Electrets in Audio

Electrostatic 'phones are generally acknowledged as the best but need a high voltage supply. Now, electret headphones are claimed to have the same performance without the need for a separate supply. Cartridges and microphones too now use electret technology.

But what exactly are electrets? What do they do and how do they work? And did you know you can even make your own? Ian Sinclair explains. .

IN its simplest form, a capacitor consists of two parallel metal plates insulated from each other by air or some other non-conducting material between the plates. If an electric charge, meaning a few electrons, is taken from one of the plates and put on the other, so (charging the capacitor) a potential difference will appear across the plates.

The ratio of the amount of charge to the value of voltage is the quantity which we call capacitance. The relationship can be described more formally as Q=CV, where C is the capacitance in farads, Q is charge in coulombs, and V is the voltage in volts (see Fig. 1). When a capacitor has charged, the charge will remain unless conduction between the plates allows the electrons to travel back to where they started. While the capacitor is charged, energy will store in the form of an electric field between the plates.

For any simple capacitor of this type, the value of capacitance is proportional to the area of the plates and mathematically this is:—

$$C = \frac{\epsilon_o A}{d}$$ (see Fig. 2)

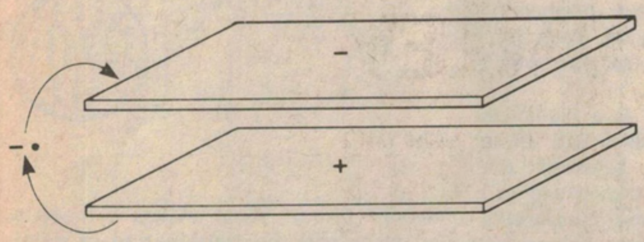
The above formula is correct only where the plates are separated by air. If any other material is used, then a numerical multiplier, called the relative permittivity, of this constant will also appear, making the formula:

$$C = \frac{\epsilon_o \epsilon \gamma A}{d}$$

In each of these formulae, A represents the area of overlap of the plates in square metres, and d is the spacing between the plates in metres. The effect of the relative permittivity is to increase considerably the capacitance between two plates which were formerly air-spaced.

The reason for this behaviour of inulating materials is that the electric field between the plates of the capacitor acts on the atoms of the dielectric, that is the insulator which is placed between the plates, so that there is a force trying to separate the electrons from the remainder of each atom in a direction which is towards the positive plate of the capacitor. These electrons cannot shift very far; if they could, the material would not be an insulator but a conductor. The result of this slight shift is to "polarise" each atom or molecule, meaning that one end of the molecule is slightly negative and the other end slightly positive, and the amount of this polarisation which takes place depends very much on how the atoms of the material are constructed.

Polarisation causes another electric



QUANTITY	SYMBOL	UNITS
CHARGE	Q	COULOMBS
VOLTAGE	V	VOLTS
CAPACITANCE	C	FARADS

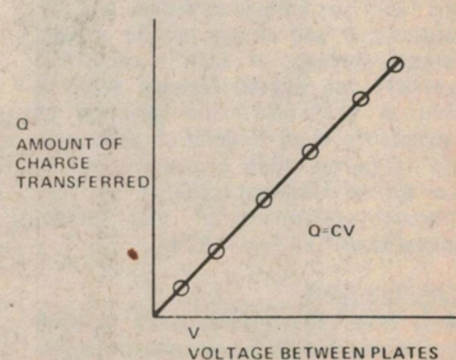


Fig. 1. The parallel - plate capacitor. (a) Charging consists of shifting electrons from one plate to the other. (b) A graph of charge transferred plotted against voltage is a straight line and its slope is the value of capacitance.

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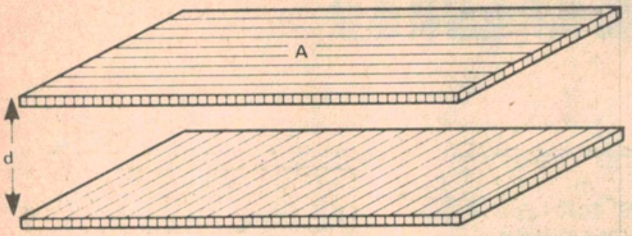


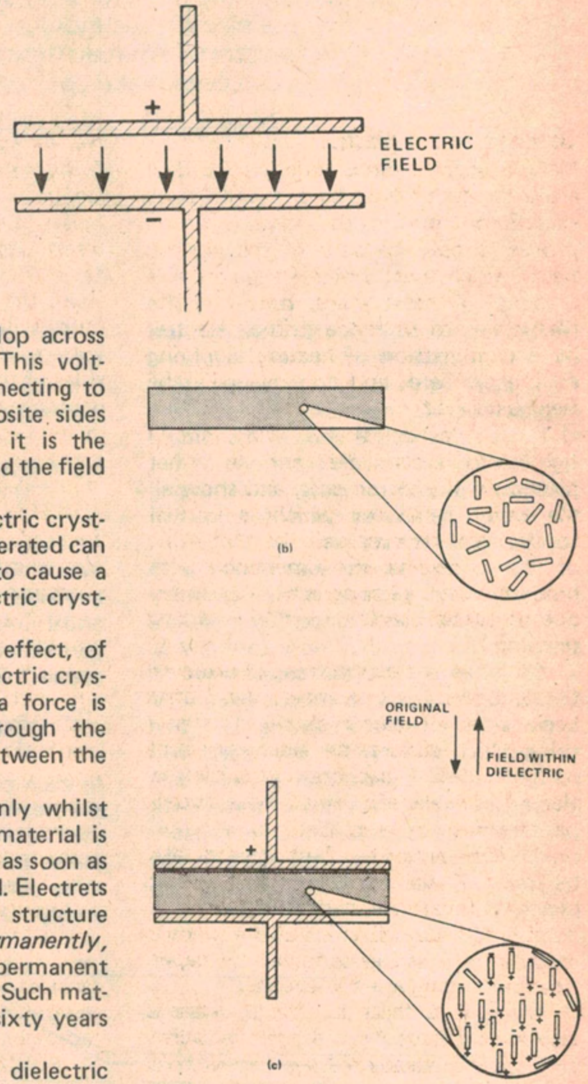
$$C=\frac{\epsilon_0 A}{d}$$

QUANTITY	SYMBOL	UNITS
CAPACITANCE	C	FARADS
AREA	A	METRES^2
SEPARATION	d	METRES
PERMITTIVITY OF FREE SPACE	ϵ_0	FARADS/METRE

$\epsilon_0 = .0895$ F/m

Fig.2. Capacitance values. The value of capacitance of a parallel-plate capacitor is decided by the area of the plates and the spacing (when no dielectric is used). Tubular capacitors are simply parallel plate types, with a thin film dielectric, which are rolled up with another layer of insulation.

Fig.3 (Below). Dielectrics. (a) The electric field between the plates of a capacitor. (b) Representing a dielectric; the molecules are randomly arranged. (c) In a polarised dielectric, the direction of the field inside the dielectric opposes the field (of the capacitor plates) which has created it.



field to appear, this time inside the material and in the opposite direction to the field between the plates. Because these two fields are in opposite directions, their effect subtracts, and the total electric field between the plates is less than it would be if the dielectric were not present. Because the field is less, so is the voltage and so the capacitance is *greater.*

Sensitive to size

The use of dielectrics in this way makes it possible for us to manufacture capacitors of comparatively large values in a reasonably small size, but can cause problems, one of which is voltage sensitivity.

We may find, for example, that the amount of the shift between the atom and the electrons of the dielectric varies with the voltage we apply to the plates of the capacitor, in which case the amount of polarisation will change as the voltage is changed. A capacitor like this will be voltage-sensitive, and its capacitance will change as the applied voltage changes. If such a capacitor, typically the high-K ceramic type, is used as a by-pass, this variation of capacitance is of no great consequence, but it makes such capacitors useless for tuning resonant circuits. A very thorough treatment of this subject appeared in ETI April 1976.

Causing a spark

Most observable effects work in both directions, and dielectrics are no exception. In this case, the opposite of the normal action of the dielectric occurs in piezo-electric crystals, where we apply a force which shifts atoms slightly out of place relative to their electrons, and cause a voltage to develop across the crystal of the material. This voltage can be detected by connecting to metal plates formed on opposite sides of the crystal. In this case it is the force which causes the field, and the field which then causes the voltage.

In many types of piezoelectric crystals, the voltages which are generated can be quite high, high enough to cause a spark, which is why piezoelectric crystals can be used as igniters.

Another variation of this effect, of course, is the familiar piezoelectric crystal pickup cartridge, where a force is applied from the stylus through the cantilever, and the voltage between the plates is the signal output.

Piezoelectric effects last only whilst the normal structure of the material is distorted, and they disappear as soon as normal conditions are resumed. Electrets are materials which have a structure which has been changed *permanently,* and which therefore have permanent amounts of charge displaced. Such materials have been known for sixty years or so.

If we use an electret as a dielectric in a capacitor then there will be a permanent dc voltage between the plates of the capacitor, though we will not be able to draw any measurable current if the plates are connected together.

There are many materials which have molecules with a natural and permanent polarisation, water is one of them, yet are not electrets. The reason is that in such materials these permanent polarisations are not held in one particular direction, so that the electric fields which are caused by one molecule simply cancels each other out, with no overall effect. What makes a material an electret is the combination of a polarised molecule with a fairly low melting point and a very high resistivity, so that the material can be heated, the molecules brought into line by an external field, and the material allowed to solidify again so that the molecules are permanently "frozen" into position again. The high resistivity then ensures that there is no movement of charge which could reverse the process.

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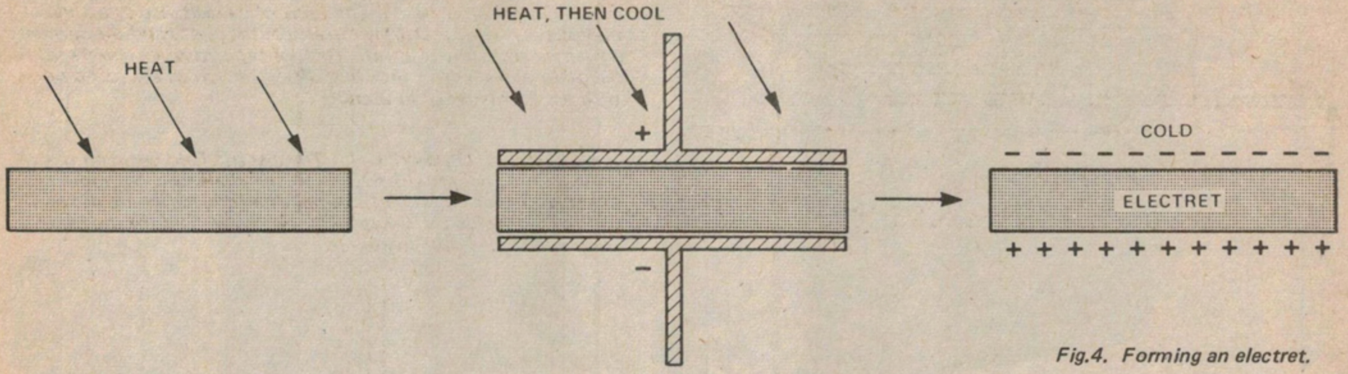

Fig.4. Forming an electret.

Getting into hot plastic!

Many modern plastics materials are ideal electrets, some even have their charges established during the manufacturing process simply because of the electric fields which exist while the material is cooling. In most cases, however, the plastic has to be made into an electret by a combination of heating, applying an intense field, and cooling while the field is applied.

Such plastics sheets will "stick" tightly to each other and to other plastics, will pick up dust, and show all the other behaviour which is normal to electrets. (It may well be that some of the problems we experience with modern vinyl phonograph records are due to partial electret formation during pressing.)

As far as the applications of electrets to electronics is concerned, these arise because an electret is sensitive to anything which disturbs the arrangement of its molecules. A capacitor containing an electret as dielectric, for example, should be sensitive to vibration, i.e. microphonic. The opposite effect should also be true; if we apply ac between the plates of an electret capacitor we should be able to cause vibration of the electret material (if it is free to move) the capacitor thus acting as a loudspeaker.

As well as these ac effects, there is also a dc effect. Any electret capacitor will have a steady voltage between its plates which is caused by the field which permanently exists across the electret.

This voltage can be detected only by an electrostatic voltmeter or by a very high input resistance electrometer, because the internal resistance of the capacitor is extremely high. The voltage will change as the temperature difference between the surfaces of the dielectric material changes, and this is particularly obvious when the electret is struck by radiant heat; the effect is called the pyroelectric effect.

Hot air and telephones

A pyroelectric detector consists of an electret sandwiched between a solid metal plate and a metal gauze, or between two transparent conducting plates, with an electrometer connected between the plates. Changes in air temperature will not cause any change in the voltage reading if they affect both sides of the electret. If we shine radiated heat on to one side of the electret a difference in temperature will exist across the electret, causing a difference in voltage. The sensitivity is quite remarkable. Placing your hand at a distance of about 1 metre from such a pyroelectric detector radiates enough energy to cause a reading of about 1 V.

With some dc amplification, a temperature difference of a millionth of a degree caused by radiated heat can be detected, so that the pyroelectric effect has immense possibilities, for measurements. Even without amplification, detectors using the pyroelectric effect have applications in burglar alarms, fire alarms, detecting hot spots in machinery, even possibly for replacing fuses.

It was recently announced that some phone companies intend to replace the old, carbon microphone in telephones by an electret type, and presumably the earpiece will be replaced similarly. Some electret pickup cartridges have now appeared, but we still waiting for a range of electret loudspeakers which would need no polarising voltages and hence no ac supply.

Stock question

This is one of the fields of modern materials research in which it is possible for almost anyone to get into the act. So many modern plastics form electrets easily that it is not impossible to manufacture them for yourself, though the effort would hardly be worthwhile on a one-off basis. Ready made electret materials are by no means easy to obtain, though there is always a possibility of manufacturers of plastics sheeting for electronics use, or capacitor manufacturers, having small quantities in stock. (Perhaps one of our enterprising surplus dealers might be able to obtain some of this material.)

Finally, suppose one were able to manufacture capacitors with a permanent voltage across them, how much would this save us on high value bias resistors for FETs?

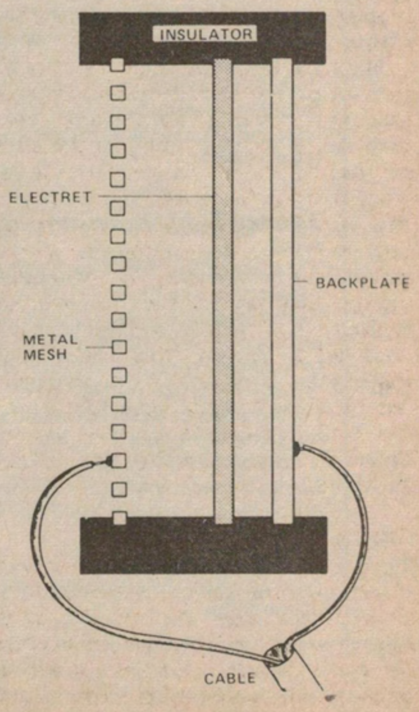

Fig.5. An electret microphone or loudspeaker in cross-section.