

# Capacitors

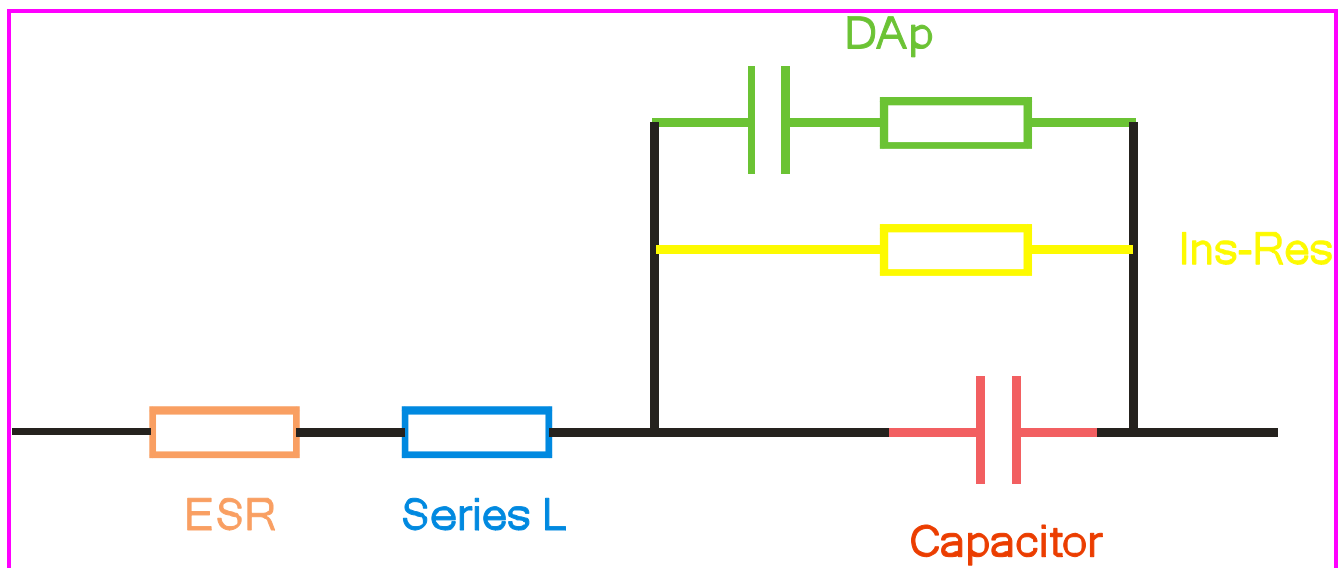
There seems to be a lot of hype and mystery concerning the sound of capacitors, the quality of capacitors and what capacitors actually do in a circuit. There are many types of capacitors including ceramic, polyester, polypropylene, polycarbonate silver mica, tantalum and electrolytic. Each has its own area of “expertise”. One type of capacitor will perform well in a particular application and perform poorly in another. A capacitor is simply two metal plates separated by a dielectric. An electrical charge is stored between these two plates. The plates and dielectric can be made from several different types of material. The closer the plates are, the higher the capacitance and the larger the area of the plates, the larger the capacitance. The dielectric material affects the capacitance as well. Here is some brief information about the particular types.

**Note:** The unit of capacitance is the Farad. It is a very large unit and so we use the following to express capacitance

Microfarad is one millionth of a farad.

Picofarad is one millionth of a microfarad

So 0.001mfd is equal to 1000 picofarad (pF)



The above diagram shows a simple representation of a capacitor.

The capacitor is shown in **RED**.

In parallel with the plates of the capacitor is a resistance, **Ins-Res** of the insulation. Teflon has the highest resistance with polystyrene, polypropylene and polycarbonate coming in second. Third is polyester and then the ceramics COG, Z5U and XR7 with tantalum and aluminium last.

**Dap** is the Dielectric Absorption. All capacitors when charged to a particular voltage and then the leads are shorted, will recover some of their charge after the short is removed. The ratio of

the initial voltage to the recovered voltage is expressed as a percentage. In general, electrolytics are the worst and film types are the best.

The **series inductance** is shown simply in series with the capacitor itself. Electrolytics have the highest inductance mainly due to how the capacitor is made. The higher the frequency the higher this inductance becomes.

The **ESR** of the capacitor is the resistance that appears in series with the actual capacitor. The higher the voltage and value the lower the **ESR**. This resistance is made up of dielectric loss, lead termination resistance and the electrode resistance. This is nearly constant with frequency.

The dissipation factor or DF is the ratio of ESR divided by the capacitive reactance( $X_c$ ) which is given by this formula ( $X_c = 1/6.28 \times F \times C$ ) where F is frequency and C is the value in Farads. Normally of course we have values in "Mfd" and so the value of C can be in Mfd and then the numerator becomes 1,000,000 instead of just 1.

**Ceramic capacitors** are used in high frequency circuits such as RF. They are also **the best** choice for high frequency compensation in audio circuits. Now some may snub their noses when hearing this. We used to manufacture some high end amps for a Japanese company and they demanded that NO ceramics be used in the amplifiers. Pretty much all amplifiers have some sort of high frequency compensation to prevent them from oscillating and instability. The frequency at which these ceramics were doing their work was at 240KHz. Now I do not know about all of you out there but my hearing does not go out THAT high. Maybe these guys were distant relatives of the bat!

They come in values from a few picofarads to 1 microfarad. The voltage range is from a few volts up to many thousands of volts. Ceramics are inexpensive to manufacture and they come with several dielectric types. Types XR7 and Z5U are the least stable as far as temperature is concerned. They have a higher dielectric constant than the higher stability types like COG. The tolerance of ceramics is not great but for their intended role in life they work just fine.

**Tantalum capacitors** are made by depositing a film of oxide on tantalum. These are polarized types and are smaller than their aluminium counterparts. They are low voltage types only with a maximum rating of about 40 volts. We at zed do NOT use these as they are notoriously unreliable. They have a bad tendency to go leaky. I will NEVER EVER use a tantalum capacitor as they are so unreliable and my experience many years ago bears that out.

**Aluminium Electrolytic capacitors** are made by depositing a film of oxide on aluminium foil. The foil is formed for a specific voltage rating. These are polarized and of course do not tolerate having reverse voltage applied to them. (Anyone been around when one of these larger value babies explodes - it is not a pretty sight?) They are also not happy campers if the rated voltage is exceeded (same thing, they will make a mess of the equipment and your face if you are too close) BUT higher quality types will tolerate about 5% over voltage. What happens in these capacitors that if one applies say 37 volts to a 35 volt capacitor it will actually reform its foil over time to the new applied voltage but its value will drop to keep CV a constant. Conversely if a lower voltage is applied it will reform to this new voltage and the capacitance will increase. Now do not get all excited and take your 10,000mfd 50v capacitor and use it at 25 volts and expect to get 20,000mfd out of it. There are limits to what these guys will do. It is also not a great idea to run electrolytics at voltages well below their rated voltage. A rule of thumb is about 25% lower voltage than rated is OK. They are normally made

by winding the foils around in each other in a cylindrical way. High capacitance is easily obtained.

The ESR is the Equivalent Series Resistance and the higher the value and voltage the lower the ESR. The lower the ESR the less heat the capacitor will generate when current is drawn from it. Also closely related to the ESR is the available ripple current that a capacitor can tolerate. This is mainly of concern in power supplies. Most manufacturers offer many grades and sizes of electrolytic capacitors. There are of course both through hole and surface mount types. Within each category there are sub categories. Through hole types offer many more variations than surface mount. There are 85 deg C and 105 deg C versions leaded, snap in and screw type terminations. Electrolytics, especially those used in high current power supplies have a fixed lifespan and once a electrolytic decides it is tired of living, then it is off to "the pie in the sky". Typically their life span is from 1,000 to 3,000 hours depending on the quality.

Their tolerance is not good but then again a low tolerance component is not essential. Typically the value can vary from -50% to +100% of the nominal value. There are non-polar electrolytics and these are mainly used in passive speaker crossovers.

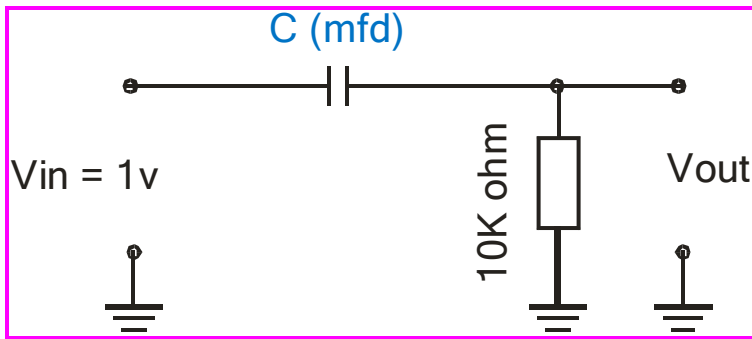
**Silver Mica Capacitors** are one of the best types of capacitors. They have excellent stability and are available in low tolerance values down to less than 0.1%. They ARE sensitive to heat and are now used mainly in RF and tuned circuits. I like them in RIAA preamplifiers as I think they do sound better in that application.

**Film capacitors** encompass polyester, polypropylene, polycarbonate and others. Each has its own strengths and weakness. These are normally used in audio for filters, equalizers and power supply bypass duty. They are available in almost any value and voltages as high as 1,500 volts. They come in any tolerance from 10% to 0.01%.

Well now that you almost know all there is to know about capacitors (Only kidding) it is time to discuss how they sound and why we use certain types in particular applications.

**Power supplies** generally demand the use of electrolytic capacitors because they have high values in small packages. The value is determined by how much ripple can be tolerated and the voltage is determined by the voltage of the power supply (Duh!). Because this type of capacitor has inductance, it is normal practice to bypass them with film type capacitors in order to improve the high frequency characteristics. In 50/60Hz supplies I have never found these bypass film capacitors do anything to improve the sound.

**Coupling capacitors** are usually electrolytic (Yes this is not a typo error) and film types. The value of the coupling capacitor is usually determined by the load impedance which the capacitor "sees". If the value is too small for a given load impedance then the low frequencies will be attenuated at a rate of 6dB/octave.



Let us examine the circuit above. The capacitor has a reactance which forms a potential divider with the 10K ohm resistor. This circuit may represent the coupling of one circuit block delivering “Vin” at 1 volt to another circuit block shown as “Vout”. We can consider the capacitor as a resistor whose value changes with frequency which is really its reactance ( $X_c$ ).

So the formula for Vout is  $[V_{out}/V_{in} = 10,000/10,000+X_c]$  and  $[X_c = 1/6.28 \times F \times C]$

We can now throw some numbers into our formulas and see what comes out. Let us pick a frequency of say 1KHz and a capacitor value of 0.22mfd as a first example. Solving for  $X_c$  we get  $X_c = 723$  ohms. Solving for Vout we get 0.932 volt. This means that at a frequency of 1KHz a 0.22mfd capacitor will cause the output voltage to drop to 0.932 (a 0.61dB drop). The frequency at which  $X_c = 10K$  ohm is 72.37Hz (I simply solved for F in the formula above)

As a coupling capacitor in a full range circuit the 0.22mfd is clearly inadequate since it rolls off the response from over 1KHz and is 3dB down at 72.37Hz. What do we do to calculate the value of C which will allow decent low end response? We shall pick a frequency at which we want the signal level at Vout to drop to -3dB as low as we desire. We shall choose 2Hz. Solving again for C in the  $X_c$  formula above we get 7.96mfd. We would then use a 10mfd. This 10mfd can be a regular polarized electrolytic, two electrolytic capacitors wired back to back with common polarity terminals joined, a non-polar version or a film type. The film type will be large and expensive. In op-amp circuits where the DC supplies are less than 20 volts, a film type rated at 25 or 63v is not that large. In tube circuits however where there are hundreds of volts, a 10mfd 450v capacitor is a large specimen. At Zed we go one step further and increase the value fivefold so the -3dB break frequency goes down well below 1Hz. My opinion is that if the value of the capacitor is so large so as to make a break point well below 1Hz the electrolytic capacitor does not degrade the sound.

An amusing story: About 14 years ago Zed Audio was building subwoofer amplifiers for a large well known speaker company in Chatsworth California. One of the projects involved a high pass active preamplifier whose output was to be 6dB/octave high pass crossover (same as the circuit above) with some simple elegant electronics. The BIG question came up from management and sound gurus whether one could tell the difference between various high quality film capacitors. I said “no” and I got hammered for this comment. I set up a test where I said they could not even hear a cheap electrolytic, never mind a film type. “You are crazy, full of you know what” were some of the comments I received. So we set up a double blind test. We had a fancy turntable, Audio Research tube preamplifiers and power amplifiers, speaker cable as thick as your arm and all the other high end toys needed for a sound system. Between the preamplifier and power amplifier a two pole switch was inserted and the switch was to select either a dead short or this one penny electrolytic capacitor. I soldered the capacitor to the switch but unbeknownst to the audio boffins, I wired a short across the capacitor so in either switch position they were listening to the same thing - a dead short, a piece of wire! This was going to be fun - I knew that.

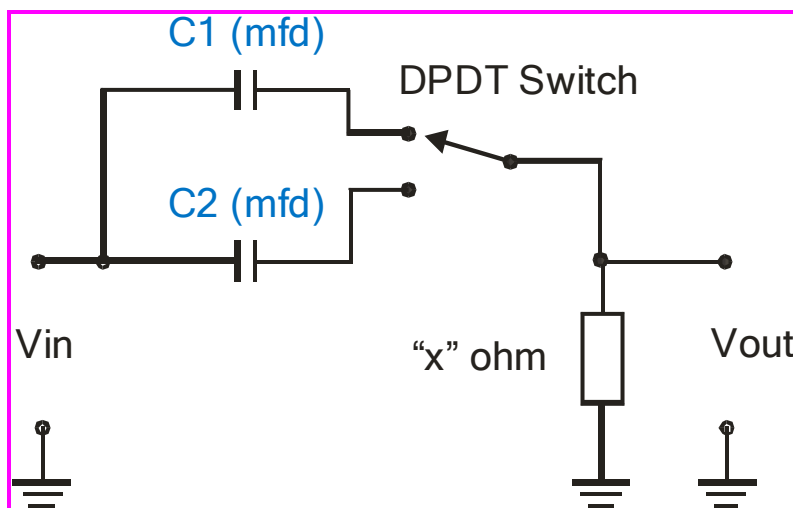
The gurus put their favourite album on the turntable and away we went. One of their technicians was flipping the switch at the listeners' command. Back and forth we went for over ten minutes with all saying "Yes that's the capacitor, no that's the wire". So we stopped and I called all these gurus over to the switch and showed them the dead short across the capacitor. Red faces, curses etc and I was a bad boy and they were fools. Most of this "component" sound is in one's head. You have to hear the difference after you have spent \$55.00 on your new coupling capacitors!

**Power supply bypass capacitors** are sometimes required in low level circuits. These should be a pair of ceramic capacitors (Yes ceramic as they perform best at high frequencies) placed as close to the power supply pins of the integrated circuit or discrete circuit block and some electrolytic capacitors placed reasonably close. Film capacitors will work fine but as they are more expensive than their ceramic counterparts I see no reason to use them.

**Switching power supplies** require the use of either low ESR capacitors or a larger quantity of "regular" ESR capacitors. It makes absolutely no difference which method is employed as long as the final ESR and ripple values are arrived at.

**High frequency compensation capacitors** in audio circuits always operate at very high frequencies. In our opinion the best type to use are ceramic capacitors. Some disagree and claim that film types are better. Since these compensation capacitors are used to roll off extremely high frequencies I seriously doubt that one could hear the difference. Unless you are of course a relative of our beloved little bats.

**Listening to different capacitors** is a time consuming. In order to compare two different types of say coupling capacitors in an audio circuit requires that you install the two types and a double pole double throw switch (DPDT) so that a direct A-B comparison may be done. The switch should be a gold plated low contact resistance type. Ideally you must install the switch at the point in the circuit where the capacitors live. This may sometimes be difficult to do because it may not always be simple to solder in the parts. The "crook" method is to do the switching between two pieces of equipment like a head unit or preamplifier and the power amplifier. The simple circuit is shown below with only one channel shown for clarity.



The two capacitors marked C1 and C2 are to be compared. The double pole double throw switch (DPDT) is toggled between the two capacitors. The Resistor shown as "x" ohm is what the capacitors "see" as their load impedance and this resistor is normally the input resistor of the next circuit block or equipment.

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