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An analyse on analogue ESR-meter

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Abstract. The paper presents an analogue ESR meter, made with a JFET integrated circuit, which can be used to identify defective electrolytic capacitors. It is powered by continuous voltage and consists of a differential voltage source, a 100 kHz oscillator, a Wheatstone bridge with resistors supplied with alternating voltage, in a connecting arm of bridge being connected the electrolytic capacitors to be checked, a voltage amplifier-comparator with optical warning, a high-pass filter and a voltage-current converter. At the output of voltage-current converter is a milliammeter pointing out the ESR value (up to 20 Ω). Measurements were made on a batch of electrolytic capacitors (new and used) and a comparative analysis was performed between the measured values with an analogue ESR-meter and a digital one.

1. Introduction

In present day, electrolytic capacitors are widely used in power electronics circuits and are the main sensitive components with the shortest life. Usually, the main functions in power sources of electrolytic capacitors are in power sources, bus voltage, stabilization, etc. [1-5]. Primary wear-out mechanism in electrolytic capacitors failures are deterioration of the electrolyte between electrodes and loss of electrolyte by vapours (dry-up).

The electrolytic capacitors have series internals resistances (ESR – equivalent series resistance) that increase with operating time, temperature and voltage [6-9]. Increasing of ESR conducts to heating of electrolytic capacitor and decreasing of capacitor value and increasing of tangent of loss angle (tan δ) [10]. Today, to fix the problems in electronic circuit must be used an oscilloscope, an analogue multimeter, a digital multimeter, and an ESR meter to verify electrolytic capacitors life.

2. Electrolytic capacitors. Design, using, and electrical models

Aluminum electrolytic capacitor is widely used in power electronics circuits. The main functions are: bus voltage, stabilization, etc. Most of electrolytic capacitors have maximum temperature ratings: 85 ^{0}C and 105 ^{0}C, and a few rated 125 ^{0}C [11], [12]. The aluminum electrolytic capacitor consists of (Figure 1): plastic insulation, aluminum, metal plate, dielectric, positive and negative charge connections.

There are different types of capacitors (Figure 2): ceramic capacitors, plastic capacitors, aluminum electrolytic capacitors, power capacitors, tantalum capacitors, double-layer capacitors and supercapacitors [13].

The electrolytic capacitors life is finite depending on electrolyte evaporation (dry-up of electrolytic capacitors). E.g.: at 35 ^{0}C, the electrolytic capacitors life is 16 years [10]. The electric conductivity depends of the type of capacitors (Figure 3).

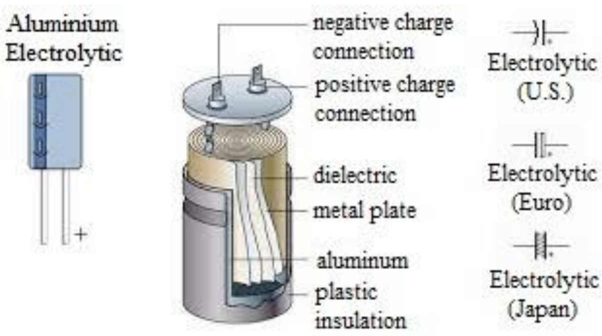

Figure 1. Design of electrolytic capacitor

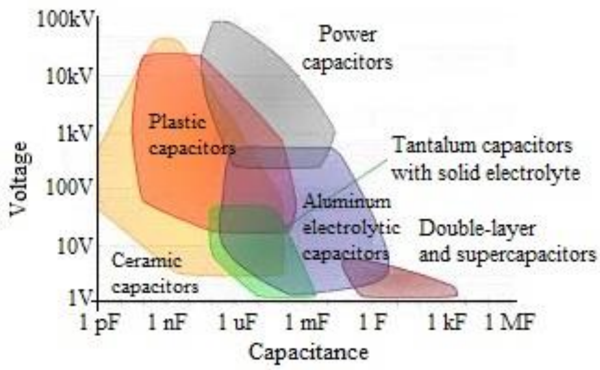

Figure 2. Typical capacitors used in practice

Capacitor life is defined as the time laps to the point when the capacitance value is decreased to 70% of the initial value. Usually, the capacitors users could not determine when should replace fault capacitors before they fail completely. Capacitor capacity decreases and tan δ increases after approximately 10000 hours of operation.

Electrolytic capacitors are sensible to: especially temperature and voltage, and humidity, temperature gradients, shocks and vibrations [11], [14], [15].

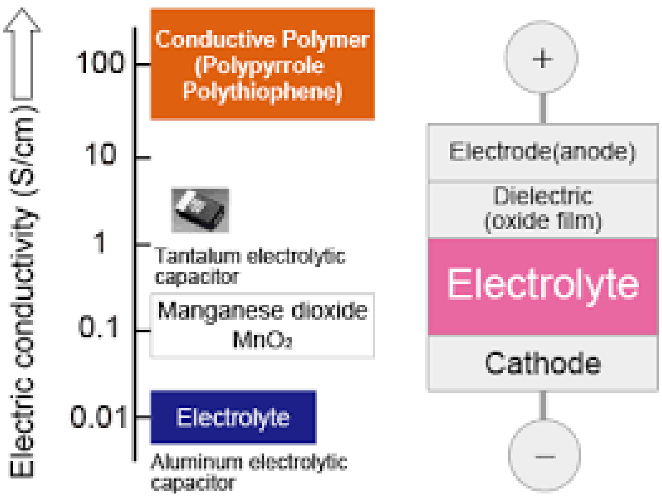

Figure 3. Electric conductivity depending on capacitors type

For switch mode power sources, the fault rate is [12]:

- 59% for electrolytic capacitors;
- 30% MOSFET;
- 5% coils;
- 2% diodes.
- 4 % others.

Capacitors have equivalent series internal resistance ESR that conduct to heating when ripple current flows [16]. The failure mechanisms and modes in aluminum electrolytic capacitor is presented in Figure 4 [17].

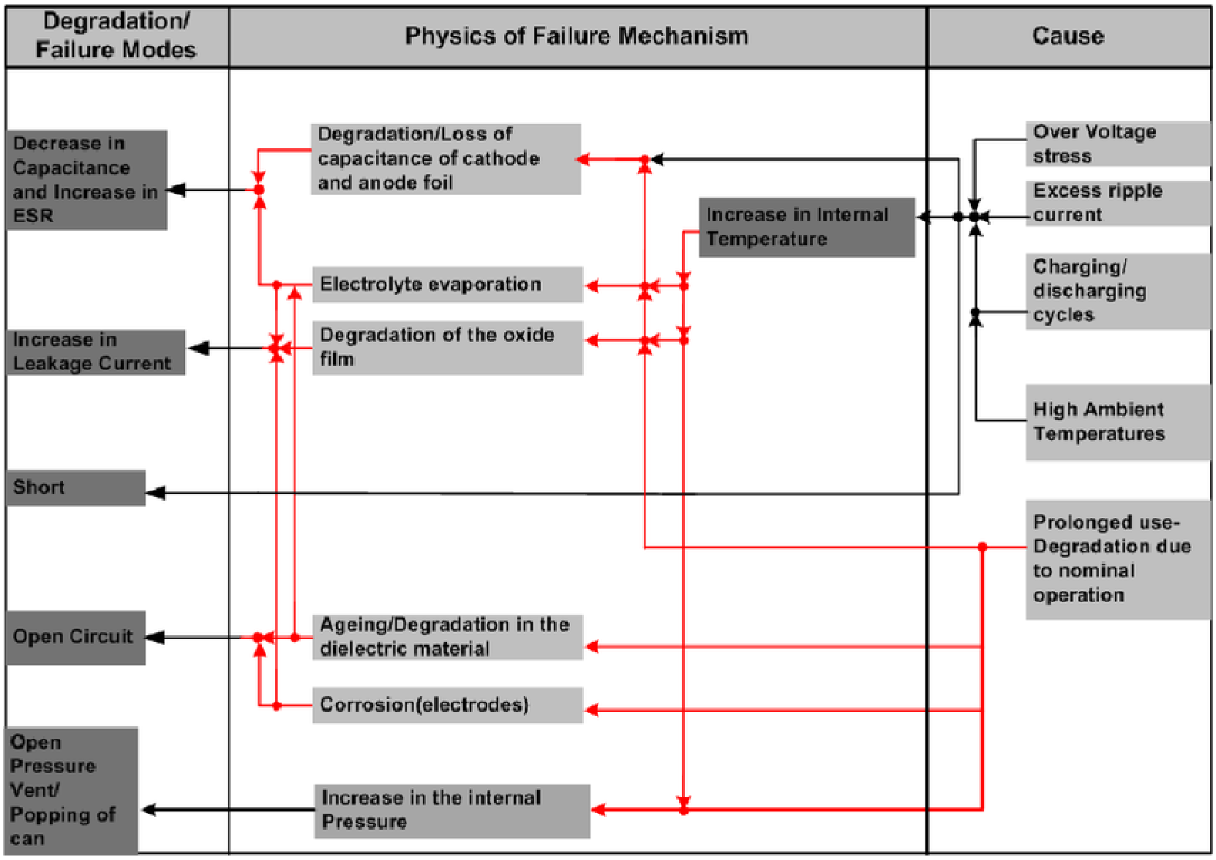

Figure 4. Failure mechanisms and modes in aluminum electrolytic capacitor [17]

Primary wear-out mechanisms in electrolytic capacitors is mainly due the loss of electrolyte by vapor diffusion and deterioration of the electrolyte. Typically, lowering the mass of the electrolyte leads to ESR growth (sometimes even 20 times), and capacitor capacity decreases by up to 40%. The detailed electrical model for electrolytic capacitor is presented in Figure 5.

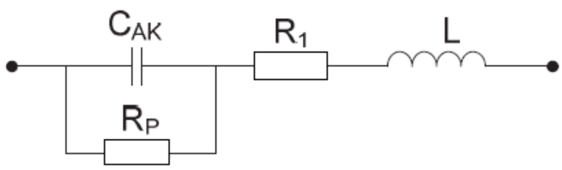

Figure 5. Detailed electrical model for electrolytic capacitor [4]

In Figure 5: C_{AK} is ideal anode-cathode capacitance (main element of the capacitor), R_P is the parallel resistance due to alumina layers, R_1 is series resistance of connections, frames and separator, and L is equivalent inductance series of connections and windings.

In practice, usually, is used simplified electrical model for electrolytic capacitor – Figure 6.

Figure 6. Simplified electrical model for electrolytic capacitor

$$Z_C = \sqrt{ESR^2 + \left(ESL \cdot \omega - \frac{1}{C \cdot \omega} \right)^2} \quad (1)$$

$$C = C_{AK} \cdot \left(1 + \frac{1}{R_p^2 \cdot C_{AK}^2 \cdot \omega^2} \right) \quad (2)$$

$$ESR = R_1 + \frac{R_p}{1 + R_p^2 \cdot C_{AK}^2 \cdot \omega^2} \quad (3)$$

$$ESL = L \quad (4)$$

3. ESR-meters

Troubleshooting power electronic circuits requires an investment in quality equipment. Today, to fix the problems in power electronic circuits must be used: an oscilloscope, a good analogue multimeter, a high quality digital multimeter, and an ESR-meter to verify electrolytic capacitors.

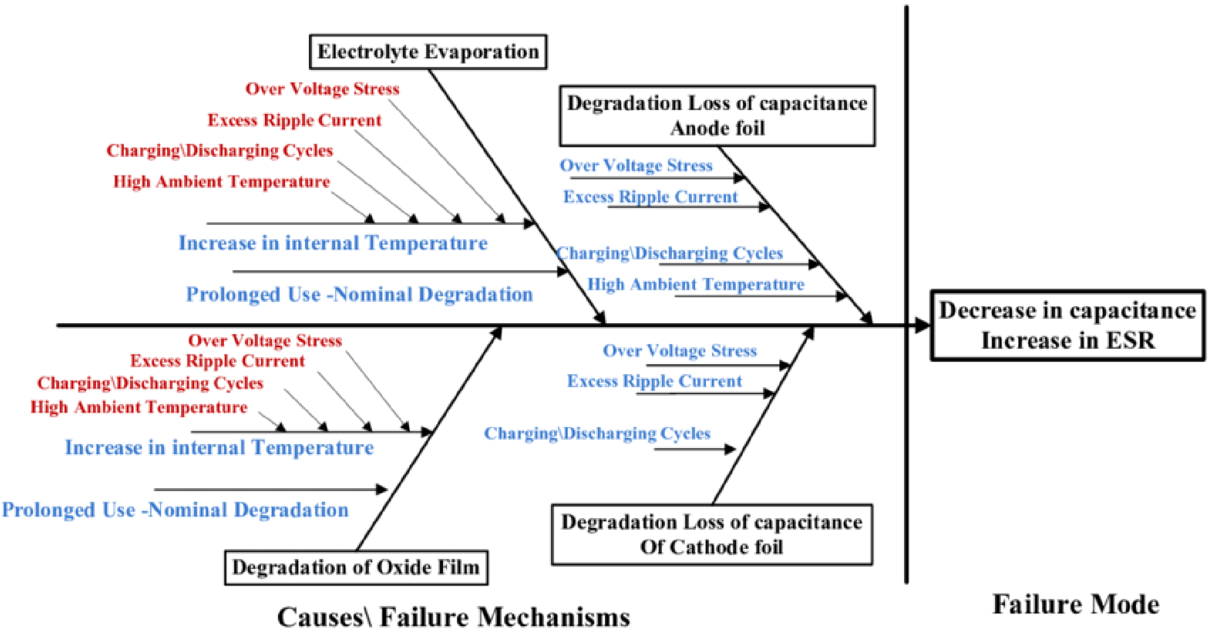

Figure 7. Fishbone diagram of failure mechanisms in aluminium electrolytic capacitor [18]

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During along a short time or a long time operation of aluminum electrolytic capacitors there are a lot of failure mechanisms which switch off the operation of electronic circuits (Figure 7).

An ESR meter is an instrument that measure of equivalent resistances for electrolytic capacitors (ESR). It is an alternating current meter using pulse or high frequency signals (tens of kHz). It can be used with AC measurement bridges.

The capacitor is measured either directly or in a circuit free of voltage, with the capacitor discharged, because the measured resistance will be less than any component from the circuit.

An ideal capacitor has a value close to 0 Ω (ESR). A second verification can be done with an ohmmeter.

If the ESR value is high, over 10 Ω, the capacitor is defective, regardless of capacity of capacitor.

Table 1. Maximum value for ESR (Ω) depending on nominal capacity of electrolytic capacitor and nominal voltage [9], [16]

Capacity (µF)	**10 (V)**	**16 (V)**	**25 (V)**	**35 (V)**	**50 (V)**	**100 (V)**	**160 (V)**	**250 (V)**
1					5.0	7.0	10.0	14.0
2.2					4.0	6.0	8.0	10.0
4.7			3.0	3.0	3.0	4.0	4.0	3.5
10		2.0	2.0	2.0	2.0	1.2	1.5	2.8
22	1.3	1.3	1.3	1.3	1.3	0.66	1.1	1.2
47	1.3	1.3	1.3	0.6	0.6	0.32	0.46	0.60
100	1.3	0.6	0.6	0.33	0.33	0.16	0.24	0.30
220	0.6	0.33	0.33	0.25	0.19	0.09	0.14	0.27
470	0.33	0.25	0.19	0.14	0.09	0.06		
1000	0.19	0.14	0.09	0.07	0.06			
2200	0.09	0.07	0.06	0.05	0.04			
3300	0.07	0.06	0.05	0.04				
4700	0.06	0.05	0.04	0.03				
10000	0.04	0.03						

4. Making an analogue ESR-meter

The analogue ESR meter is made with a JFET integrated circuit, which can be used to identify defective electrolytic capacitors (Figure 8).

It is powered by continuous voltage and consists of a differential voltage source, a 100 kHz oscillator, a Wheatstone bridge with resistors supplied with alternating voltage, in a connecting arm of bridge being connected the electrolytic capacitors to be checked, a voltage amplifier-comparator with optical warning, a high-pass filter and a voltage-current converter [16].

At the output of voltage-current converter is a milliammeter pointing out the ESR value (up to 20 Ω). Measurements were made on a batch of electrolytic capacitors (new and used) and a comparative analysis was performed between the measured values with an analogue ESR-meter and a digital one.

Components list (in Figure 8):

R1=1K5	C1,C2,C5,C6=1µF	R19=680 Ω	
R2,R3,R4,R5=10K	C3=1nF, POLY	R20=100 Ω	
R6=68K	C4=100nF, POLY	R21=500 Ω	
R7=4K7	DS1,DS2=1N4007	R10,R12=5,6 Ω, 1%	R14,R15 =1K
R8=12K	DS3=1N4148	T1,T3=BC547	T2=BC557
R9,R11=1K, 1%	DL1=LED	R13,R16,R17=47K	IC1=TL084

In Table 2: C(µF) – nominal capacity; U (V) – nominal voltage; C_m (µF) – measured capacity; ε_V (%) – percentage voltage loss; ESR_{max} (Ω) – the maximum ESR; ESR_d (Ω) – measured ESR with digital ESR-meter, LCR-T5 Multifunction Tester; ESR_a (Ω) - measured ESR with analogue ESR-meter; ε_{rESR} (%) – relative error for measuring ESR between analogue and digital ESR-meters.

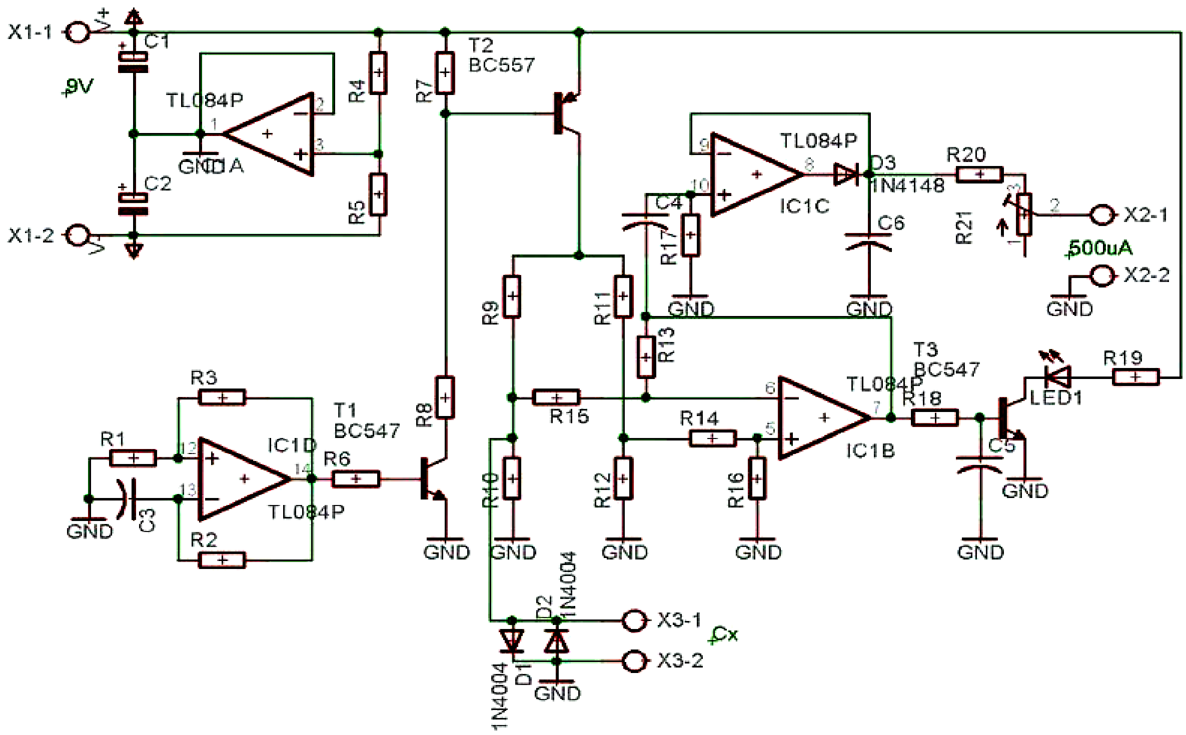

Figure 8. The electronic diagram for analogue ESR-meter [16]

Table 2. Measurements made on electrolytic capacitors (new and used) with digital and analogue ESR-meters

No.	C(μF)	U (V)	C_m (μF)	ε_V (%)	ESR_{max} (Ω)	ESR_d (Ω)	ESR_a (Ω)	ε_{rESR} (%)	Cap.
1	4.7	50	5.272	12.17	3	3.64	2.64	-27.47	√
2	10	25	11.81	18.10	2	3.94	3.44	-12.69	X
3	10	63	10.43	4.30	1.3	0.86	2.39	177.91	?
4	22	10	25.49	15.86	1.3	14	19	35.71	X
5	22	100	24.64	12.00	0.66	0.43	0.39	-9.30	√
6	47	10	48.73	3.68	1.3	13	> 20		X
7	47	10	57.03	21.34	1.3	17	> 20		X
8	47	10	61.57	31.00	1.3	1.14	1.29	13.16	√
9	47	16	46.1	-1.91	1.3	2.8	2.65	-5.36	X
10	100	10	102.8	2.80	1.3	1.24	0.99	-20.16	√
11	100	10	76	-24.00	1.3	11	18	63.64	X
12	100	10	109.3	9.30	1.3	2.6	3.2	23.08	X
13	100	10	97.91	-2.09	1.3	3.5	3.6	2.86	X
14	100	10	112.3	12.30	1.3	0.96	0.96	0.00	√
15	100	10	104.6	4.60	1.3	0.84	0.99	17.86	√
16	100	10	102.2	2.20	1.3	0.69	0.89	28.99	√
17	100	10	120.7	20.70	1.3	0.84	0.94	11.90	√

18	100	50	-		-	0.33	> 20		X
19	220	6.3	217.2	-1.27	1.3	0.46	0.49	6.52	√
20	220	10	164.6	-25.18	0.6	0.49	0.59	20.41	√
21	220	10	214.3	-2.59	0.6	0.15	0.49	226.67	√
22	220	10	214.5	-2.50	0.6	1.74	1.91	9.77	X
23	220	10	244.6	11.18	0.6	0.43	0.69	60.47	√
24	220	10	202.1	-8.14	0.6	0.32	0.59	84.38	√
25	470	10	506.4	7.74	0.33	0.23	0.24	4.35	√
26	470	25	128	-72.77	0.19	13	21	61.54	X
27	470	25	-		0.19	> 1000	> 20		X
28	470	25	-		0.19	> 1000	> 20		X
29	470	25	26x10-6		0.19	> 1000	> 20		X
30	1000	16	639.8	-36.02	0.14	0.21	0.54	157.14	?
31	1000	35	973.5	-2.65	0.07	0.12	0.04	-66.67	√
32	1000	50	705.1	-29.49	0.14	0.19	1.04	447.37	X
33	1000	50	932.3	-6.77	0.06	0.09	0.01	-88.89	?
34	1000	50	844.5	-15.55	0.06	0.1	0.09	-10.00	?
35	1000	50	932.3	-6.77	0.06	0.09	0.04	-55.56	?
36	2200	25	2219	0.86	0.06	0.08	0.04	-50.00	?
37	2200	25	2233	1.50	0.06	0.08	0.04	-50.00	?
38	2200	25	2219	0.86	0.06	0.08	0.04	-50.00	?
39	2200	25	2240	1.82	0.06	0.09	0.01	-88.89	?
40	3300	16	3447	4.45	0.06	0.08	0.01	-87.50	?
41	3300	16	3435	4.09	0.06	0.07	0.09	28.57	?
42	3300	16	3332	0.97	0.06	0.09	0.04	-55.56	?
43	3300	16	3493	5.85	0.06	0.09	0.04	-55.56	?
44	4700	25	5458	16.13	0.04	0.07	0.04	-42.86	√

Increasing the ESR over the maximum value is not related to a decrease in capacitor capacitance.

Some faulty capacitors have been identified with the analogue ESR-meter (the digital ESR-meter considers them good).

5. Conclusion

ESR-meter is an electronic device, relatively new introduced in power electronic troubleshooting. Using the ESR-meter to troubleshoot electronic circuits becomes an indispensable device because most of the power electronics failures are due to electrolytic capacitor failure. Sometimes measurements can be made without removing the capacitors in the circuit, so the repair time is greatly diminished.

ESR (Equivalent Series Resistance) is the sum of all internal resistors of a capacitor measured in ohms (reactance is not included). ESR is a dynamic size and must be measured at alternating voltage of tens of kHz.

Development of capacitors with long-life, high allowable ripple current and low impedance are effective to make high performance power supplies.

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