FOUR POLE ELECTROLYTIC CAPACITOR WITH EXTREMELY LOW INDUCTANCE, FOR HIGH FREQUENCY OUTPUT FILTERING AND FOR ENERGY STORAGE CIRCUITS IN HIGH-END AUDIO EQUIPMENTS.

Application notes

The short "life-story" of four pole electrolytics

The four pole electrolytic capacitor appeared in the early 80's when Sprague introduced a low inductance, low ESR four pole axial capacitor mainly for switching converters and regulators. As the switched mode power supplies became common in the mid-80's the demand increased for high capacitance electrolytic capacitors having improved high frequency inductance characteristic. As these requirements could be the most economical and elegant way fulfilled by using four pole electrolytics other firms - as i.e. FRAKO from Germany - followed Sprague, and developed four pole electrolytics.

Unfortunately most designers of high frequency switching mode circuits did not care about elegancy, effectiveness and EMC problems or they simply were not aware of the existence of four pole electrolytics, they used mostly cheap and bulky standard components. As a consequence of these facts the four pole electrolytics has sunken into oblivion.

Reinvention now also for high-end audio application

It was Tobias Jensen Production A/S (TJP) that "reinvented" it for high-end audio applications. Four pole electrolytics for switched mode power supplies in maritime communications systems has been produced at TJP since 1990, designed for equipments that should last and work reliable even under extreme circumstances require the best design and components.

When TJP in the early 90's started to produce passive components in larger extent for the high-end audio market and became more and more conscious of the need of audio enthusiasts and audiophiles, we came to the recognition that four pole electrolytics are ideal reservoir capacitors for power supplies (and not only for SMPS) in sensible audio equipments.

The importance of attenuation and high frequency behaviour

No matter how fast the amplifiers signal processing circuits are, you cannot utilize that speed if your power supply is too slow to follow rapid signal changes.
The power supply's reservoir capacitor constitutes a vital element in the amplifier chain effecting the signals on the main signal paths as well, because the most power amplifiers reservoir is conceptually placed in series with the loudspeaker line.

The main issue is not only that, the capacitor can give you enough charge and quickly enough, but the attenuation of the power supply toward the amplifier. In spite of the fact that the audio band is nominally 20-20 kHz, the stability of the amplifier and the overall sound quality is strongly influenced by reservoir capacitor behaviour at very high frequencies.

The function of the reservoir capacitor is not only to store energy, but also filtering, providing decoupling between the power supply and the amplifiers signal processing circuits. For energy storage a conventionally constructed aluminium electrolytic capacitor with sufficient Capacitance (F) x Voltage (V)/ Volume (cm^3) ratio and satisfactory low ESR and inductivity at higher frequencies would be suitable. However the capacitors filtering characteristic plays a very important role in decoupling and suppressing unwanted transients and other i.e. digital high frequency noises.

Extremely low inductance makes excellent high frequency capabilities

The high inductance value of a capacitor is particularly harmful when they are used for filtering at higher frequencies, as the impedance of a high capacitance capacitor over the resonance frequency - which is typically a few tens of kHz - is strongly dominated of the inductance of the capacitor winding.
In consequence of the construction, the conventionally designed, even multitabbed or extended foil electrolytic capacitors provide a significant undesired and increasing impedance vs. frequency response in the critical frequency field. The most acceptable compromise and so far the most utilized solution for this problem was the usage of several high capacitive electrolytics in parallel connection, in order to reach the desired low inductance value.

The best and the ultimate solution is no doubt a four pole electrolytic capacitor having the same Capacitance x Voltage/Volume ratio as the best high capacitive electrolytics with an inductance, which is only the fraction of theirs. Let us take a typical reservoir capacitor size of 15.000 μF 40 V and compare the Z impedance versus frequency characteristic of a traditional and a four pole device. The curve B shows the traditional two pole, and curve A the four pole capacitors frequency versus impedance characteristic. (Figure 1.)
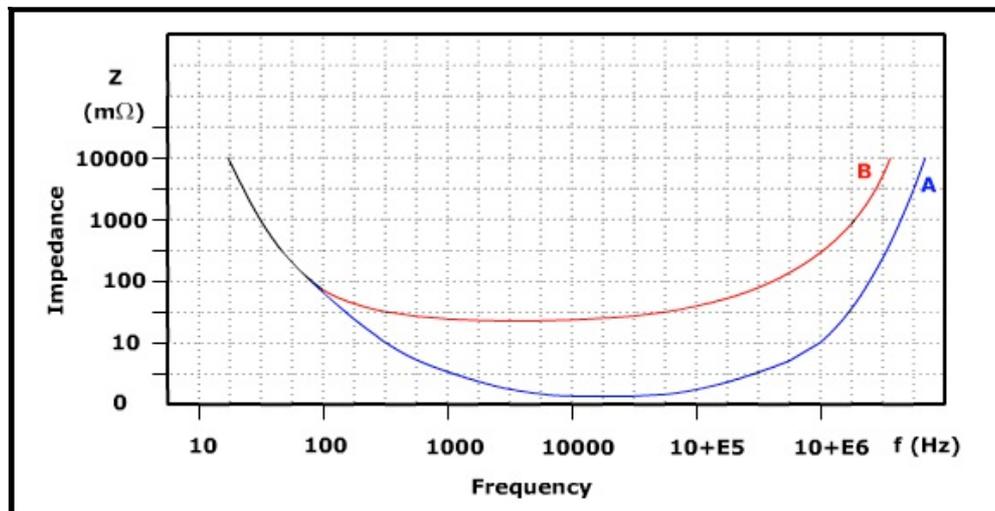
Figure 1.

(The impedance of a four-pole device rather called as transfer impedance, defined as the quotient of the output AC voltage and the input AC current and measured according to DIN 41 328 sheet 1.)

The two curves run together for a while, but already before the resonance frequency the curve A is falling steeper than B and reaching a minimum value of 0.5-0.8 mΩ in the frequency interval of 10-50 kHz. This value is almost two orders of magnitude lower than the impedance of a traditional two pole electrolytic capacitors. At the resonance point the inductive and the capacitive part of the impedance is zero and only the pure ohmic component (ESR) define the impedance. From this point the capacitor behaves as an inductor and the impedance consisting mainly of the inductive component increases again. It is very easy to realize that not only the equivalent serial resistance (ESR) but also the inductance of a four-pole reservoir capacitor is only the fraction of a conventional capacitor in a wide high frequency range. The very low transfer impedance value at higher frequencies make the four pole capacitor applicable also in other high frequency and digital signal handling equipments and circuits as preamplifiers, A/D and D/A converters, switched mode power supplies etc.

The capacitor also works as a filtering/attenuation circuit

The four pole electrolytic capacitors have other additional advantages, which are especially useful for reservoir capacitors in high-end amplifiers. If you use a two terminal, two pole capacitor the entire AC and all noises coming from the power supply appear on the capacitor and are sent toward the high frequency signal path, disturbing the load because of the common resistive and inductive parts which force the input and the output together electrically. (Figure 2.).
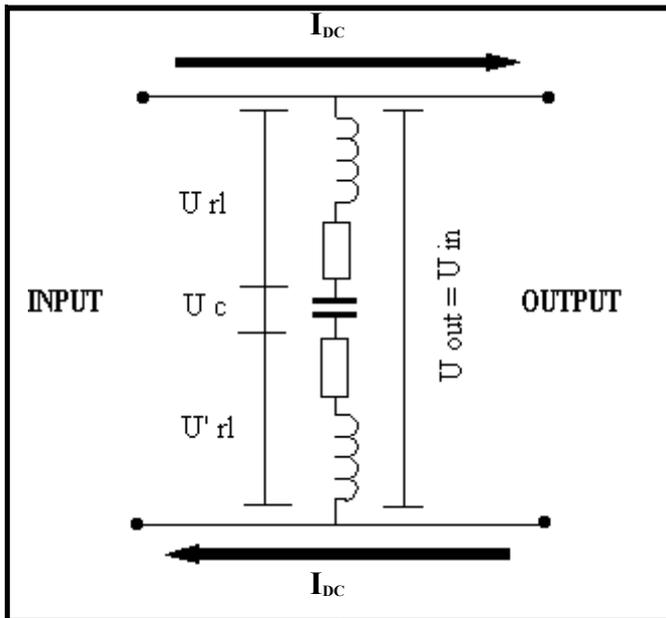
Figure 2.

Figure 3.

All these disturbances can be avoided by using four terminal capacitor constructions, where the AC on the input terminal is decoupled from the load. The inductances and resistances coming from the lead to foil connections (tab foils) form and advantageous filter circuit which attenuation increases with frequency. (Figure 3.)
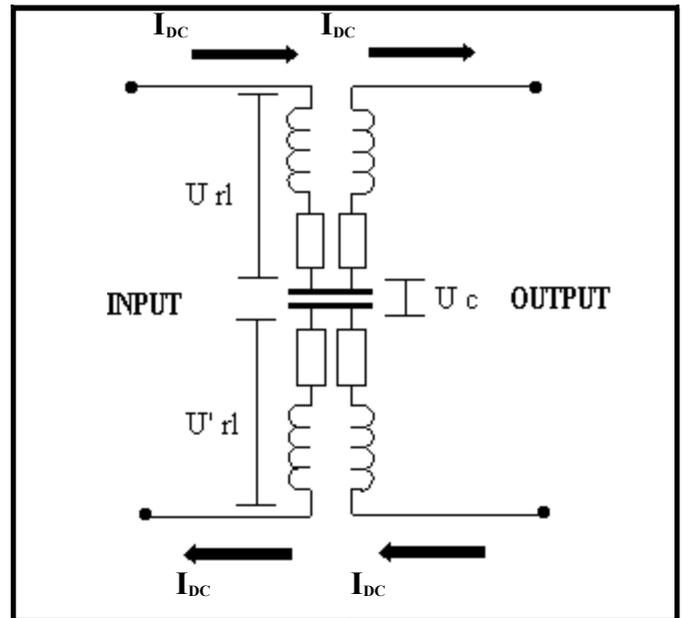
As a consequence of the damping/suppressive effect of this inherent LR filtering, often a single four-pole capacitor can replace a complicated filter arrangement.

Complex construction inside

The filter capability (the measure and the frequency dependence of the attenuation) and the transfer impedance of a capacitor is determined by the inside construction and different geometrical factors of the capacitor winding itself. As these factors depends on the dimension of the can, the length and width of the used capacitor and tab foil, and are different from type to type, the optimisation process must be accomplished for every single capacitance/voltage/dimension combination.

The manufacturing of the four-pole capacitor is also more complex then the traditional one.
As the yield capacitance value of the electrolytic capacitor foils (anode- and cathode-) can vary up to 20%, the length of the foil should also be adjusted accordingly to achieve the needed nominal capacitance. On the other hand this adjustment will destroy the hair-fine geometrical balance optimised for best filtering and impedance so you either need to re-optimise

the capacitor with the new foil length or use raw materials, which have always the same features. It's a really difficult choice/dilemma both technically and economically.

Application remarks/advices

Due to the special construction of the capacitor the DC load current pass trough the capacitor.

Any heat generated by this DC current must be taken into account when the capacitor's operating temperature is calculated.
The mixed DC/AC load can be calculated with the help of the Figure 4.
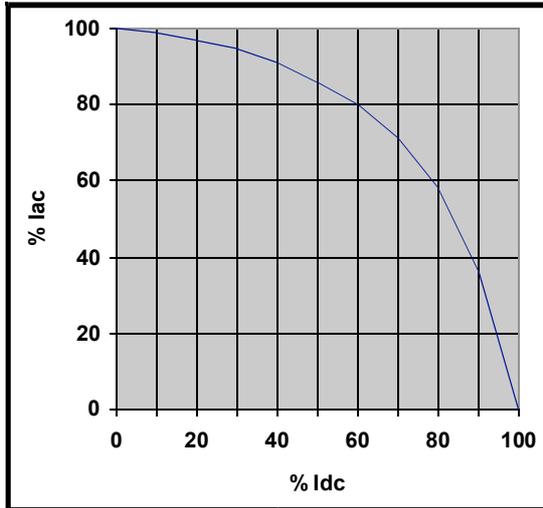
Axial type Ø D x L [mm]	Radial type Ø D x L [mm]	Idc [A]
35 x 56		3,9
35 x 76		5,5
35 x 96		6,9
	35 x 30	2,7
	35 x 40	3,4
	35 x 50	4,1
	35 x 70	5,5

Figure 4.

The 100% of Idc is coming from the DC resistance and the construction of the capacitor, and mainly depends on the heat dissipation capability of the capacitor. For Idc values of different types and constructions see the table above. For calculation of the full load the Iac values are given as max. admissible ripple current values on the capacitor data chart.

When it is necessary the DC load can be increased by means of a by-pass ferrite core winding according to Figure 5. (Not recommended for high-end audio applications).
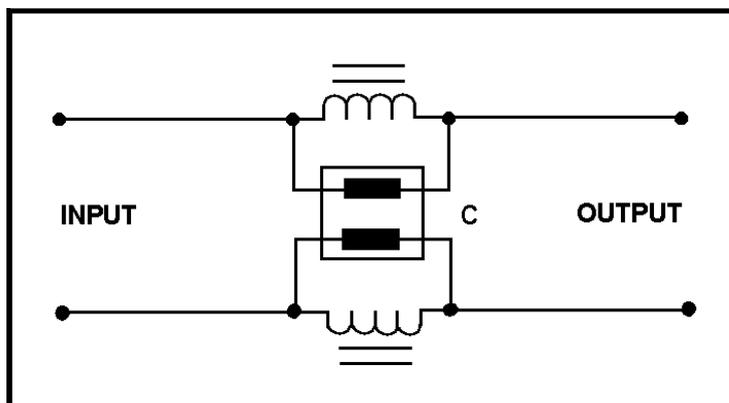
Figure 5.

As a rule of thumb the DC resistance of the by-pass winding must be about the 1/20 of the capacitors DC resistance (measured between the input and output terminals on the same polarity poles) and its AC resistance is about 20 times higher than the capacitors AC resistance (impedance) on the working frequency.

The input and output terminals are marked on the capacitor. It is recommended to use this connection thus the inherent inside filter is optimised for this signal direction. However reversing the inputs with the outputs will not damage the capacitor and the consequence is only shown as decreased damping/suppression effect and slightly higher transfer impedance.