The current I_R through the resistor R must be larger than the leakage current. Otherwise the R will not be able to control the voltage dividing process. We suppose the leakage current I_L to be 0.003CUc (normally it is considerably lower than this value), and let I_R be five times larger than I_L, then the balance resistance can be calculated by the following equation:

$$R=Uc/(5XI_L)=Uc/0.015CUc=1/0.015C$$

(Unit: R——Ohm; Uc——Volt: C——Frad)

For example: calculate the value of the balance resistance in case of connecting two CD293 400V330uF capacitors in series.

$$R=1/0.015C=1/(0.015X330X10^{-6})=202K\Omega$$

3. About the Life of an Aluminum electrolytic Capacitor

3-1 Estimation of life with minimal ripple current (negligible).

Generally, the life of an aluminum electrolytic capacitor is closely related with its ambient temperature and the life will be approximately the same as the one obtained by Arrhenius' equation.

$$L=LoX2^{\left(\frac{To-T}{10}\right)} \text{ ------------- } (1)$$

Where L: Life at temperature T

Lo: Life at temperature To

The effects to the life by derating of applied voltage etc. are neglected because they are small compared to that by the temperature.

3-2 Estimation of life considering the ripple current.

The ripple current affects the life of a capacitor because the internal loss (ESR) generates heat. The generated heat will be:

$$P=I^2R \cdots\cdots\cdots\cdots (2)$$

Where I: Ripple current (Arms)

R: ESR (Ω)

With increase in the temperature of the capacitor:

$$\triangle T=\frac{I^2 \cdot R}{A \cdot H} \cdots\cdots\cdots\cdots (3)$$

Where △T: Temperature increase in the capacitor core (deg.)

I: Ripple current (Arms)

R: ESR (Ω)

A: Surface area of the capacitor (cm^2)

H: Radiation coefficient (Approx. 1.5~2.0x10^{-3}W/cm^2x℃)

The above equation (3) shows that the temperature of a capacitor increase in proportion to the square of the applied ripple current and ESR, and in inverse proportion to the surface area. Therefore, the amount of the ripple current determines the heat generation, which affects the life. The value of △T varies depending on the capacitor types and operating conditions. The usage is generally desirable as △T remains less than 10℃ for 85℃ products and 5℃ for 105℃ products and higher temperature products.

Since it is actually difficult to measure the temperature increase at the capacitor core, the following table is provided for conversion from the surface temperature increase to the core temperature increase.

Table 3

Case diameter	~10	12.5~16	18	22	25	30	35
Core/Surface	1.1	1.2	1.25	1.3	1.4	1.6	1.65

流过电阻R的电流I_R必须远大于电容器的漏电流，否则电阻R无法控制电压分配过程。假定流过电阻R的电流为电容器漏电流的5倍，而电容器的稳定漏电流I_L设定为0.003CUc（实际漏电流小于该值），则均压电阻的计算公式为:

$$R=Uc/(5XI_L)=Uc/0.015CUc=1/0.015C$$

(单位: R——Ω; Uc——V: C——F)

例：计算2只CD293 400V330uF 电容器串联时的均压电阻值。

$$R=1/0.015C=1/(0.015X330X10^{-6})=202K\Omega$$

3. 铝电解电容器的寿命

3-1 忽略纹波电流时的寿命推算

一般而言，铝电解电容器的寿命与周围的环境温度密切相关，可以近似地由阿列纽斯方程计算。

$$L=LoX2^{\left(\frac{To-T}{10}\right)} \text{ ------------- } (1)$$

其中，L：环境温度为实际温度T时的寿命

Lo：环境温度为T0时的寿命

与温度比较，降压使用对电容器的寿命影响很小，可忽略不计。

3-2 考虑纹波电流时寿命的推算

叠加纹波电流，由于内部等效串连电阻（ESR）引起发热，从而影响电容器的使用寿命，产生的热量可由下式计算

$$P=I^2R \cdots\cdots\cdots\cdots (2)$$

I：纹波电流（Arms）

R：等效串联电阻（Ω）

由于发热引起的温升

$$\triangle T=\frac{I^2 \cdot R}{A \cdot H} \cdots\cdots\cdots\cdots (3)$$

其中，△T: 电容器中心的温升（℃）

I: 纹波电流 (Arms)

R: ESR (Ω)

A: 电容器的表面积(cm^2)

H: 散热系数(1.5~2.0x10^{-3}W/cm^2x℃)

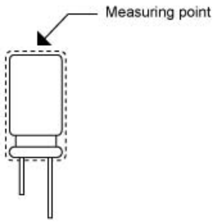
上面公式（3）显示电容器的温度上升与纹波电流的平方以及等效串联电阻ESR成正比，与电容器的表面积及散热系数成反比，因此，纹波电流的大小决定着产生热量的大小，且影响其使用寿命，电容器的类型以及使用条件影响着△T值的大小，一般情况下，85℃产品，△T≤10℃。105℃或更高温度产品，△T≤5℃。

由于直接测量电容器的中心温升存在着困难，下表列出了表面温升和中心温升的换算关系。

表3

直径	~10	12.5~16	18	22	25	30	35
中心温升/表面温升	1.1	1.2	1.25	1.3	1.4	1.6	1.65

The measuring point for temperature increase due to ripple current is shown below.



Test results:

(1) The life equation considering the ambient temperature and the ripple current will be:

$$L = L_d \times 2^{\left(\frac{T_o - T}{10}\right)} \times K^{\left(\frac{-\Delta T}{10}\right)} \quad \cdots\cdots\cdots(4)$$

Where L_d: Life at DC operation (h)

K: Ripple acceleration factor

(K=2, if with in allowable ripple current)

(K=4, if exceeding allowable ripple current)

T0: Maximum guaranteed temperature (℃)

T: Operating temperature (℃)

△T: Temperature increase at capacitor core (deg.)

(2) The life equation based on the life with the rated ripple current applied under the maximum guaranteed temperature will be a conversion of the above equation (4), as below:

$$L = L_r \times 2^{\left(\frac{T_o - T}{10}\right)} \times K^{\left(\frac{\Delta T_o - \Delta T}{10}\right)} \quad \cdots\cdots\cdots(5)$$

Where Lr: Life at the maximum guaranteed temperature with the rated ripple current (h)

△T0: Temperature increase at capacitor core, at the maximum guaranteed temperature (deg.)

(3) The life equation considering the ambient temperature and the ripple current will be a conversion of the above equation (5), as below:

$$L = L_r \times 2^{\left(\frac{T_o - T}{10}\right)} \times K^{\left[1-\left(\frac{I}{I_o}\right)^2\right] \times \frac{\Delta T_o}{10}} \quad \cdots\cdots\cdots(6)$$

Where in Io: Rated ripple current at the maximum guaranteed temperature (Arms)

I: Applied ripple current (Arms)

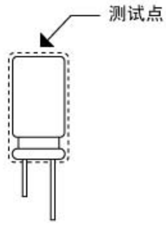
The life expectancy formula shall in principle be applied to the temperature range between the ambient temperature of +40℃ and maximum allowable working temperature. The expected life time shall be about fifteen years at maximum as a guide in terms of deterioration of the sealant.

4. Reliability

4-1 The bathtub curve:

Aluminum electrolytic capacitors feature failure rates shown by the following bathtub curve.

下图表示纹波电流引起的温升的测量点



测试结果：

（1）考虑环境温度和纹波电流发热的寿命公式为：

$$L = L_d \times 2^{\left(\frac{T_o - T}{10}\right)} \times K^{\left(\frac{-\Delta T}{10}\right)} \quad \cdots\cdots\cdots(4)$$

其中，L_d：直流工作电压下的使用寿命

K：纹波电流加速因子

（K=2，纹波电流允许的范围内）

（K=4，超过纹波电流范围时）

To：最高保证温度

T：工作温度

△T：中心温升

（2）基于上限温度和额定纹波电流发热的电容器的寿命计算公式可将上面（4）式转化得到，如下式：

$$L = L_r \times 2^{\left(\frac{T_o - T}{10}\right)} \times K^{\left(\frac{\Delta T_o - \Delta T}{10}\right)} \quad \cdots\cdots\cdots(5)$$

其中，Lr：工作在额定纹波电流和最高工作温度下的寿命（h）

△T0：最高工作温度下的电容器中心容许温升。

（3）考虑环境温度和纹波电流的寿命公式可由上面（5）式转化得到，如下式：

$$L = L_r \times 2^{\left(\frac{T_o - T}{10}\right)} \times K^{\left[1-\left(\frac{I}{I_o}\right)^2\right] \times \frac{\Delta T_o}{10}} \quad \cdots\cdots\cdots(6)$$

其中，Io：最高工作温度下的额定纹波电流（Arms）

I：实际施加的纹波电流（Arms）

寿命的推算公式，原则上适用于周围环境温度为+40℃到最高工作温度范围内，但从封口材料老化这个角度考虑，实际的推算寿命原则上最大为15年。

4. 可靠性

4-1 浴缸曲线

铝电解电容器的失效率特征可以用下图的浴缸曲线来描述