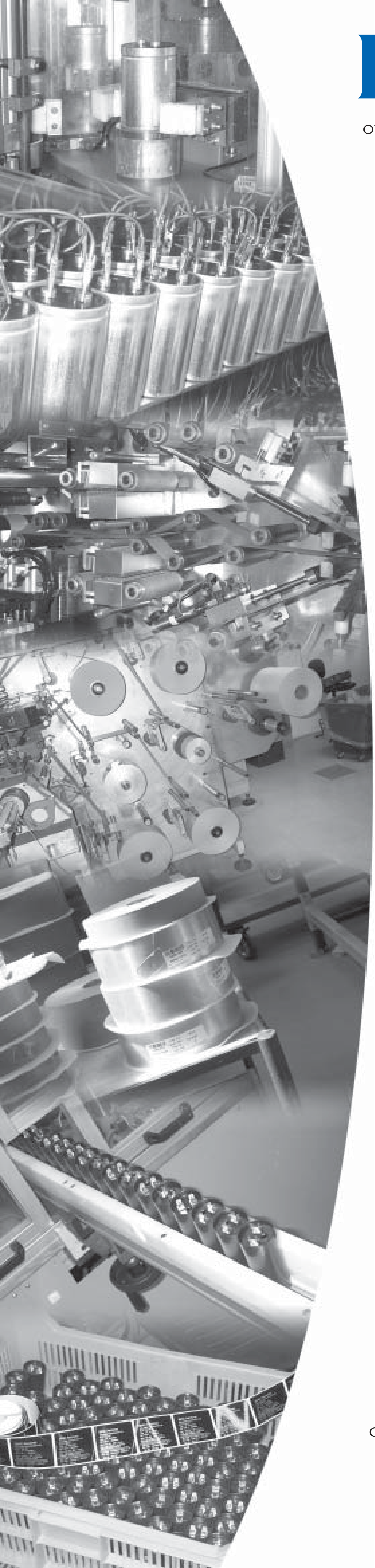
BHC COMPONENTS

part of the **EVOX RIFA GROUP**

Application Notes

Aluminium Electrolytic Capacitors



BHC COMPONENTS, now part of the Evox Rifa Group, is one of Europe's leading manufacturers of Large Can Aluminium Capacitors. The Evox Rifa Group is a major global capacitor manufacturer, offering a wide range of technologies and styles from production facilities in Sweden, UK, Finland, China and Singapore.

The ISO9001 approved BHC production plant at Weymouth in the South of England has been successfully manufacturing Aluminium Electrolytic Capacitors for the most demanding applications since 1968.

BHC prides itself on its ability to provide a flexible design service for unique customer requirements. The company has a history of working alongside design teams, providing the exact solution to a particular problem, and unrivalled support in the subsequent application. BHC recognises that its success depends on the future of its customers and sees itself not only as a supplier of technologically superior products but as a partner, mutually striving with our customers for competitive advantage.

The product development and customer service provided by BHC is backed by a totally integrated, real time information system that plays an important role in quality, design, and in all phases of production from planning to control.

The control offered by the use of information systems over the manufacturing process is only a part of the quality system that pervades at every level. Quality is the responsibility of every member of our team with the emphasis placed on "right first time" and "continuous improvement". Quality is the link that bonds us to our customers. We are committed to not only satisfy customers' current needs, but to improve and develop products in anticipation of their future requirements.

In formal recognition of this BHC has achieved approval to BS EN ISO 9001.

Manufacturing competitively priced products of the highest quality is the cornerstone of our success. If you wish to share in that success then contact us and see for yourself how we can provide a solution to satisfy your needs without having to make do with the closest standard available.

Contents

Introduction

This document contains five separate technical articles written to give the equipment designer detailed information on the application of BHC Components aluminium electrolytic capacitors. It augments the information already available within the standard product catalogue.

The technical support team at BHC Components are more than happy to offer any additional support that may be required if the information cannot be found in these notes. To obtain a feasibility of a capacitor for a particular application, the form at the back of the document should be completed, with as much information as possible, and faxed to BHC Components.

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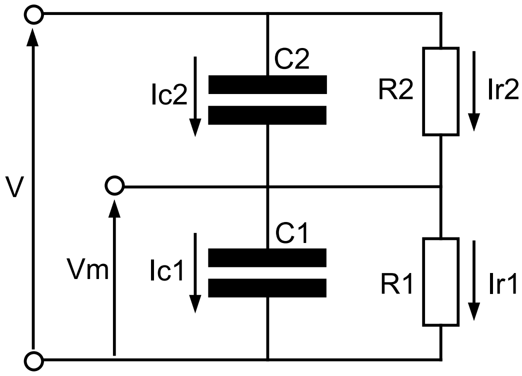
Introduction

When aluminium electrolytic capacitors are connected in series it is advisable to use balancing resistors in order to control the voltage sharing across each device.

Voltage Sharing Analysis

Consider the following circuit consisting of two capacitors in series (C1 and C2) with balancing resistors (R1 and R2) :



If a voltage V is applied across this capacitor and resistor network then, when equilibrium is reached the currents Ic1, Ic2, Ir1 and Ir2 will flow as shown.

The sum of the currents through the top half of the network will equal the sum of the currents through the bottom half of the network, thus :

$$Ic1 + Ir1 = Ic2 + Ir2 \qquad (1)$$

The voltage at the mid point, denoted by Vm, will be given by :

$$Vm = Ir1 \times R1 \qquad (2)$$

Combining equations (1) and (2) gives :

$$Vm = (Ic2 - Ic1 + Ir2) \times R1 \qquad (3)$$

Furthermore, since Ir2 can be defined as :

$$Ir2 = \frac{(V - Vm)}{R2} \qquad (4)$$

It can be shown that :

$$Vm = \frac{(Ic2 - Ic1) \times R1 \times R2}{(R1 + R2)} + \frac{V \times R1}{(R1 + R2)} \qquad (5)$$

This shows that the mid point voltage Vm is dependant on the difference in capacitor leakage current (Ic2-Ic1), the applied voltage V and the values of the resistors used.

Since the values of the balancing resistors will normally be equal we can set both R1 and R2 equal to R and simplify the equation to give :

$$Vm = \frac{(Ic2 - Ic1) \times R}{2} + \frac{V}{2} \qquad (6)$$

This clearly demonstrates that the mid point voltage Vm deviates from the ideal value of V/2 by an offset voltage (Ic2-Ic1) x R / 2 which is determined by the resistor value and the difference in leakage currents between the two capacitors.

Resistor Tolerance

The effect of different resistor values (varying within normal tolerance) can be shown by examining equation (5).

For example suppose the resistors have a ±5% tolerance and one resistor is on bottom limit and the other on top limit. We can set R1 = 0.95 x R and R2 = 1.05 x R which gives :

$$Vm = \frac{(Ic2 - Ic1) \times R \times 0.9975}{2} + \frac{V \times 0.95}{2} \qquad (7)$$

In this case the ideal mid point voltage of V/2 is reduced by 5% and the offset voltage due to leakage current difference is slightly reduced by a factor of 0.9975.

Balancing Resistors for Voltage Sharing

Choice of Resistor Value

Equation (6) can also be rearranged to determine the value of balancing resistor necessary for a given set of conditions, thus :

$$R = \frac{(2\Delta Vm - V)}{(Ic2 - Ic1)} \qquad (8)$$

To calculate the maximum resistor value required, set V to the value of applied voltage and set Vm to the maximum acceptable mid point voltage, usually the rated voltage of the capacitor.

The difference in leakage current (Ic2-Ic1) will depend on the capacitor in use, the temperature of operation and the eventual voltage that each capacitor settles to.

If the capacitor leakage currents are measured at an identical voltage then there will usually be some difference between the values, one will be higher than the other.

When placed in the circuit it is important to note that initially the capacitor with the higher leakage current will have a lower voltage across it. Since the leakage current is proportional to the applied voltage (the lower the voltage the lower the leakage current), this capacitor will tend to settle to a lower leakage current.

The opposite will be true for the capacitor with the higher voltage across it. Since this will reduce the difference between the leakage currents the mid point voltage Vm will move closer to V/2.

For practical purposes the difference in leakage currents at rated temperature can be estimated as :

$$\frac{0.003\,\Delta Cr\,\Delta V}{2000}\ \text{mA} \qquad (9)$$

where Cr is the rated capacitance in μF, and V is the applied voltage across the pair of capacitors.

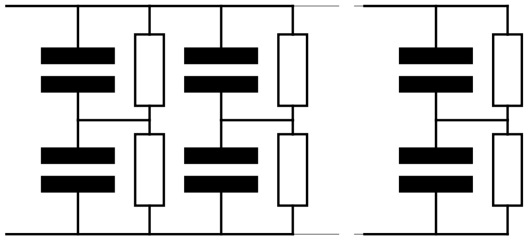
The following table gives examples using this approach.

Cap µF	Rated voltage	Ic2-Ic1 mA	V	Vm	R
3300	450	3.96	800	450	25 kT
2200	400	2.31	700	400	43 kT
470	400	0.53	750	400	95 kT
470	400	0.49	700	400	202 kT
1000	200	0.58	385	200	26 kT
2200	400	2.31	700	400	43 kT
3300	350	2.97	600	350	34 kT

Series / Parallel Capacitor Banks

There are two major configurations to consider when constructing a series/parallel bank of capacitors. The advantages and disadvantages of each are outlined below but the final choice must be made by the equipment designer.

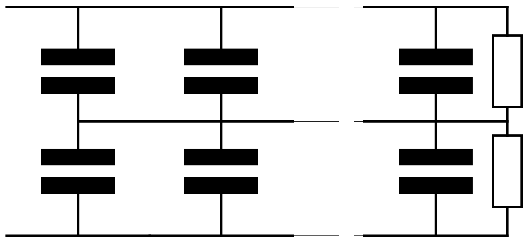
Option 1 - Individual balancing resistors



Advantages
If one capacitor fails and becomes short circuit then the capacitor in series with it will almost certainly fail but the other capacitors in the bank should be unaffected.

Disadvantages
More complex construction, many resistors to be fitted. Additional cost of resistors.

Option 2 - Common centre connection



Advantages
As the number of capacitors in parallel increases so the effective capacitance in the top and bottom of bank will tend to equalise, this will give better balancing during transient conditions.

Also the average total leakage current for the top and bottom of the bank will become closer giving improved balancing under steady state conditions.

Only two resistors required. In some cases the difference between the leakage currents in the top and bottom of the bank may be so small as to render the use of resistors unnecessary.

Disadvantages
If one capacitor goes short circuit the other half of the bank will be exposed to the full voltage and may cause several further failures.

Revision to TD001 : Balancing resistors for voltage sharing

Leakage current difference

The article TD001 has been in use for many years and over that period a few users have expressed the opinion that the resistor values are sometimes on the low side. This is on the safe side as far as balancing is concerned but does lead to higher, and possibly unnecessary levels of power dissipation in the resistors.

The key factor in determining the resistor values is the difference in leakage current between two series connected capacitors. The equation (9) given for this was based on analysis of empirical data and as such is a good guide to the difference **at the same voltage -** we still believe this to be the case. However, the value required in equation (8), Ic2-Ic1, represents the difference in leakage currents after equilibrium has taken place - i.e. at **different voltages** dependant on the final balancing voltage

In other words, we need to know the likely difference in leakage currents for the same applied voltage and then adjust this figure according to the level of offset voltage after the circuit has settled. The final voltage is unknown, we are trying to calculate it, but we do know that the change of leakage current vs voltage follows an exponential curve. So, for example, a 5% increase in voltage will cause more than a 5% increase in leakage current and vice versa. This leads to a self balancing situation whereby any voltage offset will reduce the leakage current difference, which in turn reduces the voltage offset.

For any two capacitors we have defined the max leakage current difference as equation (9), the minimum difference is clearly 0. It is impossible to be precise but we believe that after settling the difference in leakage current should at least halve leading to a revised equation (9) as shown below.

Leakage current difference = **0.0015 x Cr x V / 2000 mA.**

Capacitors in banks

When capacitors are used in banks (series/parallel) with a common centre connection the balancing resistors can be adjusted in value to account for the averaging effect on leakage current. In essence the total leakage current difference between the top and bottom banks of parallel capacitors will determine the balance point. The more capacitors placed in parallel the better the balancing since individual leakage values become less critical.

For banks of capacitor used in this way we would recommend using the following equation for the leakage current difference :

Leakage current difference = **0.0015 x Cr x V / 2000 / · n mA.**

Where n is the number of capacitors in parallel.

BHC COMPONENTS

Technical Enquiry

Please complete the boxes below with as much detail as possible and either fax to: +44 1305 760670 or complete our on-line enquiry form at http://www.bhc.co.uk.

Contact Details

Name		Tel:	
Company		Fax:	
Address		Email:	

Capacitor Details

Capacitor part number (if known)					
Capacitance		μF	Rated Voltage		V dc
Size		dia. x l en. (mm)			

Configuration
Number of Capacitors:

No in bank		No in series		No in parallel	

Operation details
The data below applies to : the whole bank [ ] each individual capacitor [ ]

Ripple currents		Hz		A rms
		Hz		A rms
		Hz		A rms
		Hz		A rms
		Hz		A rms
		Hz		A rms
		Hz		A rms
Working Voltage Vdc			Forced air cooling rate - m/s	
Ambient air temperature °C			Heat sinking °C/W	

Other details (e.g. surge voltages,...)		
Special end of life criteria (e.g. 2 x initial esr)		
Target life requirement		Hours

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11/02

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