TECHNICAL REPORT
Structure, characteristics and failures

1. Electrostatic capacitance of capacitors

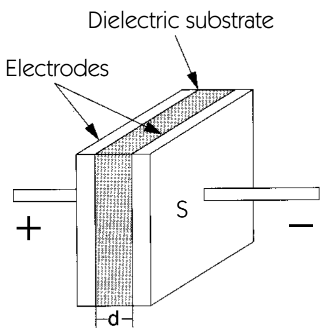


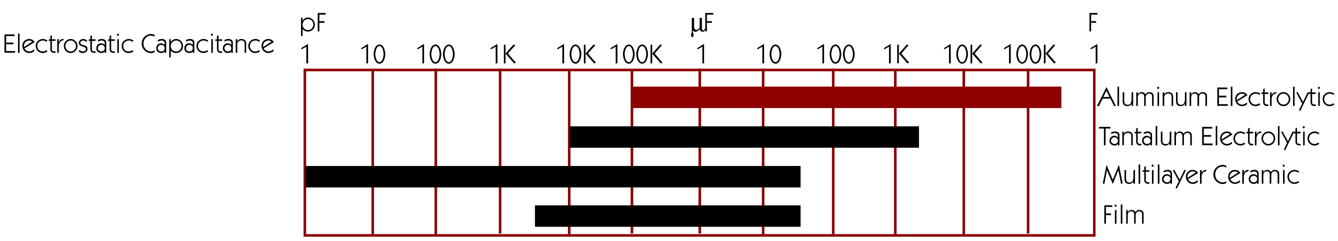
Figure 1. Basic Capacitor Structure

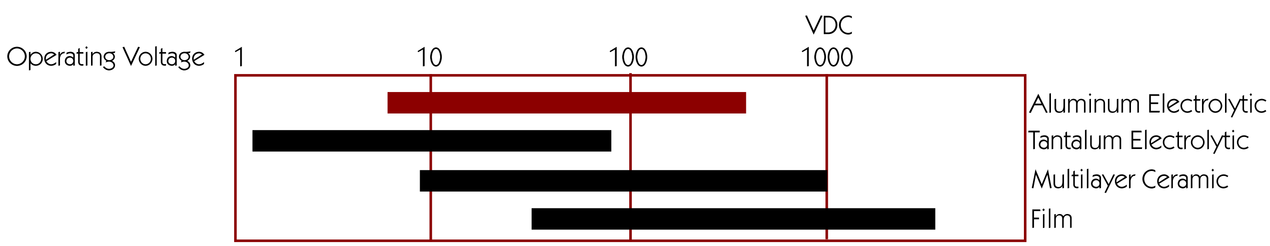
Capacitors have a structure like that shown in Figure 1, in which a dielectric substrate is sandwiched between two electrodes. The electrostatic capacitance (C) is:

$$C=\varepsilon\frac{S}{d} \qquad e=\varepsilon_r\,\varepsilon_0$$

ε_r :Proportional dielectric constant
ε_0 :Dielectric constant in a vacuum (8.85×10^{-12} F/m)
d :Distance between electrodes (m)
S :Electrode area (m^2)

2. Range of electrostatic capacitance and operating voltages for all capacitor types





3. Features of each type of capacitor

	Aluminum	Tantalum	Ceramic	Film
Dielectric	Aluminum Oxide (Al_2O_3)	Tantalum Tetroxide (Ta_2O_5)	Titanium Oxide Barium types, etc	Polyester, Polypropylene, etc.
Proportional Dielectric Constant	8 ~ 10	27	1500 ~ 15000 (Titanium Oxide Barium)	2.1 ~ 3.1
Package Style	Screw terminal, Snap-in terminal, Lead terminal, Chip	Chip (main type), dip	Chip (main type), dip	Chip dip (main type), Chip and case
Advantages	•Low price •Compact with large capacitance	•Compact with comparatively high electrolytic capacitance •Semi-permanent life	•Compact (especially multilayer types) •No polarity	•Good Characteristics •Can manufacture all voltages—low to high •High reliability
Disadvantages	•Short life at high temps •Large capacitance tolerance •Polarity (main type)	•Operation requires study of voltage derating •Polarity	•Large changes in electrolytic capacitance caused by temperature and DC voltage	•Large outside dimensions

4. Diagram of internal structure of aluminum electrolytic capacitors

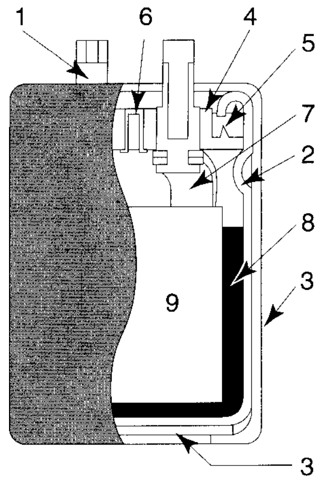


Fig. 2 - Diagram of Internal Structure

No.	Parts Name	Material
1	Terminal	Aluminum
2	Case	Aluminum
3	Exterior material	PVC
4	Insulation cap	PPS phenol
5	Rubber ring	EPT
6	Safety vent	Silicone rubber
7	Leads	Aluminum
8	Fixing compound	—
9	Element	See Fig. 3

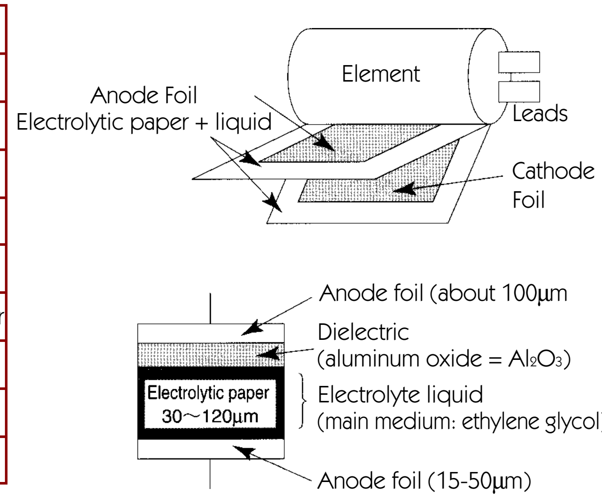


Fig. 3 - Diagram of Device and Basic Structure

5. Meanings of Terms

(1) Working Voltage (W.V.) and Surge Voltage (SV).

W.V. is the voltage that can be constantly applied, while SV is the maximum voltage that can be withstood for a short period of time (30 seconds according to JIS C5141).

Rated Voltage (V)	6.3	10	16	25	35	50	63	80	100	160	200	250	315	350	400	450	500
Rated Surge Voltage (SV)	8	13	20	32	44	63	79	100	125	200	250	300	365	400	450	500	550

(2) Permissible tolerance in electrostatic capacitance.

The allowable range of dispersion in electrostatic capacitance. Aluminum corrodes the electrodes (etches), which increases the amount of surface area and causes the dispersions.

(3) Equivalent Series Resistance.

The Equivalent Series Resistance puts together electrical resistance of negative and positive foils, electrolytic fluid resistance, and contact resistance of each connecting section.

(4) Tangent of loss angle (generally called Tan delta (tan δ)).

When current is placed on an ideal insulator, the current moves ahead 90 degrees in phase from the voltage. However, because some loss occurs in the general insulator, the forward angle of phase is 90°- δ). The δ is called dielectric loss. Tan δ is obtained by the following formula.

tan X = ω CR [$\omega = 2\pi f$ (f = frequency [Hz], C = electrolytic capacitance [F] and R = Equivalent Series Resistance [Ω].]

(5) Impedance Z (Ω).

Resistance in an AC circuit $Z = \sqrt{R^2+(\omega L-1/\omega C)^2}$

[R: Equivalent Series Resistance (Ω), C: electrolytic capacitance (F), L: inductance (H), $\omega = 2\pi f$ (f = frequency [Hz])].

(6) Leakage current.

DC current will not flow in a capacitor after it has been completely charged with DC current. However, dielectric resistance is not infiinite and a micro-current will flow through the capacitor. Electrolytic capacitors can be damaged during processing by an oxide film and when it is recovered the micro-current will flow.

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(7) Ripple Current

(I_{RMS}) Ripple Current is the RMS value of the alternating current flowing through the capacitor, measured in Amps. If the ripple current applied is higher than the specified maximum permissible ripple current, the life of the capacitor becomes shorter. In extreme cases the capacitor will rupture.

6. Manufacturing processes for aluminum electrolytic capacitors

(1) Etching (expanding surface area)

The processing for expanding the surface of aluminum foil. High purity aluminum foil, 500mm wide and 0.1mm thick is continuously processed electrochemically by flowing direct current through a chlorine bath solution. The surface area is expanded 50-100 times for low-voltage use capacitors and 10-40 times for medium to high-voltage use capacitors.

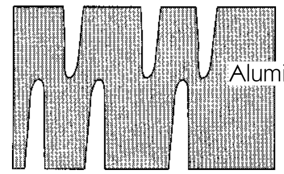

Fig. 4 - Diagram of etching model

(2) Forming (dielectric formation)

The process of forming the dielectric (Al_2O_3). The dielectric is formed in a continuous electrochemical process by passing a voltage that is 120-200 percent of the working voltage through etched aluminum foil that is in a bath of boric acid ammonium. The dielectric is extremely thin, about 14Å/V.

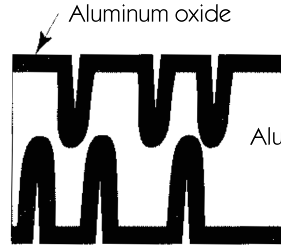

Fig. 5 - Diagram of formation model

(3) Slitting

The formed aluminum foil (positive electrode foil), negative electrode foil and electrolytic paper are slit according to the product size.

(4) Winding

Capacitors contain a positive (Anode) foil and a negative (Cathode) foil. These are separated by electrolytic paper and wound into a cylinder. The separator paper prevents the two foils from contacting each other and shorting.This "sandwich" of separator paper and foil is wrapped around the lead wires and tabs to form the capacitor element.

(5) Impregnation

The process of inserting the electrolytic liquid into the wound assembly by pressurization and depressurization.

The electrolytic fliud uses such things for solvents as boric acid and organic acid ammonium with ethylene glycol as a main medium. These have a very big effect on the life, frequency characteristics, range of operating temperature and temperature characteristics of the capacitor.

(6) Sealing

The impregnated assembly is sealed in an aluminum can. Sealing material is used to keep it airtight.

(7) Reforming (aging)

This is the process of applying voltage greater than the rated voltage of the capacitor at an elevated temperature to reform or repair dielectric that may have been damaged during assembly.

(8) Inspection of all parts

Inspection is made of the external appearance and the electrical characteristics of all aged parts.

(9) Sampling, packaging and shipping

An inspection is made according to fixed sampling standards and the capacitors that pass the inspection are packed and shipped. Detailed tests are made periodically to check quality.

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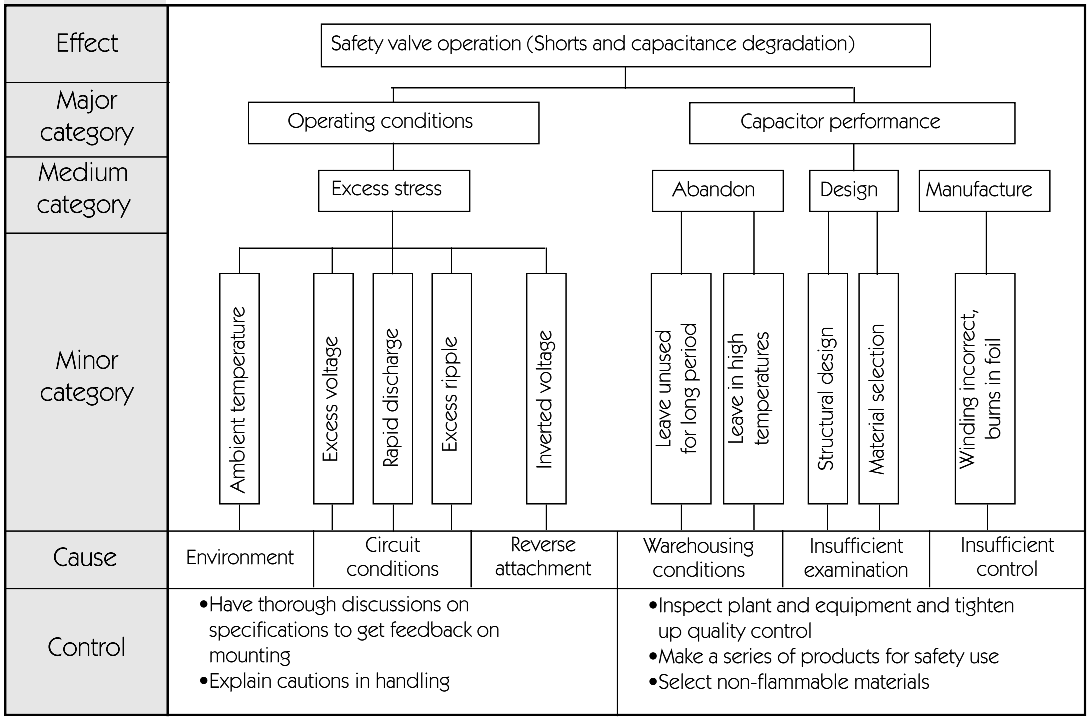
7. FTA map of failures



8. Formula for calculating the estimated service life of an aluminum electrolytic capacitor

The estimated service life of Hitachi AIC's mid-to-high pressure aluminum electrolytic capacitors can be expressed as follows:

$$L' = L_0 \times 2^{\frac{(T_0 - T')}{10}} \times \left(\frac{W.V.}{V'}\right) \quad \text{where} \quad (0.6W.V. \leq V' \leq W.V.)$$

T_0: Maximum core temperature setting when subjected to a maximum permissible ripple load at a maximum operating temperature.

L_0: Actual service life at a core temperature T_0 and with rated voltages W and V

L': Estimated service life at core temperature T' when voltage V' is applied.

(See Max. Core Temperature Rise Setting tables on the following page.)

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The tables below show the Maximum Core Heat-up Setting when subjected to a permissible ripple current (the value corrected by a specific temperature correction factor).

Max. Core Temperature Rise Setting (Snap-in Capacitors)

Snap-in Capacitors	Ambient Temp (°C)	MODEL NUMBER						
		HF2	HV2	HUL HVL	HP3	HU3 HU4 SS2 SS3	HL1 HL2	XL1
Core temperature rise setting at various ambient temperatures conditions (K)	40	17	17	17	30	30	30	30
	60 (55)	12	12	12	20	20	20	20
	70	9	9	9	15	15	15	15
	85	5	5	5	10	10	10	10
	105	—	2	2	—	5	5	5
T_0 (°C)		90	107	107	95	110	110	110
L_0 (h)		4000	4000	8000	4000	4000	8000	15000
Guaranteed service life (h)		2000	2000	5000	2000	2000	5000	10000

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Max. Core Temperature Rise Setting (Screw Terminal Capacitors)

Screw Terminal Capacitors	Ambient Temp (°C)	MODEL NUMBER									
		HCG7	HCGH (250W.V.)	HCGH (400W.V.)	HCGF5 HCGF6	FXA FX2	GXA GX2 (500V)	HXA	FXR	GXR	GXH
Core temperature rise setting at various ambient temperatures conditions (K)	40	21	31	35	31	35	35	35	40	40	—
	60 (55)	15	22	30	19	25	25	25	30	33	35
	70	—	12.5	15	12.5	—	—	—	—	—	—
	85	5	5	8.5	5	8.5	20	5	10	26	25
	105	—	2	5	—	—	5	—	—	6.5	10
T_0 (°C)		90	107	110	90	93.5	110	90	95	111.5	115
L_0 (h)		4000	4000	4000	4000	8000	8000	20000	8000	8000	8000
Guaranteed service life (h)		2000	2000	2000	2000	5000	5000	20000	5000	5000	5000

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9. Cautions in using Aluminum Electrolytic Capacitors

(1) General description of cautions

Table 2. Cautions in use

Item		Caution	What to do	Failure mode
Handling	Storage time limit *1	Store at room temperature and humidity with no direct exposure to sun. Maximum of 3 years.	Voltage application processing and replace	Increase leakage current and short
Handling	Shock	Do not drop or subject to bumping.	Recover	Tube cracks
Attachment	Polarity	Do not install in any way that would reverse polarity.	Replace	Heat emission and vent operation
Attachment	Stress on terminals	Do not rotate or bend.	Replace	Broken wires, shorts, leakage current increase
		Do not apply any external force after installation.		
Attachment	Terminal attach-ment torque *2	Recommend attaching at 2.2N•m, MAX3.0N•m.	Replace and re-tighten	Screws broken, overheating, baking
		Use pressure applied terminals of no more than 2mm thickness. (Hitachi standard screws)	Change screw length	Overheating, baking
Attachment	Soldering	Don't allow soldering iron to come in contact with can.	Recover	Tube melt, leakage current increase
		Solder for 10 seconds at 260°C or 3 seconds at 350°C.	Replace	
Attachment	Substrate cleaning *3	Never wash with halogen solvents (such as freon, chlorosen, trichlorine, triethane).	1. Clean with methyl alcohol, etc. 2. Recommend wash resistance capacitors	Broken wires (corroded)
Attachment	Methods	Do not disconnect the wires of the main circuits under the safety vent.	1. Leave a space of at least 3mm on top of the valve. 2. Change the position of attachment.	Short (apply dielectric liquid)
		Set so that it will not be subject to subsidiary heat from heat emitting bodies (transformers, resistors, reactor motors, etc.).	1. Change the position of attachment. 2. Reduce ambient temperature.	Temperature rise, leakage current increase and shorts
Attachment	Fixing	Do not place under the screw terminal.	Change method of attachment	Cut wires (loose device)
		Do not use in locations where it would be subject to constant vibration.	Change attachment location	Cut wires (loose device)
		Do not connect blank terminals of substrate independent type to circuits (4-pin).		Short
Voltage and current		Do not apply voltages higher than working voltage.	Replace and select appropriate part	Leakage current increase, short
		When AC overlaps DC, set the peak value of the AC voltage so that it is no higher than the working voltage.		
		Do not use in circuits that rapidly charge or discharge.	Recommend charge-discharge resistant capacitors	Heat emission: vent operation
		Do not apply excess ripple current.	Re-select, reduce ripple current	Heat emission: vent operation
		Do not use in AC circuits.	Recommend AC capacitors	Leakage current increase, short
Temperature		Use at or under operating temperatures.	Re-select, reduce ambient temperature	Leakage current increase, short

*1 See page 16 (2) reference *2 See page 16 (3) reference *3 See page 16 (4) reference

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(2) Storage time limit (leaving stored with no load).
Hitachi performs actual tests with capacitors left with no load at room temperature (1-5 years) and the results show that if these devices are left for three years or less, there is little increase in leakage current, and although there is some increase in leakage current after testing with those that are left three to five years, we have been able to confirm that the increase in temperature calculated here shows that this is not fatal.
This shows that **if the capacitors are used within three years, there will be no aging.** If more than three years passes, we recommend that they be aged under the following conditions.

First, apply 80 percent of working voltage, then 90 percent of working voltage, then finally apply working voltage for one hour (at room temperature).

(3) Attachment torque of M5 terminals.
Table 3 shows the results of measuring torque resistance on screws and terminals by inserting spacers with thicknesses of 1, 2, 3 and 4 millimeters, using M5 X 10 pan screws and testing attachment to the aluminum terminals. Table 3 also shows the relation between tightening torque, spacer thickness and contact resistance.

Table 3. Destruction conditions and torque with different spacer thicknesses.
Number of tests (Destruction torque test: 30 for each spacer thickness. Contact resistance measurements: 30 for each spacer thickness and torque.)

Spacer thickness (mm)	Destruction torque test					Tightening torque and terminal contact resistance (mΩ)					
	Destruction T (N•m)			Destruction conditions & numbers		Tightening torque (N•m)					
	Min	Max	X	Terminal screw top	Screw & head cut	0.5	1.0	1.5	2.0	3.0	4.0
1	5.6	7.0	6.2	5	25	0.20	0.12	0.07	0.06	0.06	0.06
2	5.7	6.9	6.2	8	22	0.24	0.11	0.08	0.07	0.06	0.07
3	5.4	6.0	5.7	15	15	0.22	0.13	0.07	0.07	0.06	0.06
4	3.8	5.7	4.5	26	4	0.20	0.12	0.07	0.07	0.07	0.10

Destruction torque was steady with spacers of 2mm thickness but at 3mm or greater, the values decreased and there was an increase in the terminal screw top destruction. The contact resistance also increased when the tightening torque was too low (10N•m or less) but stabilized at 1.5N•m or higher. These results allow us **to recommend an optimum tightening torque of 2.2N•m and a maximum of 3.0N•m.** We also recommend **a contact bar thickness of 2mm or less** (with M5 X 10 standard screws) and if the value is exceeded, we recommend the use of M5 X 12 or M5 X 15 screws.

(4) Horizontal attachment of screw types and washing resistant capacitors.
If standard snap-in terminal aluminum electrloytic capacitors are cleaned with freon, the positive electrode leads will **corrode and then break.** If the capacitors are cleaned with freon, we recommend using **cleaning resistant capacitors.** The following are generally used to deal with this problem.

1. Seal the inserting end (rubber boundries, surfaces and terminals) with resin.
2. Mix with dielectric liquid additive so that the inserted chlorine does not separate.

There are limits to the mix quantity and type with method 2, according to the type of cleaning agent and cleaning conditions. This is why Hitachi recommends the method of dealing with this problem using the cleaning resistant types in method 1 above.
The halogen compounds, including chlorine, are converted by negative ions into positive ions. Hitachi implements thorough chlorine control in its processes, but if you are unsure about the operating environmenrt or the devices are to be horizontally screw-mounted, **you should put the positive electrode terminals on top** so that dielectric liquid will not leak on the positive electrode leads. (Do not use in halogen environments.)

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(5) Balancing Resistor Selection.

Equation 1:

$$V_1 - V_2 = R_0 (I - I_1) - R_0 (I - I_2) = R_0 (I_2 - I_1)$$

Equation 2:

$$R_0^{[k\Omega]} = \frac{(V_1 - V_2)_{[V]}}{(I_2 - I_1)_{[\mu A]}} X\ 10^3$$

The following formula establishes the maximum permissible imbalance for divided voltage.

Equation 3:

$$V_1 - V_2 = W.V. - (V_0 - W.V.) = 2W.V. - V_0$$

(Here, W.V. is working voltage)

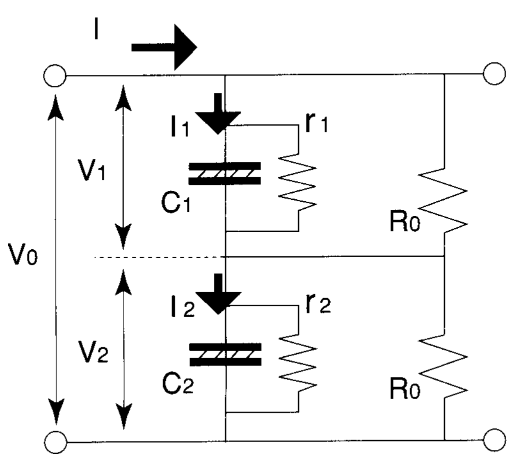
There are several different ways of finding out the actual leakage current value, but if we take the leakage current maximum value (Imax) to be the regulation value (Imax) X 0.5 and the leakage current minimum value (Imin) to be Imax X 0.1, then

Equation 4:

$$I_2 - I_1 = Imax - Imin =$$
$$Imax - 0.1\ Imax = 0.9\ X\ 0.5\ X\ I_{MAX} = 0.45\ I_{MAX}$$

Leakage current also has temperature characteristics, and the multiplier K for 20°C with 60°C and 85°C is approximately two and three times. If we insert this into Equation 2, we will then have the following equation:

$$R_0^{[k\Omega]} = \frac{(2W.V. - V_0)_{[V]}}{0.45\ X\ I_{MAX}\ X\ K_{[\mu A]}} X\ 10^3$$



C_1 and C_2 are the aluminum electrolytic capacitors
r_1 and r_2 are the internal capacitor resistances
V_1 and V_2 are the divided voltages for each capacitor
R_0 is the balancing resistor
V_0 is the line voltage