or Wire GND
13	DATA I/O 5
14	DATA I/O 6
15	DATA I/O 7

16	DATA I/O 8
17	Remote Enable
18	GND
19	GND
20	GND
21	GND
22	GND
23	GND
24	Logic GND

Table 2 IEEE-488 Pin Assignments

9.8   PROTOCOL

All communications between the computer and the RQCM are in the form of messages with the format:

* Two byte header - (FFh, FEh i.e. Chr$(255), Chr$(254)) The header indicates the beginning of a message.

*One byte device address - (1 to 32) The device address byte defines the bus address of the instrument that sent or should receive the message. The device address will range from 1 to 32. A message sent to a device address of zero will be received by all RQCMs except in the case of the IEEE-488 interface. With this interface, only the addressed device will receive the message.

*One byte instruction code - (0 to 6) Defines the code number of the message.

*One byte message length - (0 to 249) Indicates the number of data bytes contained in the message.

* One byte checksum - (0 to 255) The checksum byte is used for transmission error detection. If the TM receives a message with an incorrect checksum, it will disregard the message. The checksum is the compliment of the one-byte sum of all bytes from, and including, the instruction code to the end of the message. If the one-byte sum of all these bytes is added to the checksum, the result should equal 255.

If the sum of all bytes occupies more than one byte, a single byte checksum can be generated using the expression: checksum=! (Sum MOD 256), i.e. the checksum is the complement of the remainder byte, which results from dividing the sum of all bytes by 256.

9.9   DATA TYPES

There are three data types stored in the RQCM: One byte, two byte, and three byte parameters. All data types are stored as integers in binary format with the most significant byte first. The one-byte data types are ASCII characters, numeric values (0-255), or 8 bit registers. Some of the multiple byte data types are decimal values stored as integers. To convert these values to their decimal equivalent, use the following equation:

Decimal Value = (Integer Value)/(10*DP)

Where:

DP = the value's decimal point position.

The decimal point positions for all the parameters are constant and are given in tables along with the parameters' range.

9.10 MESSAGE RECEIVED STATUS

Following the receipt of each message, the RQCM will send a one-byte 'received status' message, indicating how the message was received, with the following format:

Header

Address

Inst=253

Length=2

Instruction Code

Receive code

Checksum

A value of 253 for the instruction byte indicates that this is a received status message. The Instruction Code byte indicates the instruction code of the message that was received. The following table shows a list of possible receive codes:

Receive Code	Description
0	Message received O.K.
1	Invalid checksum.
2	Invalid instruction code.
3	Invalid message length.
4	Parameter(s) out of range.
5	Invalid message.

9.11 INSTRUCTION SUMMARY

The following table is a list of valid instruction codes.

Instruction Code	Description
0	Send RQCM configuration
1	Initiate automatic data logging of binary values
2	Set analog to digital board configuration
3	Internal command
4	Internal command
5	Internal command
6	Set Relay Outputs
7	Internal command
8	Set interface address

9.12 INSTRUCTION DESCRIPTIONS

The following is a description of the valid instructions along with an example of how they are used. All the examples assume the device address is 1.

1. Send RQCM hardware configuration (Code #0)

Instructs the RQCM to send its configuration data to the host computer. The following is a description of the configuration data message:

Name	Length (bytes)	Message
Software Version	35	Maxtek RQCM Software Version X.XX
Communication Port	1	(1=RS232, 2=RS-485, 3=IEEE488)
Sensor Board Status	1	(Bit0=Ch. #1, Bit1=Ch. #2, Bit2=Ch. #3)
Accessory Board Status	1	(Bit0 = Digital I/O, Bit 1 = Analog Input)
Total 38 bytes		

Example: To instruct the RQCM to send the configuration data the computer would send:

Chr$(255)+Chr$(254)+Chr$(1)+Chr$(0)+Chr$(0)+Chr$(255)

2. Automatic Data Logging of Binary Values (Code #1)

This instruction allows the computer to setup the RQCM to automatically output selected binary values to the communication port every 50 milliseconds. The values sent are determined by the bit value of the message byte in the data logging instruction message.

Byte #	Bit #	Description	Length bytes	Format	Range	Units
1	0	Message counter	1	Binary	0 to 255	
	1	Sensor #1 Period	4	Binary		Counts/sec
	2	Sensor #1 Resistance	2	Binary	0 to 65535	Counts
	3	Sensor #1 Period	4	Binary		Counts/sec
	4	Sensor #1 Resistance	2	Binary	0 to 65535	Counts
	5	Sensor #1 Period	4	Binary		Counts/sec
	6	Sensor #1 Resistance	2	Binary	0 to 65535	Counts
	7	Analog Input #1	2	Binary	-33,333 to 33,333	--------
2	0	Analog Input #2	2	Binary	-33,333 to 33,333	--------
	1	Analog Input #3	2	Binary	-33,333 to 33,333	--------
	2	Analog Input #4	2	Binary	-33,333 to 33,333	--------
	3	Analog Input #5	2	Binary	-33,333 to 33,333	--------
	4	RTD Temperature	2	Binary	-33,333 to 33,333	0.1 °C or °F
	5	Thermocouple Temperature	2	Binary	-33,333 to 33,333	0.1 °C or °F
	6	Thermistor Temperature	2	Binary	-33,333 to 33,333	0.1 °C or °F
	7	Discrete Inputs	1	**		
3	0	Discrete Outputs	1	**		

** The discrete input and output bytes indicate the status of the inputs and outputs such that bit 0 corresponds to input/output #1, bit 1 to input/output #2, etc.

All values are sent in Binary format with the most significant byte first. To convert binary values to decimal, use the following formula:

Decimal Value = Sum of Byte[n]*256^(Y-1) where n goes from 1 to Y and Y is the total number of bytes that make up the value.

For example, say you want to read sensor frequency. You first have to setup the RQCM to send sensor period. Say you receive the four following bytes representing sensor period: 31,255,109,53

This equals (31*256^3 + 255*256^2 + 109*256 + 53) = 536,833,333

To convert period to frequency, use the following formula:

Frequency (Hz) = (3.221E15)/Period = (3.221E15/536,833,333) = 6,000,000.0 Hz

Like sensor period, sensor resistance is also in special units. Use the following formula to convert the resistance counts value sent by the RQCM to OHMs:

Sensor Resistance (OHMs) = (273,300/Counts) - 20

The scaling of the analog inputs depends on each inputs configuration as shown in the following table.

Input Range	Scaling (mV)
0 – 5	0.0001
+/- 5	0.0002
0 – 10	0.0002
+/- 10	0.0005

Example: To instruct the RQCM to output sensor #1 period and resistance, the computer would send the following message:

Chr$(255)+Chr$(254)+Chr$(1)+Chr$(1)+Chr$(3)+Chr$(3)+Chr$(0)+Chr$(0)+Chr$(248)

The RQCM will then send one message every 50 milliseconds that it 12 bytes long and contains 6 bytes of data. The first four bytes of data is sensor period and the next two bytes are sensor resistance.

Data logging is stopped by sending the following message:

Chr$(255)+Chr$(254)+Chr$(1)+Chr$(1)+Chr$(3)+Chr$(0)+Chr$(0)+Chr$(0)+Chr$(251)

3. Configure Data Acquisition Board (Code #2)

This instruction allows the computer to configure the input range and temperature units of the RQCM's Analog Input/Temperature card. The following table shows the byte configuration for this message.

Byte #	Description	Length bytes	Range
1	Input #1 Range	1	0 to 7
2	Input #2 Range	1	0 to 7
3	Input #3 Range	1	0 to 7
4	Input #4 Range	1	0 to 7
5	Input #5 Range	1	0 to 7
6	Temperature Configuration	1	0 or 7
	Total Bytes	6	

Each inputs voltage range and filter frequency can be independently configured. There are four voltage ranges and two frequency ranges. The available values are as follows:

Input Code	Voltage Range (Volts)	Filter Freq. (Hertz)
0	0 to 5	1
1	0 to 10	1
2	+/- 5	1
3	+/- 10	1
4	0 to 5	8
5	0 to 10	8
6	+/- 5	8
7	+/- 10	8

The temperature configuration byte sets the units for the three temperature inputs. A value of zero selects Fahrenheit and a value of seven selects Celsius.

Example: To set inputs 1 through 5 for 0 to 5 volt range and 1 hertz filter and the temperature inputs to Celsius, computer would send:

Chr\$(255)+Chr\$(254)+Chr\$(1)+Chr\$(2)+Chr\$(6)+Chr\$(0)+Chr\$(0)+Chr\$(0)+Chr\$(0)+ Chr\$(0)+Chr\$(7)+Chr\$(240)

4. Internal Command

5. Internal Command

6. Internal Command

7. Receive Relay Output Status (Code #6)

This instruction allows the computer to open or close the RQCM's relay outputs. Each bit of the one-byte command code in the message determines the status of one output. If the bit is 1 then that output relay will close. If the bit is 0 then that relay output will open. Bit 0 = relay #1, bit 1 = relay #2, etc.

For example: To instruct the RQCM to close relays 1 & 2 and open all other relays, the computer would send:

Chr\$(255)+Chr\$(254)+Chr\$(1)+Chr\$(6)+Chr\$(1)+Chr\$(3)+Chr\$(245)

8. **Internal Command**

9. **Set RQCM Interface Address (Code #8)**

This instruction allows the computer to set the RQCM's interface address. The RQCM's interface address allows for multiple instruments to share the same communications bus. You can have multiple RQCM's on the same bus but each must have a unique interface address so the computer can communicate with each one individually.

The interface address can range from 1 to 32. All RQCM's are shipped with the interface address set to one.

For example: To set the RQCM's interface address to 2, the computer would send:

Chr$(255)+Chr$(254)+Chr$(1)+Chr$(8)+Chr$(1)+Chr$(2)+Chr$(244)

If using the IEEE interface then the computer must also send a device clear before the new interface address takes affect. The new interface address will take affect immediately when using either RS-232 or RS-485.

10 DATA ACQUISITION CARD (OPTIONAL)

The RQCM has one rear panel slot for the optional Data Acquisition Card. The card has three (3) temperature inputs to accommodate an RTD, thermocouple or thermistor. There are also five (5) scalable analog inputs for measurement and logging of DC voltages. Except for the thermocouple input, which has its own connector, all other temperature inputs and analog inputs are on a D-SUB 25 pin male connector. Figure 23 shows the connector pin configuration and Table 3 shows the pin signal assignments. Refer to the online help included in the RQCM software for instructions on setting up and programming these inputs.
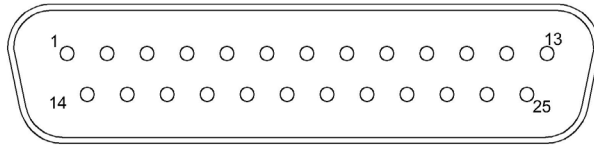

Figure 23 DB25P Data Acquisition Rear Panel Connector

Pin Number	Function
1, 2, 3	Voltage Input #1 (Input, Common, Shield)
4, 5, 6	Voltage Input #2 (Input, Common, Shield)
7, 8, 9	Voltage Input #3 (Input, Common, Shield)
10, 11, 12	Voltage Input #4 (Input, Common, Shield)
14, 15, 16	Voltage Input #5 (Input, Common, Shield)
17, 18, 19	Thermocouple Input (Hi, Lo, Shield)
20, 21, 22, 23, 24	RTD Input (Hi, Hi Sense, Lo Sense, Lo, Shield)
25	Voltage Reference
13	Not used

Table 3 DB25P Data Acquision Rear Panel Connector Pin Assignments

10.1 VOLTAGE INPUTS

Each of the five (5) inputs can be configured as 0 to 5V, 0 to 10V, ±5V, or ±10V. The unipolar positive inputs can be connected as unipolar negative inputs. The resolution of the data is dependent on the range selection as shown in the table below.

Configuration	Resolution
0 to 5V	0.1 mV
0 to 10V	0.2 mV
±5V	0.2 mV
±10V	0.5 mV

Table 4 Input Voltage Resolution

The voltage input pairs are labeled as Input and Common. The Input pin is the positive input and the Common pin is the negative input. The common mode range is ±200V, so the Common pin can be used to read unipolar negative voltages with the input pin as common. Each input also has a Shield pin for shielded cable termination. Shielded, twisted pair cable is recommended for connections longer than a foot.

10.2 TEMPERATURE INPUTS

Three temperature inputs are included to support the three most commonly used temperature sensors: thermistor, Resistance Temperature Detector (RTD), or type T (copper constantan) thermocouple.

10.2.1 THERMISTOR INPUT

The Thermistor Input is designed to use an Omega 10 KΩ @ 25°C – Precision Interchangeable Thermistor P/N 44006, or equivalent. Shielded, twisted pair is recommended for the leads.

This thermistor has a range of 0 to 150°C. The use of a thermistor provides high accuracy measurements within its temperature range, or when long leads are required.

10.2.2 RTD INPUT

The RTD has a range of 0 to 600°C. The use of the RTD is for the measurements in the higher temperature ranges.

The RTD input is designed to use an RTD conforming to the European standard curve with an alpha of 0.00385 for the Calendar-van Dusen equation and a resistance of 100 ohms @ 0°C. The RTD is connected as a four-wire element, using a pair of wires for excitation and pair of wires to sense the voltage across the element. This configuration should be continued all the way to the probe for maximum accuracy. A single shielded cable with two twisted pairs, or two shielded, twisted pair cables should be used.

10.2.3 THERMOCOUPLE INPUT

The Type T Thermocouple input uses true internal cold junction compensation. For accurate measurements, thermocouple grade copper and constantan wire must be used from the thermocouple to the rear panel thermocouple connector. Figure 24 shows the rear panel thermocouple connector. The mating connector is an Omega NMP-T-M (included with each Data Acquisition Card), or equivalent. If it is desired to use shielded thermocouple wire, which is recommended, the shield drain wire can be connected to the RTD or thermistor shield pin.

The Type T Thermocouple has a range of 0 to 371°C. The use of a thermocouple is recommended in oxidizing, reducing, inert or vacuum atmosphere within its temperature range.
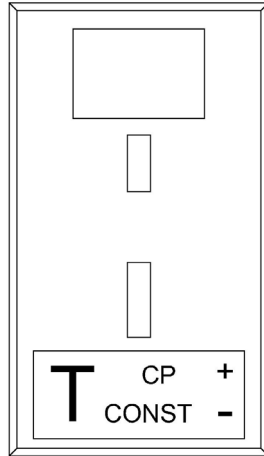
Figure 24 Rear Panel Type T Thermocouple Connector

10.3 GROUNDING CONSIDERATION

Proper grounding and shield termination is mandatory for accurate measurements.

10.3.1 VOLTAGE MEASUREMENT GROUNDING

If the voltage to be measured is returned to earth ground (within the common mode voltage range) at its source, neither the Input nor the Common lead should be grounded at the voltage measurement point, since the RQCM will return to earth ground through its power cord. The shield for the input leads must only be terminated at the Data Acquisition Card connector.

If the voltage to be measured is isolated from earth ground, the shield or its drain wire should be connected to the common side of the voltage to be measured at the voltage source as well as at the shield terminal on the RQCM Data Acquisition Card.

10.3.2 TEMPERATURE MEASUREMENT GROUNDING

All three temperature-sensors *must* be of the isolated or ungrounded type. Sensor lead wire shields should be terminated at the RQCM Data Acquisition Card connector only. The measured device should be connected to earth ground. Exposed junction probes should not be used to measure the temperature in a conductive media like water.

11 I/O CARD (OPTIONAL)

The RQCM has one rear panel slot for the optional I/O card. The card has eight (8) TTL level (0 to 5 volt DC) inputs. The inputs are pulled up to 5 volts internally through a 4.7 KΩ resistor and are set true, assuming the input's True level is set to Low, by shorting the input pins together.

There are eight (8) SPST relay outputs capable of handling 120 VA, 2A max. per relay.

These inputs and outputs can be used to control external instruments and peripheral devices such as pumps, heaters, valves, instruments, etc.

Figure 25 shows the connector pin configuration and Table 5 supplies pin signal assignments. Refer to the online help of RQCM computer software for I/O definition and programming instructions.
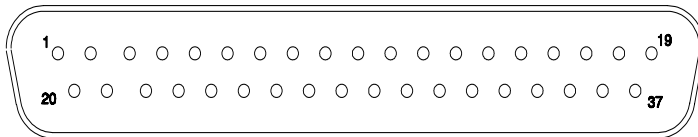

Figure 25 DB73P I/O Rear Panel Connector

Pin Number	Function
1, 20	Abort output
2, 21, 11	Output 1 (Common, N.O., N.C.)
3, 22, 29	Output 2 (Common, N.O., N.C.)
4, 23	Output 3
5, 24	Output 4
6, 25	Output 5
7, 26	Output 6
8, 27	Output 7
9, 28	Output 8
30	Input 1
12	Input 1 Return
31	Input 2
13	Input 2 Return
32	Input 3
14	Input 3 Return
33	Input 4
15	Input 4 Return
34	Input 5
16	Input 5 Return
35	Input 6
17	Input 6 Return
36	Input 7
18	Input 7 Return
37	Input 8
19	Input 8 Return

Table 5 DB37P I/O Rear Panel Connector Pin Assignments

12 TROUBLESHOOTING GUIDE

This section is intended primarily as an aid in understanding the RQCM operation and to help insolating common problems external to the RQCM. If it is determined that the problem lies inside the unit, please contact the factory for further assistance.

Symptom	Possible Cause	Remedy
Line fuse blows when the power switch is switched to "on".	Wrong line voltage is selected at the rear of RQCM	Set line voltage on RQCM rear panel to match with line voltage being used.
	Incorrect fuse rating.	Replace line fuse with correct fuse size.
None of the front panel LED indicators illuminated.	Blown line fuse.	Replace fuse
	Power switch is not on.	Switch front panel power switch to "on".
	No power being applied to unit.	Check and correct power source and/or power cord.
	Wrong line voltage is selected at the rear of RQCM.	Set line voltage on RQCM rear panel to match with line voltage being used.
Unable to adjust fine and coarse adjustments to compensate for capacitance	The total capacitance of the cable, crystal, and crystal holder is out of the range of 40 to 200 pfd.	Adjust cable length to reduce/increase its capacitance.
Unit does not lock onto a frequency when a crystal is installed.	Crystal fundamental frequency exceeds the frequency range of the crystal channel.	Verify crystal frequency against crystal channel frequency range. (To verify the crystal channel frequency ranges, press Reset button and observe the output. A 3.8 MHz indicates the channel is set for 3.8 to 6 MHz. A 5.1 MHz indicates a 5.1 to 10 MHz.) Replace crystal.
	Crystal resistance exceeds the range of 5 and 5,000 Ohms.	Replace crystal.
Unit looses lock when crystal is exposed to liquid.	Total capacitance of the crystal, holder and cable changes when going from air to liquid.	Adjust capacitance compensation with crystal in the liquid. Refer to Section 5.
Unstable frequency reading when the crystal or the holder or the cable is being touched.	Same as above. The crystal measurement is reacting to the change in total capacitance when the setup is being touched.	Avoid contact with the hookup during an experiment. This is especially important if the crystal is a low Q crystal.
Frequency reading is unstable or drifting.	Temperature (of the crystal) is changing. An AT-cut crystal frequency may drift as much as 10 Hz/°C.	Control temperature of the test environment.
	Humidity (level on the crystal) is changing. Moisture being absorbed or exuded from the crystal surface.	Control humidity of the test environment.

	"Unbalanced" or damaged coaxial cable.	Check cable for any signs of damage such as broken shield. Replace cable.
Unit shows "Lock" with no crystal, holder and cable connected to the crystal channel.	The capacitance was probably adjusted with the crystal, holder and cable combined. With everything removed, the "Lock" light just means that the capacitance is now grossly out of adjustment.	This is normal. Re-connect the crystal, holder and cable.
Unit shows "Lock", but the frequency reading is at its lowest and the resistance reading is about 1 ohm.	An electrical short across the crystal input.	Check the cable, holder, and the crystal for short. Remove short or replace the defective part.
"No Clear to Send Signal" error message when attempting communications with RQCM.	Wrong COMM port number selected.	Set the correct COMM port number in the Setup|Comm Port Setting Menu.
	RS-232 Cable not connected to RQCM.	Connect RS-232 cable to RQCM
"Error reading data" message, "Timeout" when attempting communications with RQCM	Wrong COMM port number selected.	Set the correct COMM port number in the Setup|Comm Port Setting Menu.
	Incorrect RQCM Interface address.	Set an Interface Address in the Setup|Comm Port Settings Menu and click the Send Address button to send to RQCM
	COMM port not enabled.	Enable COMM port in PC's BIOS