晶体介绍 Crystal introduction

1.Quartz 石英晶体

石英是由硅原子和氧原子组合而成的二氧化硅（Silicon Dioxide, SiO2）, 以32点群的六方晶系形成的单结晶结构（图一）.单结晶的石英晶体结构具有压电效应特性, 当施加压力在晶体某些方向时, 垂直施力的方向就会产生电气电位. 相对的当以一个电场施加在石英晶体某些轴向时, 在另一些方向就会产生变形或振动现象. 掌握单结晶石英材料的这种压电效应, 利用其发生共振频率的特性, 发挥其精确程度作为各类型频率信号的参考基准, 就是水晶振荡器的设计与应用.

Quartz ,a kind of crystallized Silicon Dioxide, SiO2, 32 symmetry group of trigonal system(Fig 1)exhibits piezoelectric property, which is the operating base of the electromechanical products.With its intrinstic high Q-value, the quartz based resonator and oscillator are the most wildly adopted as the reference signal source in circuitry for frequency control applications.

图1

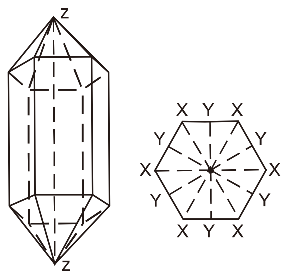
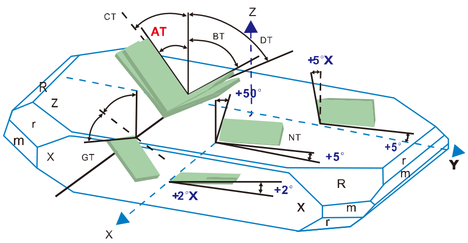


图2



2.TYPE OF QUARTZ CRYSTAL CUT 石英晶体典型的切型

依据不同的应用领域及工作温度需求, 对应了许多不同的石英切割角度种类. 例如AT, BT, CT, DT, NT, GT ,SC等不同的切割板片. 不同的切割方向的晶片具有不同的弹性常数张量, 不同的压电常数张量,及不同的介电常数张量. 这些张量在石英组件的设计及应用上展现了不同的振荡及温度特性. (图2)表现了在Z-plat石英结构上,几种不同方向的石英板片切割方式.

According to different cut angles to quartz bars, there are different kinds of quartz plates,for examples,AT-, BT-, CT- ,DT-, NT-, GT- SC-plates different types of quartz cuts,indicated by a set of Euler angles,have different available elastic piezoelectric and dielectric properties, which are the basic parameters for designing a quartz crystal device.The most often used Quartz-cut types are shown in (Fig 2) schematically.

3. Frequency-Temperature Characteristics(频率-温度特性)

石英晶体作为谐振器在使用时，要求其谐振频率在温度发生变化时保持稳定。温频特性与切割角度有关，每个石英晶体具有结晶轴，晶体切割是按其振动模式沿垂直于结晶轴的角度切割的。典型的晶体切割和温频特性。(见图3)

To use a crystal unit as an oscillator. its oscillated frequency is required to be stable against temperature variations. A quartz crystal has crystallographic axes. and crystal cut is defined according to the cutting angle against a crystallographic axis and its associated mode of vibration. -Typical types of crystal cut and frequency—temperature characteristics are shown in Fig.3.

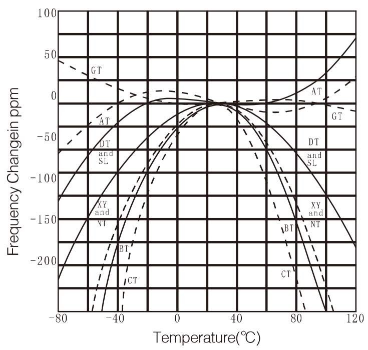


图3

Fig 4 Frequency-Temperature characteristics and Manufacturing Difficulty of an AT-Cut Crystal Unit

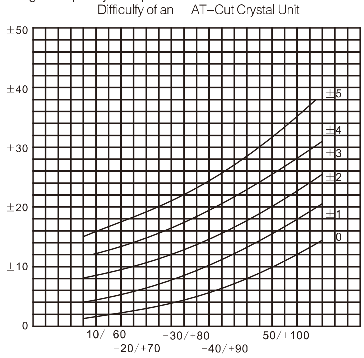


图4

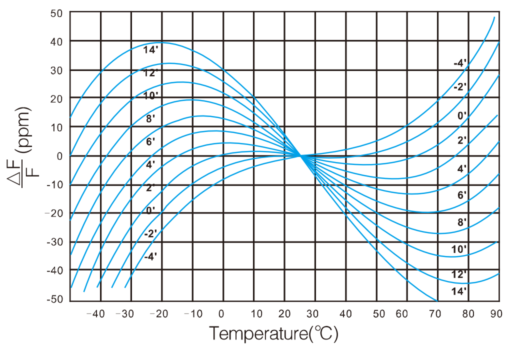
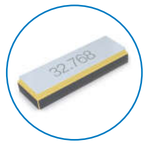


图5



4:Frequency-Temperature Characteristics of an AT-Cut(AT型切片的温频特性)

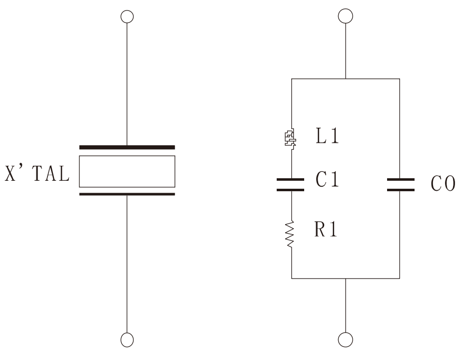
1、目前最普遍使用的AT切，晶体的频率温度特性的三次曲线表示（见图5）。

2、一个石英晶片在所需要的频率范围己满足的情况下在某一角度被切割，以达到要求的工作温度范围。在图4中可以看到频率公差和生产难度等级的关系。

1.The frequency—temperature characteristics of an AT-Cut crystal unit most generally used at present are expressed by cubic curves. (See Fig.5.).

2: A crystal plate is cut at an angle at which a required frequency tolerance is obtained in the given operating temperature range. (See Fig.4.).

图6

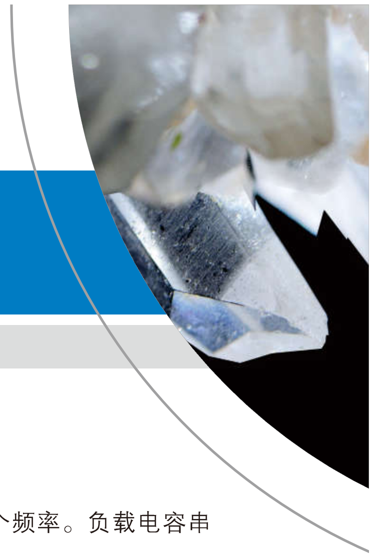


C0	Shunt capacitance	(静态电容)
L1	Motional inductance	(动态电感)
C1	Motional capacitance	(动态电容)
R1	Motional Resistance	(动态电阻)

5:Equivalent Circuit Parameters (等效电路参数)

石英晶体谐振器的振动实质上是一种机械振动。实际上，石英晶体谐振器可以被一个具有电子转换性能的两端网络测出。这个回路包括L1、C1，同时C0作为一个石英晶体的绝缘体的电容被并入回路，与弹性振动有关的阻抗R1是在谐振频率时石英晶体谐振器的谐振阻抗。(见图6)

Vibration of a crystal unit is actually mechanical vibration. However. the crystal unit can be expressed by a two—terminal network if its behavior is electrically converted. The series circuit consisting of L1. C1. and R1 is related to elastic vibration. while the element C0 connected in parallel to the series arm as a capacitance attributable to the dielectric body of a quartz crystal plate. The resistance R1 is a resonance resistance of the crystal unit at the series resonance frequency. (See Fig.6.)



6：Frequency vs Load capacitance (频率同负载电容的关系)

在规定的条件下，晶体元件与负载电容串联或并联，其组合电气阻抗呈电阻性的两个频率中的一个频率。负载电容串联时，负载谐振频率是两个频率中较低的，负载电容并联时，负载谐振频率是两个频率中较高的。

Under specified conditions, the crystal element and the load capacitance in series or parallel combination of electrical impedance was the resistance of the two frequencies in a frequency。when the load capacitor is in Series, the frequency is the lower of the two frequencies, when the load capacitor is in parallel ,the frequency is higher of the two frequency.

6.1 谐振频率及反谐振频率 (fr , fa) (见图7)

Resonance frequency and anti–resonance frequency(Fig.7)

图7

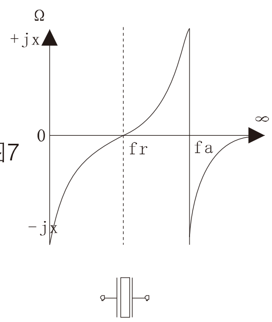


图8

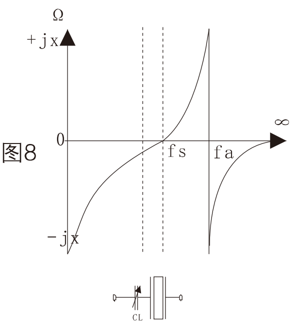
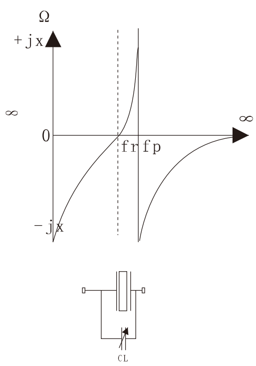


图9



6.2 串联谐振频率及并联谐振频率 (fs 见图8； fp 图9)

series resonance frequency and parallel resonance frequency (Fig 8 Fig 9)

$$Fs = \frac{1}{2\pi\sqrt{L1C1}} \qquad Fp = Fs * \sqrt{1+(C1/C0)} \qquad FL = \frac{1}{2\pi\sqrt{\frac{L1C1(C0+CL)}{C1+C0+CL}}} = Fs * \sqrt{1+C1/(C0+CL)}$$

6.3 Quality factor (Q) (品质因数)

对于石英晶体谐振器, 电气品质因素Q是很重要的一个特性. 电气品质因素可以用下列公式表示:

As a resonator,Quality factor–Q value is a very important parameter.In specification,unloaded and loaded Q values are specified.The unloaded Q,or mechanical Q,can be expressed by

$$Q = \frac{2 * \pi * F_S * L_1}{R_1} = \frac{1}{2 * \pi * F_S * C_1 * R_1}$$

6.4： Trim sensitive of load measure (TS) （频率牵引灵敏度 ）

在并联振荡线路中，负载电容变化量同频率变化的关系。

In a parallel–load capacitance,the increment fractional frequency change for an increment change in the load capacitance.

$$TS = \frac{C_1}{2(C_0 + C_L)^2}$$

7. Load Capacitance(负载电容)

负载电容CL是组成振荡电路时的必备条件。在通常的振荡电路中，石英晶体谐振器作为感抗，而振荡电路作为一个容抗被使用。也就是说，当晶体两端均接入谐振回路中，振荡电路的负阻抗-R和电容CL即被测出，这时，这一电容称为负载电容。负载电容和谐振频率之间的关系不是线性的，负载电容小时，频率偏差量大，当负载电容提高时，频率偏差量减小。当振荡电路中的负载电容减少时，谐振频率发生较大的偏差，甚至当电路中发生一个小变化时，频率的稳定性就受到巨大影响。负载电容可以是大于Co的值。

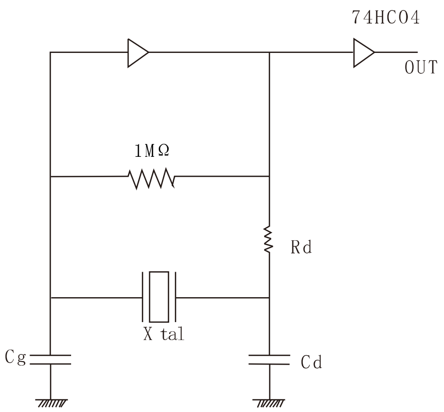
The load capacitance CL is a factor for determining the "conditions" of a crystal unit when used in the oscillation circuit. In an ordinary oscillation circuit the crystal unit is used in a range where it functions as an inductive reactance in such usage, the oscillation circuit operates as a capacitive reactance. In other words. when the oscillation circuit is seen from both terminals of the crystal unit. this oscillation circuit can be expressed as a series circuit of a negative resistance –R and a capacitance CL.At that time this capacitance is called the load capacitance. The relationship between load capacitance and oscillation frequency is not linear. When the load capacitance is small. the amount of frequency variation is large. and when the load capacitance iS increased. frequency variation lowers. If the load capacitance is lessened in the oscillation circuit to secure a large allowance for the oscillation frequency. the frequency stability will be greatly influenced even by a small change in the circuit. The load capacitance can be greater than Co Value.

8:Oscillation Circuit(振荡电路)

一个由石英晶体谐振器组成的典型振荡电路如图10所示

A typical oscillation circuit composed of a crystal unit is introduced below Element constants used are for example.

图10



Freq(MHZ)	Cg,Cd(pF)	Rd(Ω)	CL(pF)
3~4	27	5.6K	16
4~5	27	3.9K	16
5~6	27	2.7K	16
6~8	18	2.7K	12
8~12	18	1.8K	12
12~15	18	1.0K	12
15~20	15	1.0K	12
20~25	12	560	10

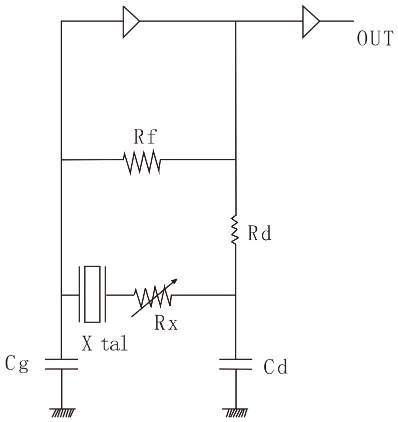
9: Negative Resistance(负阻抗)

负阻振荡电路的质量判断的指标,如果振荡电路的负阻抗不充分，由于晶体老化，温度，电压等因数的影响，振荡回路将可能不工作。

The negative resistance is an indicator for judging the quality of oscillation circuits.A circuit might not oscillate due to aging, temperature, voltage etc.if the negative resistance of an oscillation circuit is not good enough.

9.1: Negative Resistance Measurement Method(负阻抗测试方法)

图11



1：Connect the resistance(Rx) to circuit in series with crystal (See Fig.11)
同晶体串联的方式接一个可变电阻（RX)在振荡回路中。(见图11）
2：Adjust Rx so that oscillation can stsrt(or stop)
调整RX以便振荡器能工作或不工作。
3：Measure Rx when oscillation just starts(or stop)in above
测量RX的阻值，当振荡器刚刚工作或者不工作时。
4：Calculate the negative resistance using the formula:
-R = R + R1
使用上述公式计算负阻抗。
5：It is preferable when -R, -R> CI X (5 to 10)
当负阻抗超过晶体阻抗5~10倍时，振荡线路充分。

10.crystal oscillator 晶体振荡器

当把石英共振子与振荡线路或集成电路(IC)一起整合在一个封装内,由外部提供电源电压,形成一个主动元件输出频率信号,就是所谓的石英晶体振荡器.石英晶体振荡器可以藉由单一封装元件内部不同的振荡线路及输出线路,提供不同特性需求的参考频率(reference frequency).例如有 石英时脉振荡器SPXO (Simple Package Crystal Oscillator) 或称为 CXO (Clock Crystal Oscillator),可程式化石英晶体振荡器PCXO (Programmable Crystal Oscillator),电压控制石英晶体振荡器VCXO (Voltage Controlled Crystal Oscillator),温度补偿石英晶体振荡器TCXO (Temperature Compensated Crystal Oscillator) 及 恒温槽控制石英晶体振荡器OCXO (Oven Controlled Crystal Oscillator).

When a quartz resonator is integrated with an oscillating circuit or an integrated circuit (IC) in a package, a power supply voltage is supplied from the outside to form an output frequency signal of an active component, which is called a quartz crystal oscillator. Quartz crystal oscillator can be provided by different oscillating circuits and output lines within a single package element. Reference frequency for different characteristics. For example, there is a quartz time-pulse oscillator SPXO (Simple Package Crystal Oscillator) or CXO (Clock Crystal Oscillator), programmable quartz crystal oscillator PCXO (Programmable Crystal Oscillator), voltage-controlled quartz crystal oscillator VCXO (Voltage Co.) Ntrolled Crystal Oscillator, Temperature Compensated Crystal Oscillator and Oven Controlled Crystal Oscillator controlled by thermostat.

为了满足应用面需求而言,石英晶体振荡器内部的振荡线路有以基本波或三倍频不同方式.若要达到数佰兆赫的输出频率时,振荡线路後级可以采用锁相回路方式或倍频方式,将较低频率的石英振荡频率提升.对於输出端的输出准位及输出波形也有各类不同需求,如 CMOS, LVPECL, LVDS……等.这些规格都要仔细的定义.

In order to meet the application requirements, the oscillation lines in quartz crystal oscillator have different modes of basic wave or tripling frequency. If the output frequency of several megahertz is reached, the latter stage of the oscillation line can adopt phase-locked loop or frequency-doubling mode to raise the oscillation frequency of lower frequency quartz. The output frequency of the output terminal is accurate. Bit and output waveforms also have different requirements, such as CMOS, LVPECL, LVDS, etc. ... etc. These specifications should be carefully defined.

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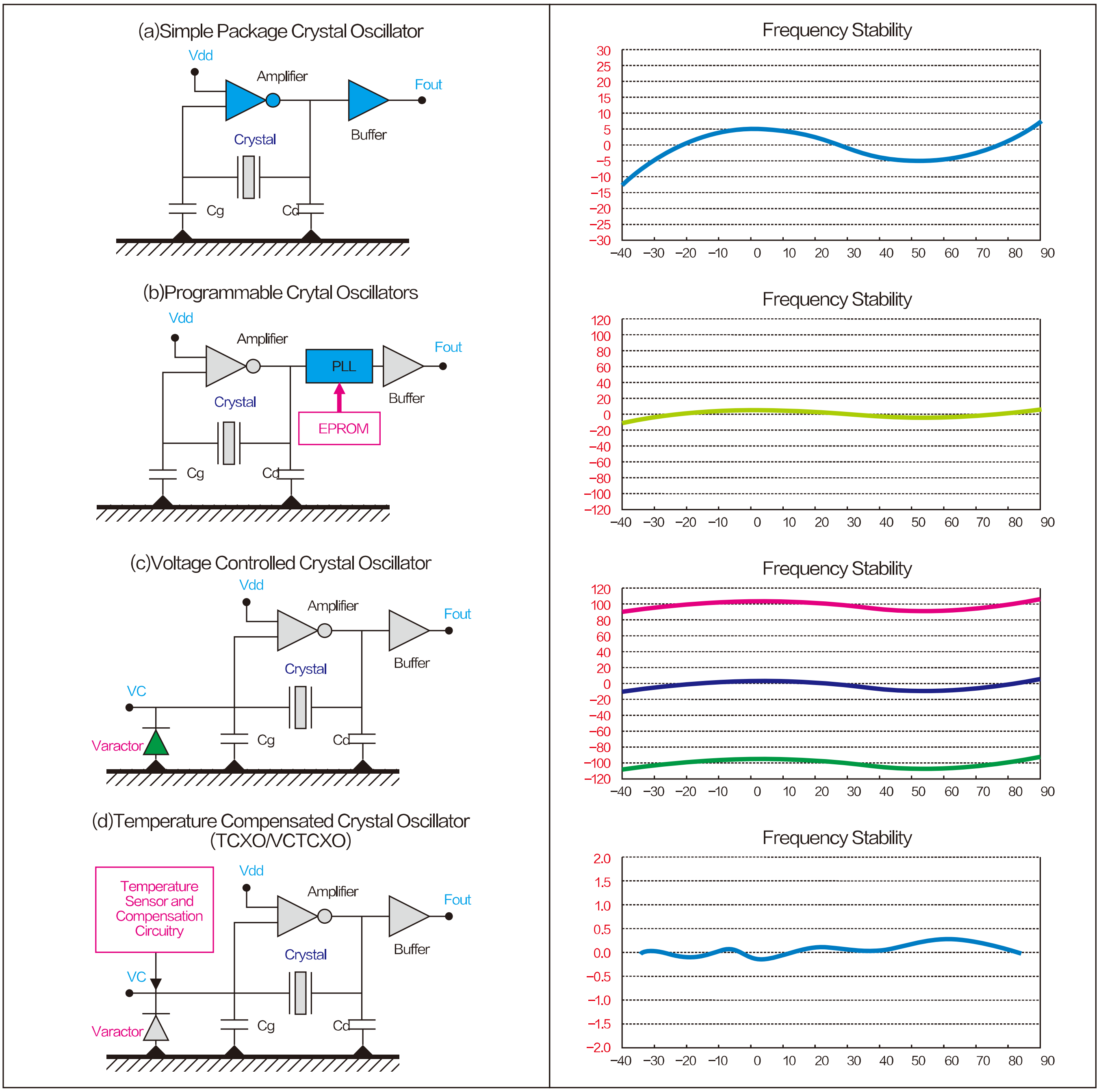
JWT24.000
JWT 26.000
32.768

图12



(a)Simple Package Crystal Oscillator
Vdd
Amplifier
Fout
Crystal
Buffer
Cg
Cd
(b)Programmable Crytal Oscillators
Vdd
Amplifier
Fout
PLL
Buffer
Crystal
EPROM
Cg
Cd
(c)Voltage Controlled Crystal Oscillator
Vdd
Amplifier
Fout
Crystal
Buffer
VC
Varactor
Cg
Cd
(d)Temperature Compensated Crystal Oscillator (TCXO/VCTCXO)
Temperature Sensor and Compensation Circuitry
Vdd
Amplifier
Fout
Crystal
Buffer
VC
Varactor
Cg
Cd
Frequency Stability
Frequency Stability
Frequency Stability
Frequency Stability