The Saga of Crystals

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In recent years, demand has been so high for nearly all technology-related products that just about any product implemented could find a ready customer base, one way or the other. It is now apparent that the technology is where the size shrinks and the numbers expand. Consequently, the new products disappear from the scene, falling prey to the same logic.

But, there is only one side of the story to quartz crystals. After a relatively humble beginning as a speciality technology, quartz soon conquered the world of 'periodicity' And now, it is moving on to the technology of choice for custom and semicustom, very large-scale integration applications.

Quartz was introduced into the wrist watch by Bulova in the first quarter of 1970s in the USA. Then it fetched a handsome 395 US dollars. This luxury was affordable by only the rich elite of the society. The power for the watch was derived from button cells which were said to last for one year. It was claimed that these wrist watches would gain or lose no more than one to two seconds per week when worn. The driver IC was fabricated by Intersil of Cupertino, California according to the specifications of Bulova. The subminiature crystal used in the wrist watch had a frequency of 32768 Hz which was then divided by the IC circuitry to $341\frac{1}{3}$ Hz by a factor of 96. The driver IC was also a breakthrough since it used a single plastic-encapsulated, low-threshold CMOS genre.

The noble trio

Piezoelectric effect has been exploited since its discovery in 1880 by Pierre and Paul Curie. Electronically piezoelectric materials are termed as the royal sandwich between mechanical and electric forces. Rochelle, tourmaline and quartz are the noble trio. If pressure is applied to these crystals in certain directions a proportional amount of electric voltage is produced. Soon after this discovery, the reverse effect also came to light. If an electric field is applied to these crystals, they either expand or contract.

Crystals are neutral due to the presence of equal number of positive and negative charges. The 'centres of gravity' of positive and negative charges are stationary relative to each other. A relative motion of these centres due to physical movement caused by compression or expansion results in the production of electric current for the time in which the charges are in motion. However, the availability of current for the external circuits is very much limited but the potential difference that is developed in the crystal is sufficient to set-up a visible arc, a few centimetres in length.

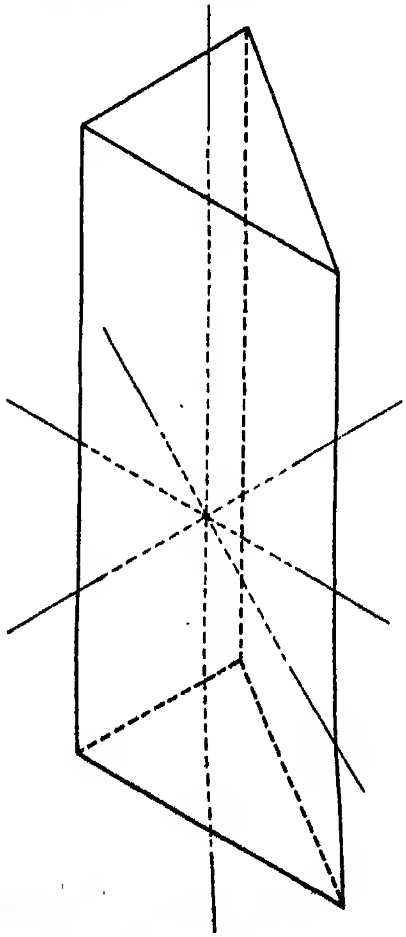


Fig. 1: The tourmaline crystal structure.

The lack of a centre of symmetry in the crystal is the root cause of piezoelectric effect. The compression and expansion of the crystal can be easily identified by the polarity of the potential developed by the crystal. Thus, a variable pressure can be translated into its electrical equivalent without missing any of its finer details. Conversely, the crystals are equally vulnerable to the changes in the applied voltage across them which induces a physical movement of compression or expansion to the crystals.

Rochelle salt ($NaKC_4H_4O_6.4H_2O$ or sodium potassium tartrate), belongs to crystallised orthorhombic class. (The orthorhombic system has three axes, all at right angles to each other and having different lengths. Common forms are the four sided prism and the flattened tabular crystal.) The Curie brothers used rochelles in 1880 to study the behaviour of piezoelectric materials. In crystalline form, rochelle salt can have a dual life depending on the temperature. It is monoclinic (also a three-axes system having different lengths with two axes inclined at an angle other than 90° and the third at right angles to the other two) in the range -18°C to 23.7°C and orthorhombic outside this range. In the latter state, the field produced in the x-direction by shear strain, which is about the x-axis, is fairly independent of temperature over a limited range. (Thus the X cut crystals are most useful in applications like gramophone pickup, microphones and similar transducer applications.)

Prominent piezoelectrics

A few more prominent piezoelectric crystals that emerged in the late forties were: ammonium dihydrogen phosphate or ADP ($NH_4H_2PO_4$), potassium dihydrogen phosphate or KDP (KH_2PO_4), ethylene diamine tartrate or EDT ($C_6H_{14}N_2O_6$) and dipotassium tartrate or DKT ($K_2C_4H_4O_6.\frac{1}{2}H_2O$). Since ADP is free from water of crystallisation it does not dehydrate and can handle relatively high acoustic power without breakdown. Its stability is considerably high and hence it is in great demand for ultrasonic transducers in underwater applications.

Well over 1000 piezoelectric crystals have been identified due to the fact that 21 out of the 32 crystal systems are capable of exhibiting piezoelectric effect. Of these, very few find their way to the market. Polycrystalline ferroelectric ceramics such as leadzirconate titanate, lithium niobate, lithium tantalate, cadmium sulphide, zinc oxide, etc, have found their applications in less prominent areas. If lithium niobate were not so temperature-sensitive, it would have easily superseded the all-powerful quartz crystals. Even so, lithium niobate is of considerable importance for electro-optic purposes. Materials like CdS and ZnO can be evaporated or sputtered on to a suitable substrate which makes them notable amongst the other potential piezoelectric members.

The origin of the word 'piezo' is in the Greek word 'piezein' (to press). All piezoelectric materials are crystalline in structure and anisotropic in many properties such as thermal conductivity, cubical expansion and dielectric constant (non-piezoelectrics are invariably amorphous and isotropic), in addition to their unique optical properties. Piezoelectrics can be classified into pyroelectrics and ferroelectrics. Pyroelectrics generate electricity by heat. Ferroelectrics have a domain structure and show a well-defined hysteresis like ferromagnetic materials. PZT series of devices by Clevite Corporation, USA and PXE series by Mullard in the UK are the examples of ferroelectric devices.

Quartz is the most widely used piezoelectric material. Chemically, quartz is silicon dioxide (SiO_2) which crystallises in the trigonal trapezohedral structure. Quartz crystals have an axis of three-fold symmetry, i.e., the distribution of the molecules is such that rotation through 120 degrees about one of the axes brings into identical conditions and surroundings. Quartz melts at 1750°C. Large single crystals are found in nature, principally in Brazil. Due to the extensive research during the 1950s, large synthetic crystals of high purity can now be grown by the hydrothermal process which has replaced almost all natural crystal slots.

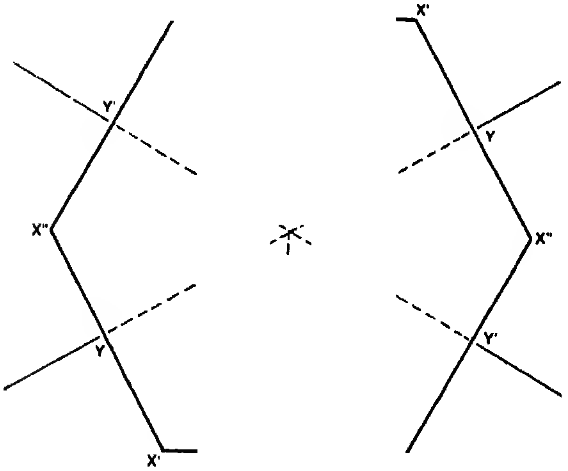
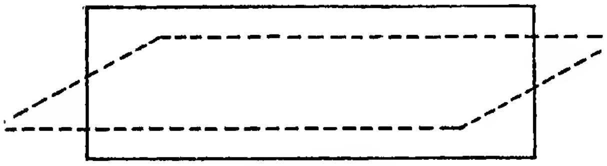


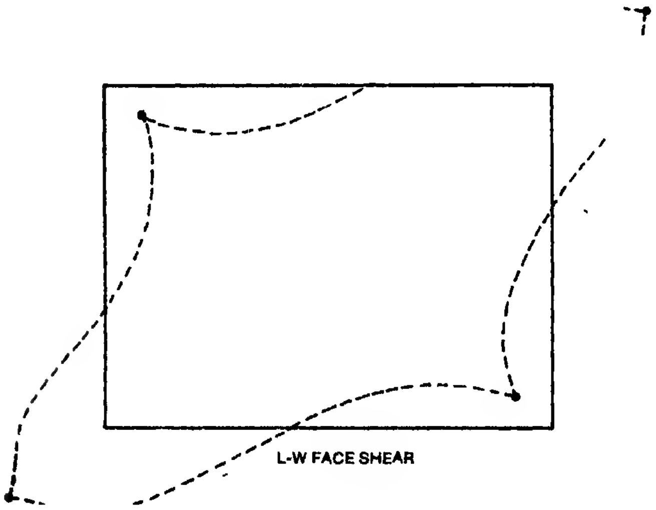
Fig. 2: Axes of natural quartz (z axis perpendicular to the plane).

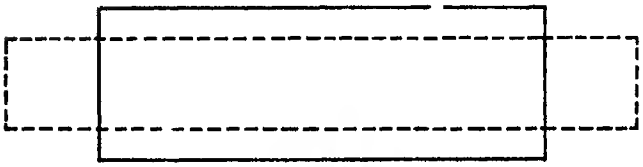
Natural and cultured quartz wafering is done using modern slurry saws and the crystal cuts are precisely oriented with respect to the three crystallographic axes. Tolerances in the planes are held much below two minutes of an arc. Wafers typically range from over 2 mm to 0.1 mm of thickness. Crystals are dimensioned to a wide variety of specifications by employing surface grinders, blanchard grinders and rounding equipments. Flatness and parallelism are achieved with the help of double-sided planetary lapping machines. These have a tolerance of ±10 millionth of a centimetre. Surface finishes range from 1 to 40 microns. Crystals with tighter angle specifications are manually X-rayed on a pendulum diffractometer. Tolerance in this final production step ranges from ±5 minutes to +10 seconds of an arc.

Modes of mechanical motion

The physical dimensions of the crystal give rise to four different modes of mechanical motions in quartz crystals. They are, thickness shear, face shear, extensional mode and flexure mode (Fig. 3). Shear stress has a turning effect owing to the formation of a couple with a definite force. The crystal does not collapse in this strained equilibrium position due to the balancing effect of the opposing couple inside the material provided, the elastic limit is not exceeded. (It is appropriate to recall the popularity of the quartz fibres here. Quartz fibres are very fine but strong and have high precision elastic properties. The celebrated experiment to measure the universal gravitational constant by Cavendish in 1798 was reformed by C.V. Boys in 1895 by using the quartz fibre as suspension medium for the pendulum. Dr F. Dolezalek used quartz fibres in the construction of the quadrant electrometer. The only alternative ever developed to this approach is phosphor-bronze strips).


THICKNESS SHEAR


L-W FACE SHEAR


EXTENSIONAL

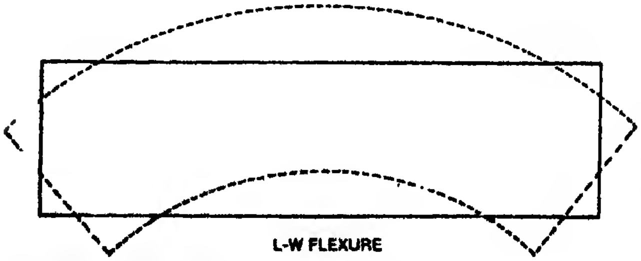

L-W FLEXURE

Fig. 3: Modes of vibrations.

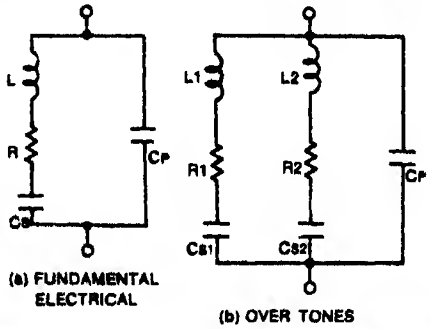
Shear force can introduce deformations in thickness and facial symmetry. The extensional mode arises due to the longitudinal expansion and contraction of the crystal structure. In flexure mode, the crystal vibrates as if it is a stretched string plucked at the centre and released.

In all these modes, the frequency stability is directly related to the amplitude of vibration of the crystal. The frequency stability nosedives with the increase in amplitude. The current passing through the crystal, therefore, has to be carefully controlled to restrict the amplitude of oscillation. Electronic technicians often call these crystals "elephants who do not forget any deed meted out to them in their life span."

An excess crystal current, even of the order of 0.01 per cent than its ratings, will upset its characteristics and this may introduce a chronic state where deviations may continue even after the excess is withdrawn. Worse still, the nature of deviation is largely unpredictable. On an average, the crystal takes few hours to retrace its original frame and sometimes may stretch beyond a few days.

Quartz as a capacitor

The electromechanical behaviour of the quartz crystal can now be summarised in another way. For a driving frequency less than the mechanical resonant frequency, the crystal behaves like a pure capacitor. At the mechanical resonance, its capacitance becomes infinitely large. At a frequency greater than the mechanical resonance, the crystal behaves like an inductor. This is what the electrical analogue of the crystal projects, as given in Fig. 4. In fact, the constituent



(a) FUNDAMENTAL ELECTRICAL

(b) OVER TONES

Fig. 4: Analogues of crystal. (a) Fundamental electrical. (b) Overtones.

elements represent the equivalents of mechanical parameters. A series combination of inductance, resistance and capacitance is representative of their mechanical counterparts such as mass, mechanical friction and crystal elasticity, respectively. The capacitance across this series chain is the distributed capacitance and is much higher than the series capacitance, Cs. Typically, Cs = 0.01pF, Cp = 1pF, L = 0.1 to 1 henry and R varies from 100 ohms to 100k. Consequently, the inductive time constant L/R is always much higher than the capacitive time constant CsR.

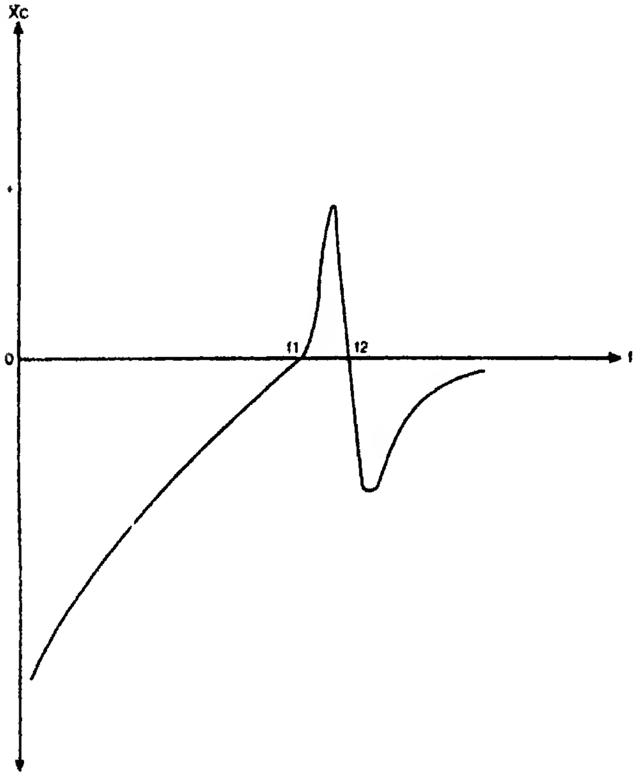
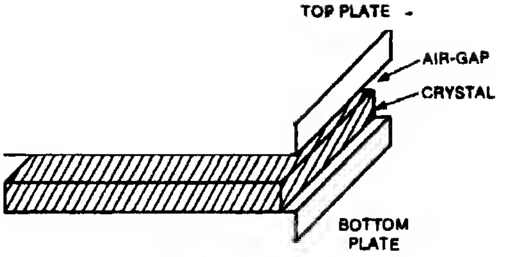


Fig. 5: Variations in crystal impedance with f.

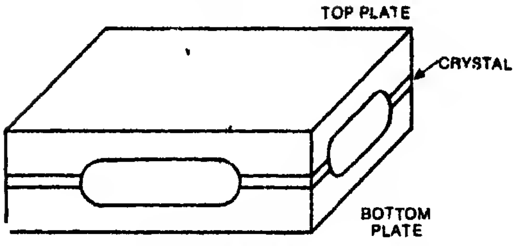
The parallel capacitance, Cp, also has a say in the frequency of oscillation of the quartz crystals though it is formed by the electrodes with quartz as the dielectric. It also includes the shunt capacitance of the crystal holder. The resonant frequency formed by Cp is slightly higher than the frequency due to the series capacitance. This frequency is known as the anti-resonant frequency of the crystal. Conversely, the series resonant frequency (where the reactance of the series arm nullifies the reactance of the distributed capacitance, Cp) nests slightly below the anti-resonant frequency. Corresponding resistive and reactive components and their variations at the resonant frequencies are presented graphically in Fig. 5.

Types of crystal mounting

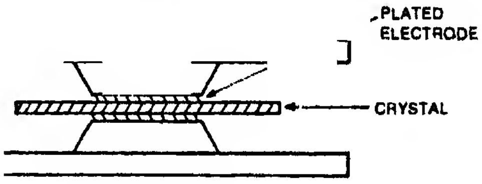
Most commonly used crystal mountings are air-gap mounting, pressure mounting, solder lead type mounting and cement lead type mounting. Air-gap mounting is used in



AIR-GAP MOUNTING

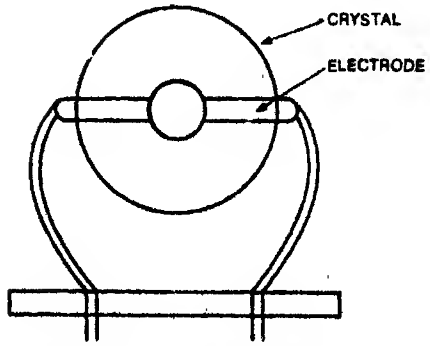


PRESSURE AIR-GAP MOUNTING



PRESSURE MOUNTING

SOLDER LEAD MOUNTING



CEMENTED LEAD MOUNTING

Fig. 6: Types of crystal mounting.

low frequency applications, preferably for A and B cut crystals. Pressure air-gap mounting is employed when the crystal length is much larger than its thickness as an alternative to simple air-gap mounting. Crystals operating in flexure, face shear and extensional modes prefer to have solder lead type mounting while the simple pressure mounting is adopted in extensional mode of operation. In these cases, electrodes are plated directly on the crystal faces and the leads are vacuum deposited. The additional weights included by the solder on the crystal will be helpful in fine tuning of their mechanical resonances. For ultra-high frequency shear mode crystals, cemented lead type mounting is more convenient. Apart from these popular approaches, there are various other techniques in vogue depending upon the specific requirements.

Crystals are placed in vacuum or any convenient inert atmosphere. Practically any inert gas can be used for this purpose. The pressure level inside the encapsulation will affect the amplitude of crystal vibration. A low pressure level is often preferred but it varies from type to type. This precondition places a number of restrictions on the metallic casing such as its tensile strength, coefficient of expansion etc. Flat high tensile strength metal casings in rectangular or circular configurations are available. Another version is the common plastic encapsulation, for extremely small size crystals, e.g., the TO-18 casing. In all these varieties, the lead length is kept as small as possible, especially in plastic encapsulation where the lead length is not more than 3 mm.

Standard crystal holders, usually designated as HCxx according to their dimensional specifications, are all hermetically sealed metallic versions. The subminiature low-frequency crystals introduced by Statek, USA, have a range of 10 to 1500 kHz. A 1MHz crystal is 48 times smaller in volume than the industry standard case HC33. The physical dimension of this subminiature crystal is only 6.99 × 2.74 mm. Crystals for wrist watches are mostly in cylindrical form, varying in diameter from 2 to 4 mm and in length from 5 to 8 mm.

Overtones

The electrical analogue shown in Fig. 4 is only an approximation with the least error and is valid at the vicinity of the resonance. There are, in fact, a few more resonances in the crystal. Hence, the arms of the series in the crystal appear to have some features identical to one another in terms of their basic structures. There exist a minimum of three or more odd mechanical overtones of the crystal's fundamental frequency. (Basically all the mechanical and electrical oscillations of fundamental frequency are accompanied by overtones. These are higher modes of vibrations which are, as a rule, harmonics of the fundamental mode. However, overtones produced by musical instruments need not necessarily be exact harmonics. Depending upon the mode of vibration, the first overtone may be the third or the second harmonics.)

Fundamental crystal parameters are indeed different from that of the overtones and large enough to have an effective isolation. Third, fifth, and seventh overtones have distinct characteristics and are extremely useful at higher frequency operations.

The series resistance of the crystal analogue has the vital and pervasive role in the crystal frequency of furnishing impedance and Q of the crystal. The equivalent series resistance decreases with increase in the crystal frequency. Typically, it varies from 450 ohms to 20 ohms corresponding to a frequency variation of 1 MHz to 30 MHz. The unusually large Q factor of the crystal which accounts for its frequency stability is directly related to the series resistance. An extremely large Q factor is indicative of the very low rate of energy dissipation in the crystal. In practical cases, it varies from 10,000 to 100,000.

It is often necessary to express the degree to which the mechanical resonance is coupled to the chain of distributed reactive elements of the crystal in an electrical circuit. This is termed as the electromechanical coupling ratio of the crystal unit. A fairly accurate expression of electromechanical coupling of the crystal evolves from the ratio Cp/Cs itself. Thus an enormously large ratio is possible if Cs is negligible. In the poorest of cases, Cp may decrease to a minimum due to the dielectric effect of quartz, thus diminishing the holder and external shunt capacitance. It is important to keep this ratio above 100, below which the resonance characteristics will deviate seriously. (The electromechanical coupling ratio or coupling coefficient is defined as the ratio of the mutual energy to the square root of the product of the primary and secondary energies. It can also be a measure of how much of the energy supplied in one form, such as electrical or mechanical, is stored in the other form.)

Fabrication techniques

Making application-specific crystals more attractive and easier to deal with is the use of new tools and computer-aided fabrication techniques whose developments have been hastened by the advances in computer technology. As a result, extremely high precision in crystal cuts and orientation angle is now possible. A brief schematic, in terms of the orientation angle, cuts and application is presented in Fig. 7.

The most commonly used cuts are AT and BT cuts which are also known as the rotated Y cuts. These are obtained by rotating the plane perpendicular to the Y axis (Y plane about the X axis). These are the kindest cuts in the world without drift. Zero temperature coefficient over a wide range is the key attraction of these two cuts. Thickness vibrations and their overtones exist for each individual mode, viz. A, B and C. Mode A is essentially the thickness extensional mode while B and C are thickness shear modes. The frequencies for each mode always follow in the sequence of increasing time period, i.e., Ta > Tb > Tc.

The frequency-temperature behaviour of the various quartz cuts is determined by taking into consideration the

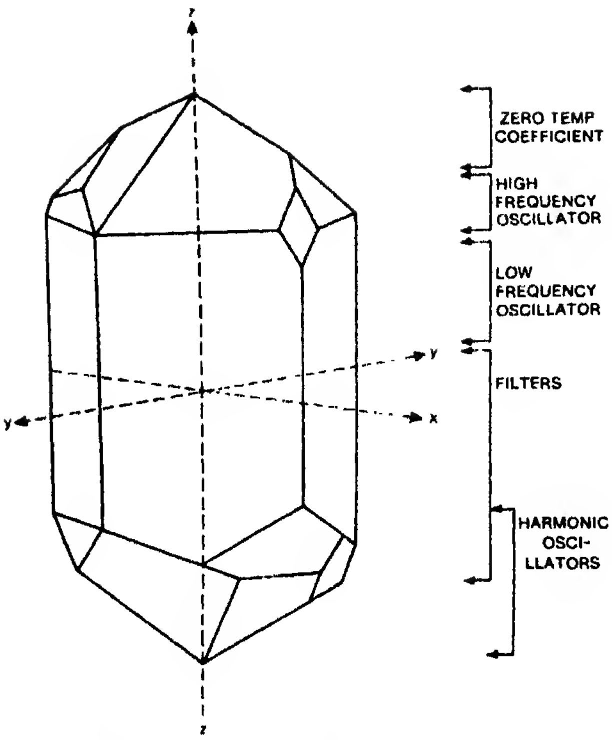


Fig. 7: Schematic showing the orientation angle, cuts and applications of crystals.

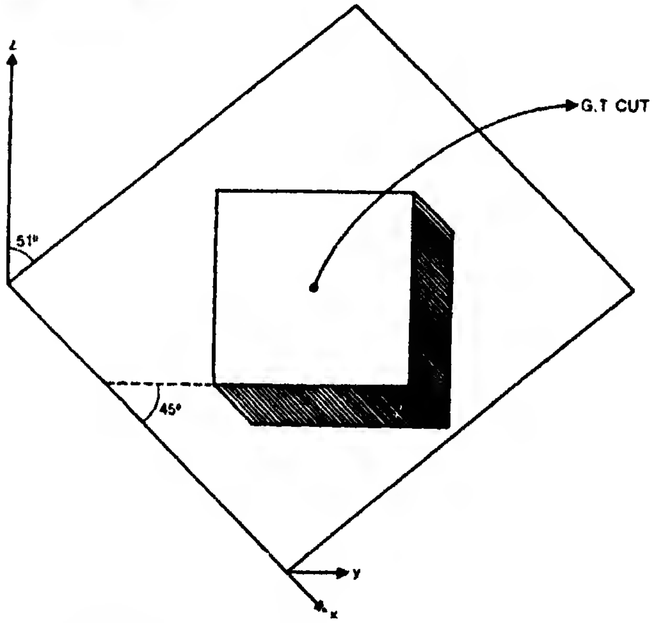


Fig. 8: Orientation of G.T. Cut.

higher order temperature coefficients of a power series. Mode A, basically a longitudinal mode, has a negative temperature coefficient of frequency for all orientations but at certain orientations (e.g., 35° 21') it reaches the minimum. Shear mode B has a first order zero temperature coefficient of frequency for orientations 0° to 13°, both on the negative side. The shear mode C has zero temperature coefficient of frequency for orientations 0° to 30° at both positive and negative angles.

Various types of crystal cuts are used in specific applications. A brief review is given in Table I. The temperature coefficient is measured by the frequency change divided by the centre frequency per degree celsius variation in temperature. This factor varies according to the crystal cuts. The frequency may either increase or decrease with an increase in temperature for a particular cut depending on the absolute value of temperature. The frequency temperature characteristics of each crystal cut will approach zero at a particular temperature. Conversely, the temperature coefficient can approach zero value at a given temperature by changing the nature of the element and its orientation angle. The deviations above this critical temperature are taken as negative.

TABLE I

Temperature stability of crystals cuts

Standard element	**Standard cut**	**Mode of vibration**	**Temperature stability ppm per deg. celsius**
A	AT	Thickness shear	- 0.05 for 35° 21' + 0.80 for 35° 13'
B	BT	Thickness shear	±4.4
C	CT	Face shear	± 3.5
D	DT	Face shear	± 2.0
E	+ 5°X	Extensional	- 7.0
F	- 18°X	Extensional	—
G	GT	Extensional	—
H	+ 5°X	l-w flexure	—
J	Duplex	l-t flexure	- 3.5
M	MT	Extensional	—
N	NT	l-w flexure	± 2.5

Crystal vibrations

Amplitude of mechanical vibration of the crystal influences the frequency stability, irrespective of the crystal cuts. The higher the amplitude of vibration, the poorer the frequency stability. So here we have an evident area for improvement, though little can be done with the rest of the parameters. The amplitude is directly proportional to the

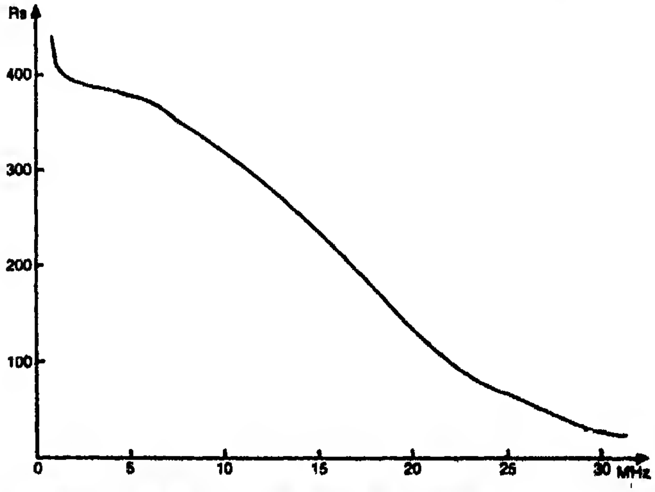


Fig. 9: Variation of Rs with resonant frequency.

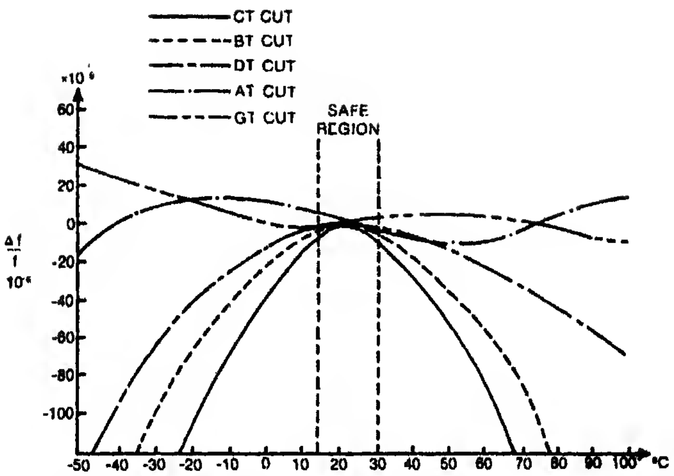


Fig. 10: Graph showing frequency deviation with temperature.

current through the crystal which means the crystal oscillators are most reliable at the minimum safe-operating current. According to present standards the fractional drift of a crystal oscillator is less than 10^{-10} Hz per day and the temperature sensitivity is less than 10^{-11} Hz per degree Celsius within the prescribed level of supply voltage. This is virtually insignificant compared to the average frequency drift of an RC or LC oscillator. The estimated RC is approximately 6×10^{4} Hz per day while that of an LC oscillator is 72×10^{-4} Hz per day. However, RC oscillators are absolutely unreliable beyond a frequency of 2 MHz. A brief comparison of RC, LC and crystal sections is given in Table II.

TABLE II

Frequency stability of basic sources**

Oscillator type	Frequency range MHz	Fractional drift per day	Thermal drift per deg. C
RC oscr	2	6×10^{-4}	5×10^{-5}
LC oscr (fund)	65	7×10^{-3}	5×10^{-5}
LC oscr (harmonics)	512	2×10^{-3}	4×10^{-5}
Crystal oscr (fund)	22	1×10^{-10}	1×10^{-11}
Cesium atomic	5	4.5×10^{-15}	

**Figures are approximate indicators.

There are various methods for desensitising the crystal oscillators from the temperature variations. One of them is to use a series reactance in the crystal circuit whose temperature coefficient cancels the temperature coefficient of the crystal. Another method commonly practised is the use of a voltage variable capacitor with a temperature-dependent bias such as a thermistor. A typical circuit employing this approach is given in Fig. 11.

For an extremely high degree of stability, thermostatically controlled ovens are used. Double ovens or an oven within an oven are not uncommon. When the oven temperature coincides with the critical temperature of the crystal, a near-zero temperature coefficient is achieved. In high precision applications, a suitable combination of above-mentioned methods is used. Finally, in any application, the proper choice of crystal cutting angle will decide the temperature coefficient of the crystal.

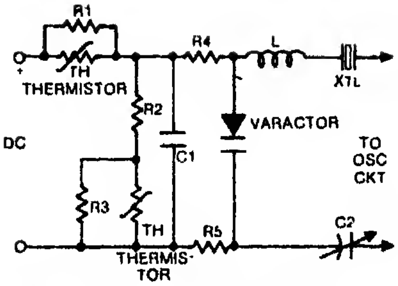


Fig. 11: Temperature compensation circuit.

The predominant factors of the clock or signal source are accounted not only by its precision in frequency in short and long run, but by several other factors also, such as duty cycle or mark-space ratio, impedance of the source, stability of the amplitude with respect to frequency and load, the range of frequency and so on. There is practically no such clock which satisfies all these requirements. Nevertheless, all these specifications are not inevitable for all the applications.

Deterministic fluctuations

Fluctuations in frequency due to ageing, deviations in ambient temperature and supply voltage, humidity variations, vibrations, etc are often referred to as 'deterministic' fluctuations, which are the major contributers to the short term stability. Short-term frequency stability is generally not an important consideration in RC oscillators and LC circuits. Fortunately, crystals can offer a very high degree of short-term stability merely by careful selection and mounting. However, long-term stability (nondeterministic), governed by random variations and shot and thermal noise is not fully covered in crystal oscillators. (Frequency of domestic supply has better stability in this respect.) The measures taken to ensure the long-term stability in crystals are broadly classified into two sections. One is to use special circuits for suppressing spurious modes of oscillations, especially in overtone crystals. The other method is related to crystal mounting and encapsulation.

Crystal—the undisputed leader

The crystal is the undisputed leader of signal and clock generators. Now it is moving on to an important, in some cases, dominant position in standard chips like memories, microprocessors and random logic. There are several reasons to support this move such as increase in precision, reliability and mean time between failures of the crystal based devices. It also removes the need for drift elimination or trimming, leading to an acute reduction in maintenance expenditure. With this, it is easy to incorporate diagnostic support for self-testing and remote-diagnosis in not-so-easily accessible devices.

Basically, any LC oscillator can be crystal controlled. The crystal can be used to set the frequency of operation with an adjustable LC or RC circuit used to trim the oscillator output to an exact frequency. The most popular formation is the Pierce oscillator, though Hartley, Colpitts and harmonic or overtone oscillators are equally favourable.

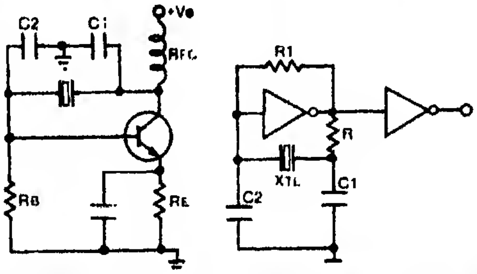


Fig. 12: The Pierce oscillator. (a) With transister. (b) With gate.

In a Pierce oscillator, no LC circuits are required for frequency control. Instead, the frequency is set by the crystal (Fig. 12(a) and (b)). At frequencies below 2 MHz, a capacitive voltage divider may be required across the crystal. The connection between the voltage-divider capacitors must be grounded so that the voltage developed across the capacitors is 180° phase-inverted. Moreover, like many other oscillators, these can also be set by single gate, transistor or op-amp configuration and the losses in the crystal be controlled by simple resistors. (Crystals reduce oscillator efficiency as a result of losses in the crystal which is represented by their series resistance. Oscillator efficiency may be increased by reducing signal currents in all dissipative elements.)

Minute trimmings and adjustments can make a big difference in the frequency of oscillation of the crystal circuits and drift and production tolerances can be effectively checked. A typical configuration is shown in Fig. 13. Frequency adjustments can be made with a variable inductor or capacitor in series with the crystal which provides a means for frequency tuning too. The lower limit of frequency is set by the inductor in series with the crystal. However, a reduced Q and an associated instability can be anticipated at lower frequencies.

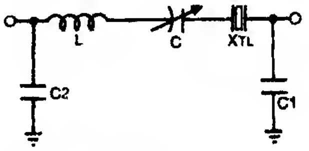


Fig. 13: Frequency correction circuit.

Crystal oscillator

The low frequency crystal oscillator shown in Fig. 14 uses capacitor C2 in series with the crystal for fine adjustments. The oscillator frequency increases with decrease in the series capacitance. The crystal is placed in the feedback circuit between the emitters of the two transistors and operated in the series mode. Another example of the series oscillator using inverter gates is given in Fig. 15.

The practical limit of the fundamental resonance is around 33 MHz. Higher order frequencies are derived by overtone operations or multipliers. From 20 to 60 MHz, third overtone crystals are used. Between 60 and 120 MHz, fifth overtones are used and above 120 MHz seventh overtones are preferred. Beyond 200 MHz, overtone operation is almost ineffective, leaving the task to frequency multipliers.

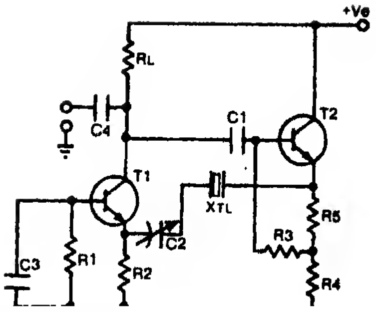


Fig. 14: Low frequency oscillator.

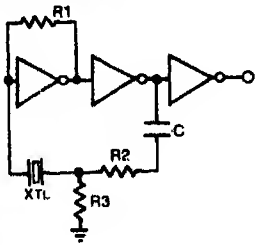


Fig. 15: Series oscillator.

In general, high frequency generation is not easy. It requires more critical adjustments to arrest the tendency of the circuit to oscillate at the lower overtones or frequencies. Specially designed filters and frequency selectors are pressed into use in the circuits of high frequency generation, primarily to avoid the overlapping of the frequencies.

A tuned LC circuit is a part of the overtone oscillators. The reactive elements of the LC circuit and crystal form a coupling network between the amplifier output and input producing the necessary phase shift. The crystal introduces an additional reactive element making extremely large phase shift changes for a very small frequency change. The inherent reduction in the efficiency is a foregone conclusion: An approximate picture of the power relationships between the fundamental frequency of the crystal and its overtones and harmonics is drawn in Table III. Extraction of harmonics from the overtones is rarely practised. Another critical area is the close proximity of the fifth and seventh power

TABLE III

Power relationship between overtone and harmonics

R.F. power output as a percentage of DC power input				
Crystal freq.	Fund	2nd harmonics	3rd harmonics	4th harmonics
Fundamental	32	15	10	5
3rd overtone	25	15	10	5
5th overtone	20	12	7	3
7th overtone	20	12	7	3

relationships.

With all the microcomputers, microprocessors, digital clocks and watches available today, it is surprising that time-keeping and signal clock generation is often so meticulous an affair. The fact is that the required circuitry is already incorporated in the IC, so that very few external components are called for. The design problem is also made easier by the fact that no timing fluctuations are involved as long as IC types are selected for the right speed to cope with the application in hand. To take care of the relative aspects of the price index, the present day ICs have included the provision for RC or LC timing networks in place of expensive crystals.

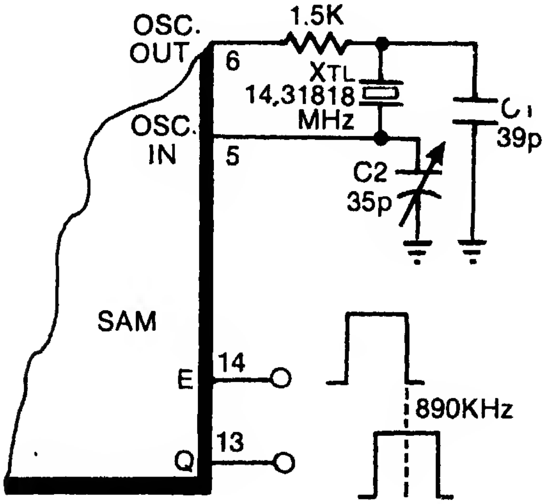


Fig. 16: TRS-80 colour computer clock.

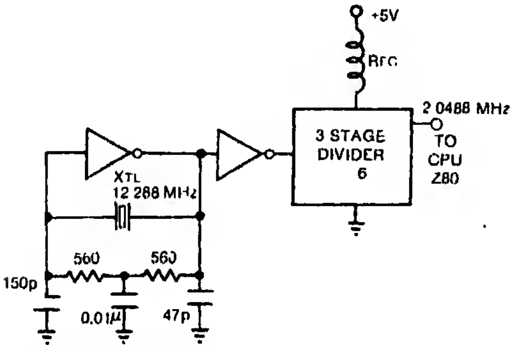


Fig. 17: H-89A system clock

Majority of the microprocessor or MPU crystal oscillator sections are designed to interface with an AT cut crystal, operated in a suitable mode in the frequency range specified for the crystal. The crystal should be mounted as close as possible to the input pins to minimise the output distortion and start-up time. The start-up stabilisation time plays an important role in the operation of the microprocessors. The built-in 'power on' circuitry provides a definite delay from he time of the first oscillator pulse. If the external reset pin is low at the end of the set time delay, the processor remains in the reset condition.

MPU crystals are treated as special brands and marked by their low series resistance, tight frequency setting, stable frequency tolerance and excellent long-term stability. Reliability is assured by the use of MIL-approved manufacturing processes. All the MPU or processor crystals feature low start-up resistance. MPU crystals are used in baud rate generators, bit rate generators and dual baud rate generators. MIL specifications related to the QPL crystals are MIL-0-55310, MIL-C-45662A, MIL-I-45208A, MIL-Q-9858A, MIL-C-3098F and MIL-F-18327. These standards define prerequisites to cope with humidity, vibration, shock and radiation effects.

(To be continued)

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