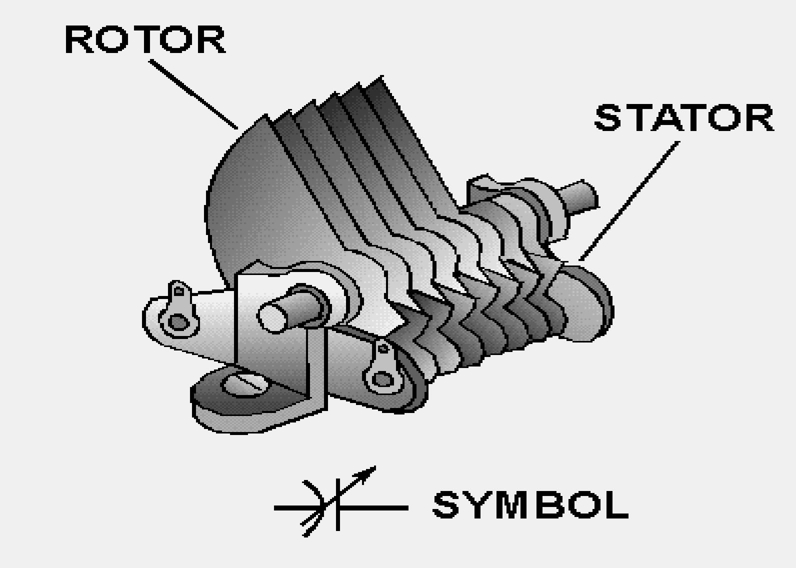
Tech Notes - Variable capacitors

A Variable Capacitor is one whose capacitance may be intentionally and repeatedly changed mechanically. Variable capacitors are often used in L/C circuits to set the resonance frequency, for example, to tune a radio (therefore they are sometimes called *tuning capacitors*), or as a variable reactance for impedance matching in antenna tuners. Can also known as a "variable air" capacitors. **The old name for a capacitor was condensor.**

Tuning capacitors:

A typical variable capacitor consists of two sets of metal plates arranged so that the rotor plates move between the stator plates. Air is often the dielectric. As the position of the rotor is changed, the capacitance value is likewise changed. This type of capacitor is used for tuning most radio receivers. A typical physical construction is shown below.



The capacitors pictured above, from left, include our 365 pF dual-gang variable, a 365 pf variable with 8:1 shaft reduction drive built into the shaft, a 365 pF with shaft extended with nylon parts to isolate the capacitor from the user, and a 365 pF attached to a 6:1 external planetary reduction drive.

Variable capacitors for tuning radio equipment are made in many formats and can be single gang type (the second and fourth ones above) but can have two three or four sections “ganged” in the same shaft. The fourth one above has a five to one reduction drive connected between the capacitor and the tuning knob to make tuning easier. Simple radio receivers will have a “dial drum” connected to a small diameter shaft to achieve the same aim.

The most common form of mechanically controlled variable capacitors, the amount of plate surface area which overlaps, is altered by the control shaft. They consist of a series of semicircular metal plates on a rotary axis **(“rotor”)** that are positioned in the gaps between a set of stationary plates **(“stator”)** so that the area of overlap can be changed by rotating the axis. Air or plastic foils can be used as dielectric material. By choosing the shape of the rotary plates, various functions of capacitance vs. angle can be created, e.g. to obtain a linear frequency scale. Various forms of reduction gear mechanisms are often used to achieve finer tuning control, i.e. to spread the variation of capacity over a larger angle, often several turns.

Miniature Plastic Tuning Gangs

The tuning capacitors (tuning gangs) pictured above are too large for most modern radios and so much smaller capacitors with plastic insulation material between the plates are now very common. Very cheap variable capacitors are constructed from layered aluminium and plastic foils that are variably pressed together using screws.

The one pictured here has only two sections and is used in AM radio receivers but there are others available with four or more sections for AM / FM type radios. The FM sections have a much lower capacity than the AM sections because of the much higher frequencies tuned.

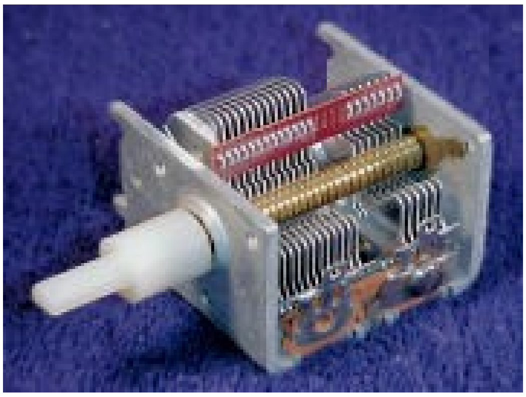
All tuned circuits need to have some way of presetting the capacitance value so the circuits are tuned to the correct frequencies at each end of the band being received. **Trimmer capacitors** are used for this and the two small holes in the right hand photo above allow access to two built in trimmer capacitors.

Multiple sections (referred to as Tuning Gangs)

Very often, multiple stator/rotor sections are arranged behind one another on the same axis, allowing for several tuned circuits to be adjusted using the same control, For example an RF Stage (preselector), a mixer stage and the corresponding oscillator in a high performance receiver circuit, three sections in total. Typical capacitance ranges for the gang in an AM radios is somewhere in the range of 330pF to 400pF and 25pF to 45pF for the FM section of a   receiver.

The sections can have identical or different nominal capacitances.

The tuning gang pictured below is typical of those used in AM radios before the introduction of FM broadcasts. The local oscillator generates an RF signal 455 KHz above that being received and this has caused some difficulties in design over the years as the RF and oscillator must track each other across the band, staying 455 Khz apart. Up to the 1960's identical sections were used in all tuned circuits of an AM radio and a **padder capacitor** was used to lower the maximum capacitance of the oscillator section so that circuit would track the Antenna input tuned circuits. As radios were made smaller tuning gangs with different sections were used. One such example is pictured below and all the miniature plastic tuning gangs are guilt this way.



Butterfly

A butterfly capacitor is a form of rotary variable capacitor with two independent sets of stator plates opposing each other, and a butterfly-shaped rotor arranged so that turning the rotor will vary the capacitances between the rotor and either stator equally.
Butterfly capacitors are used in symmetrical tuned circuits, e.g. RF power amplifier stages in push-pull configuration or symmetrical antenna tuners where the rotor needs to be “cold”, i.e. connected to RF (but not necessarily DC) ground potential. Since the peak RF current normally flows from one stator to the other without going through wiper contacts, butterfly capacitors can handle large resonance RF currents, e.g. in magnetic loop antennas.

In a butterfly capacitor, the stators and each half of the rotor can only cover a maximum angle of 90° since there must be a position without rotor/stator overlap corresponding to minimum capacity, therefore a turn of only 90° covers the entire capacitance range.

Split stator

The closely related split stator variable capacitor does not have the limitation of 90° angle since it uses two separate packs of rotor electrodes arranged axially behind one another. Unlike in a capacitor with several sections, the rotor plates in a split stator capacitor are mounted on opposite sides of the rotor axis. While the split stator capacitor benefits from larger electrodes compared to the butterfly capacitor, as well as a rotation angle of up to 180°, the separation of rotor plates incurs some losses since RF current has to pass the rotor axis instead of flowing straight through each rotor vane.

Differential Variable Capacitor

Differential variable capacitors also have two independent stators, but unlike in the butterfly capacitor where capacities on both sides increase equally as the rotor is turned, in a differential variable capacitor one section's capacity will increase while the other section's decreases, keeping the stator-to-stator capacitance constant. Differential variable capacitors can therefore be used in capacitive potentiometric circuits.

Vacuum variable capacitor

A vacuum variable capacitor uses a set of plates made from concentric cylinders that can be slid in or out of an opposing set of cylinders (sleeve and plunger). These plates are then sealed inside of a non-conductive envelope such as glass or ceramic and placed under a high vacuum. The movable part (plunger) is mounted on a flexible metal membrane that seals and maintains the vacuum. A screw shaft is attached to the plunger, when the shaft is turned the plunger moves in or out of the sleeve and the value of the capacitor changes. The vacuum not only increases the working voltage and current handling capacity of the capacitor it also greatly reduces the chance of arcing across the plates. The most common usage for vacuum variables are in high powered transmitters such as those used for broadcasting, military and amateur radio as well as high powered RF tuning networks.

Electronically controlled (varactors or varicaps)

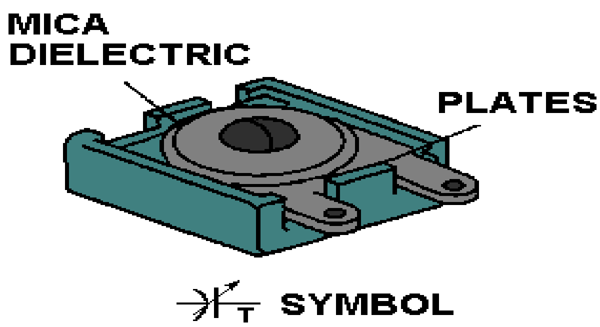
The thickness of the depletion layer of a reverse-biased semiconductor varies with the DC voltage applied across the diode. Any diode exhibits this effect (including p/n junctions in transistors), but devices specifically sold as variable capacitance diodes are designed with a large junction area and a doping profile specifically designed to maximise capacitance.

Their use is limited to low signal amplitudes to avoid obvious distortions as the capacitance would be affected by the change of signal voltage, precluding their use in the input stages of high-quality RF communications receivers, where they would add unacceptable levels of intermodulation. At VHF/UHF frequencies, e.g. in FM Radio or TV tuners, dynamic range is limited by noise rather than large signal handling requirements, and Varicaps are commonly used in the signal path.

Varicaps are used for frequency modulation of oscillators, and to make high-frequency voltage controlled oscillators (VCOs), the core component in phase-locked loop (PLL) frequency synthesizers that are ubiquitous in modern communications equipment.

Trimmer Capacitor

Trimmer capacitors come in all shapes and made in a variety of ways. The oldest and simplest consists of two plates separated by a sheet of mica. A screw adjustment is used to vary the distance between the plates, thereby changing the capacitance. These are often called compression trimmers and are not stable enough for very high frequency circuits or critical applications.



Pictured below is a selection of more modern trimmer capacitors:

Tech Notes - Variable capacitors

In addition to air and plastic, trimmers can also be made using a ceramic dielectric. The first two have plastic plates as a dielectric, the third has a ceramic material, these are very stable devices.

Much of the older communications equipment you will come across will have the Bee Hive trimmers and these are excellent in all respects