PIEZO ELECTRICITY

It sparks when you hit it. Well, that's not an altogether bad description of the Piezo Electric effect, but these crystals can do a whole lot more as Ian Sinclair explains.

PIEZO ELECTRICITY HAS been with us for some time, and yet we seem to keep meeting new applications of this remarkable effect. How is it that we can use the crystals to generate sparks, to convert vibration into electrical waveforms, to stabilise the frequency of oscillation, or to make precise electrical wave-filters? Here's how — just switch off that soldering iron for a minute or two.

By this time, you should be getting used to the idea that most materials form crystals. Crystals are regular arrangements of atoms, probably the most perfect structures we know, but that doesn't mean that the structures are exactly alike in each direction. The key word here is isotropic. •An isotropic crystal has the same properties in any direction (Fig. 1). Properties in this case means measurable quantities like electrical conductivity, heat conductivity, expansion coefficient, elasticity and all the other measurable quantities which fundamentally depend on how atoms are arranged.

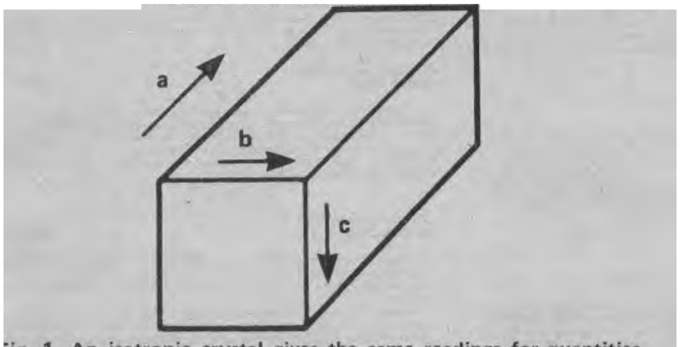


Fig. 1. An isotropic crystal gives the same readings for quantities ike expansivity, resistivity, etc., in any direction along the crystal. a, b, or c.

Crystal Clear

An isotropic material is mercifully easy to make measurements on, because you don't have to choose any special direction in the material. The materials we call anisotropic (meaning not isotropic) aren't like this, though, how they behave depends on which direction we choose to work on. Wood is a simple example, everyone who has ever worked on a piece of wood knows how differently wood cuts across the grain as compared to along the grain.

Many crystals are anisotropic, because the spacings between atoms are quite different in different directions along the crystal. The result is that each quantity that we can measure will have different values, depending on the direction that we choose in the crystal.

Now when a crystal is anisotropic, it usually behaves in a peculiar way in a strong electric field. Any material will be affected by a strong electric field; usually what happens is that the material has some electrons separated off, starts to conduct, then sparks across. Some very anisotropic crystals behave differently, their atomic spacings re-arrange themselves a bit. When this happens there is no way the crystal can be the same size as it was before, because the size of the crystal is decided by the size of the atoms and the way they are arranged. Usually what happens is that the atoms move slightly closer to each other *in one direction* so that the crystal becomes slightly shorter in that direction. The dimensions of the rest of the crystal may remain unchanged These changes of length are very small, but they're certainly not undetectable.

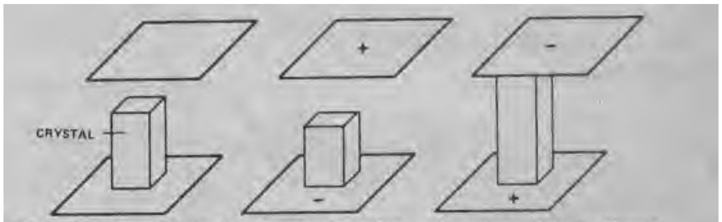


Fig. 2. The drawing's an exaggeration, of course, but it shows the idea. Piezo-electric crystals become shorter in one direction of electric field and longer when the field is reversed.

What makes the process more interesting is that if an alternating electric field is applied to the crystal, it will become longer and shorter alternately, in phase with the field. How do we apply an alternating field? Simple enough, we simply sandwich the crystal between metal plates and connect an alternating voltage between the plates. Since we usually want the distance between the plates to be very small, the usual way of achieving this is to deposit a metal, usually silver, on opposite faces of the crystal, making sure that we have chosen the right direction in the crystal.

With a crystal treated in this way, an alternating voltage across the metal conducting will cause vibration, with the crystal length becoming longer and shorter at the frequency of the AC. This is a piezoelectric transducer, which will vibrate at the frequency of the AC signal and pass on the mechanical vibration to anything in contact with the crystal. Cementing one face of the crystal to a diaphragm creates a piezoelectric tweeter, a loudspeaker unit which will give out a sound wave from the large surface of the diaphragm which is being vibrated by the crystal.

Fast Movers

There's no reason to stick to frequencies in the audio range of 30 Hz-20 kHz though. The crystals themselves can vibrate quite happily at much higher frequencies, even up to several MHz. In this way we can have ultrasonic tweeters, giving out invisible beams of air vibration like sound but at frequencies too high to hear. The favourite frequency range is around 35—65 kHz, because the vibration of the 'crystal can be transferred to air reasonably easily in that frequency range.

Any material that is in contact with the crystal will be vibrated along with it, though, so that this ultrasonic vibration has many applications...One is non-destructive testing. A piezoelectric crystal vibrates a sample, perhaps a metal casting, and the path of the beam of vibration through the material is traced, using another piezoelectric crystal as a detector. An invisible flaw inside the material causes the beam path to be unaccountably shifted, so that the material can be rejected. This principle is used widely, along with X-ray methods, for detecting holes and faults in metal. casting, particularly if the casting is valuable or if its failure could cause likes to he in danger. They don't bather too much with things like the kick-start cranks of motor bikes, though!

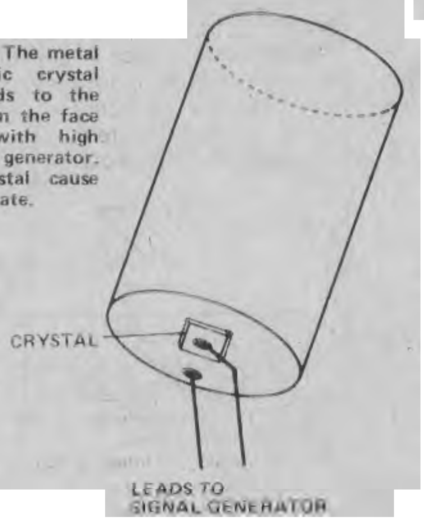


Fig. 3. An ultrasonic cleaner. The metal beaker has a piezo-electric crystal soldered to the base. Leads to the beaker and to the contact on the face of the crystal are fed with high frequency signals from the generator. The vibrations of the crystal cause the liquid in the beaker to vibrate.

Clean Sound

Ultrasonic cleaning is another widespread use of ultrasonics. A piezoelectric crystal is mounted on the base of 8 metal beaker, so that it will vibrate any liquid in the beaker — the liquid can be water or any grease solvent like benzene, and anything placed in the vibrating liquid will be thoroughly cleaned with no need for scrubbing. Of course, you've all got cheap digital watches and probably don't remember the old fashioned tick-tock type, but ultrasonic cleaning Was the standard method for cleaning these things. Using an ultrasonic cleaner meant that the watch didn't have to be taken apart, so saving an immense amount of time and skilled work.

A piezoelectric crystal with quite a different type of application is the quartz crystal. Quartz crystals are prepared in just the same way as the barium titanate crystals of ultrasonic cleaners, but the aim is not to harness the mechanical vibration but to make use of the electrical behaviour of the crystal. Any insulator with a couple of metal contacts on opposite faces is a capacitor, but the materials we usually make into capacitors are not piezoelectric; so that the capacitor behaves, well, just like a capacitor.

A capacitor made from a piezoelectric material is rather special, though, because electrical energy is converted into mechanical energy of vibration when the crystal is driven by an alternating voltage. This , in turn, alters the electrical behaviour A good comparison is a loudspeaker speech coil which may measure 6 ohms on a meter, but whose apparent resistance, equal to AC volts divided by AC amps, can change considerably from one frequency to another because of the transfer of energy from the coil to the core.

An ultrasonic transducer utilizing the piezo electric effects.

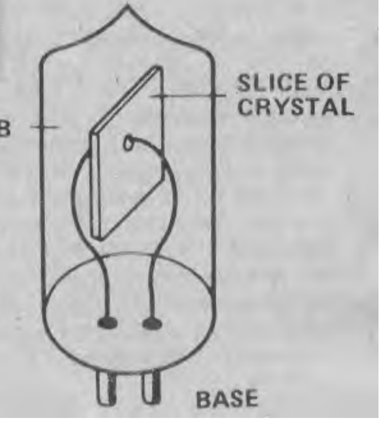


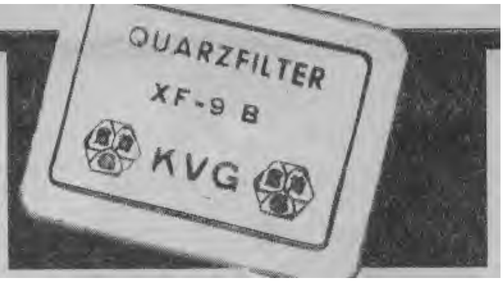
Fig. 4. A quartz crystal inside an evacuated bulb. This is a type of mounting used for crystals that control radio transmitter frequencies.

The crystal and the loudspeaker also show the effects of resonance. At one particular frequency, the energy converting process is very much more efficient than it is at other frequencies, so that a very large amount of vibration can be caused by a very small amount of electrical energy Now this resonance is the same sort of effect as we get when an inductor and a capacitor are connected together either in series or in parallel, but with one important difference Mechanical resonances are usually very sharply tuned, with a very small bandwidth, a quantity which is measured by the Q' factor of a tuned circuit. Q factors of 100 to 250 are considered pretty good by the standards of electrical tuned circuits, but mechanical resonances can achieve O values of 30,000 or more.

Crystal gazing

All of that prepares us for the tact that the quartz crystal behaves electrically like an incredibly efficient tuned circuit. At a frequency well below the frequency of mechanical resonance, the whole thing behaves like a capacitor. with a value of reactance which decreases as the frequency is increased, and a 90° phase shift, current leading voltage. This behaviour keeps up until near the frequency of resonance when the crystal starts

Various types of crystals used in radio equipment. The one on the right is a 100KHz unit used for frequency marker generators.



PIEZO

A crystal filter centering on 9MHz.

to behave as if it had a resistor connected in parallel with the capacitor, allowing more current to flow, and reducing the phase shift. At the first peak of resonance, the crystal behaves for AC like a small value resistor, with no phase shift. This peak is called the series resonant peak. As the frequency of the signal across the crystal terminals is raised, the resistance rises, the phase shifts violently again and at a frequency a few kHz higher than the series resonant frequency another resonance occurs. This time the crystal behaves like a parallel resonant circuit, and at the peak of resonance the resistance appears now to be very high, once again with no phase shift. At higher frequencies still, the crystal behaves like a capacitor again. with a 90° phase shift, current leading voltage.

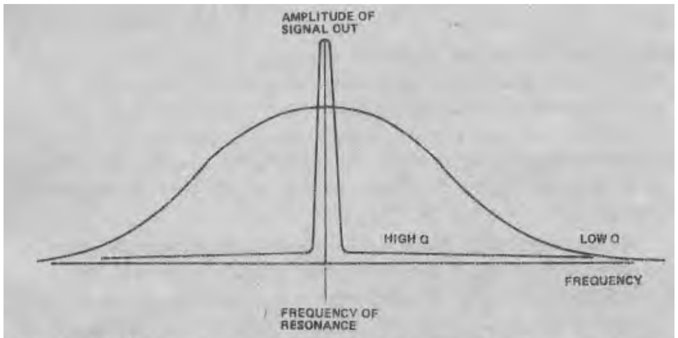
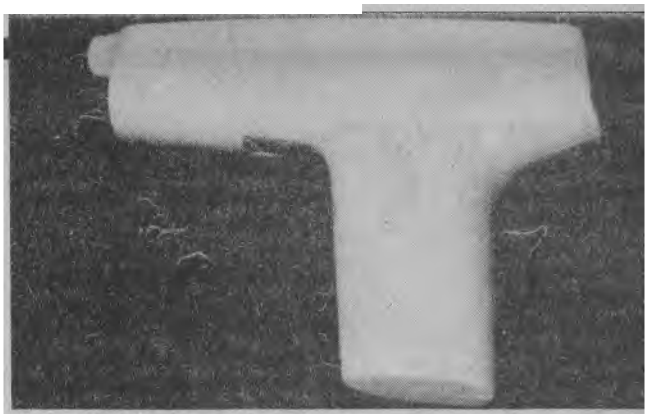


Fig. 5. Q-factor of a tuned circuit. A high-Q tuned circuit tunes sharply to one frequency, so that there is very little output at other frequencies.

All of this leads to crystals being used in oscillator circuits which can maintain a very precise frequency--used for applications as diverse as digital watches and radio transmitters. In addition, crystal filters can be designed which will pass only a very small bandwidth around a selected frequency.

Quartz crystals intended for osiliators are never driven very hard—too much vibration could split the crystal--but the vibration can be used. The piezoelectric effect can work both ways however, particularly in ceramic crystals and if we put a second set of electrode plates onto a ceramic crystal then a mechanical vibration of the crystal will cause an alternating voltage to appear across these additional plates. This arrangement can be used as a very efficient filter, passing only a narrow bend of frequencies around the resonant frequency of the crystal. This can permit the use of untuned (IC) amplifiers, with just a couple of these ceramic filters providing the tuning. In addition, the removal of unwanted frequencies is much easier than when coil-capacitor tuned circuits are used.



An anti-static gun using piezo electricity to generate a high voltage.

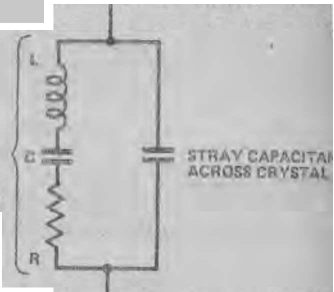


Fig. 6. Equivalent circuit of a crystal — this circuit would behave electrically just like a crystal if we could ever get suitable components for L, C and R.

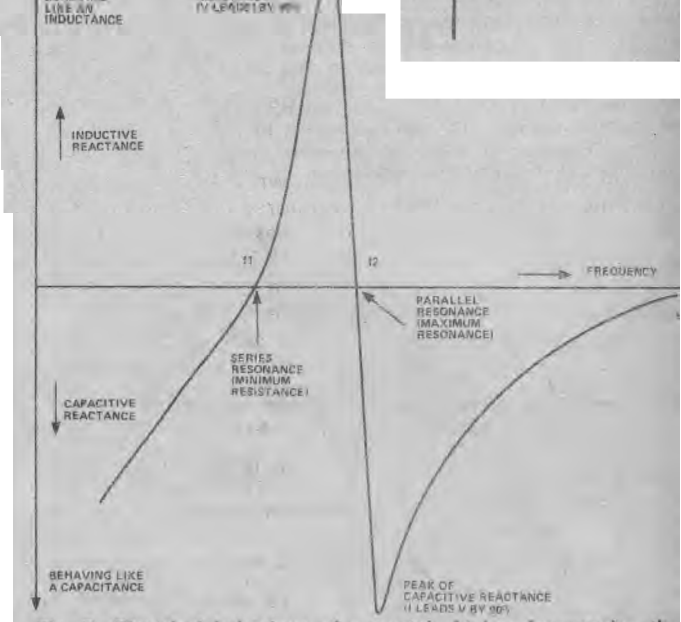


Fig. 7. Electrical behaviour of a crystal. At low frequencies, the crystal behaves like capacitance, with its reactance decreasing until it reaches zero at f1, the frequency of series resonance. Just about this frequency, the crystal behaves like an inductor, reaching a peak of reactance which then reduces to zero again at f2, the frequency of parallel resonance. The crystal then behaves like a capacitor again, with a peak of reactance occurring before the normal capacitor reactance curve is resumed.

The fact that the effect works the other way around—with mechanical vibration causing an electrical output—has, of course been the basis of ceramic gramophone pickups for many years. Less well known is the application of the same transducers to measure speed and acceleration of aircraft and missiles. The transducers give a voltage proportional to acceleration, and analogue computers transform this into readings of speed and distance. In addition, the transducers which are used as ultrasonic sources can also be used as receivers for the same frequency, so that ultrasonic burglar alarms are possible.

The familiar piezoelectric gas lighter is yet another example of these crystals in use. A barium zirconate crystal can give an enormous voltage, 20kV. or more, when it is hit hard enough. These gas lighters pull a hammerhead back against a spring and then suddenly release the lot on the unsuspecting crystal. Result is a sudden pulse of voltage, enough to produce a spark across a gap. Sparks, squeaks and squeezes; they're all part of the piezoelectric story!