

# DOUGS TECH NOTES

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# Capacitor

 **WIZARD**<sup>®</sup>  
IN-CIRCUIT ESR METER

## The Mystery of Capacitor ESR Exposed

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Fig 1: ESR symbol

As technology meets the 21st century the need to test capacitors for ESR (Equivalent Series Resistance) has become a necessity. No longer is just measuring capacitance an adequate test. The increasing use of capacitors in high frequency, high power circuits demands low ESR. A test without measuring ESR is an **incomplete test**. Frequently capacitors pass capacitance tests yet are BAD due to high ESR! A bad capacitor may easily go undetected if you do not test for ESR.

### What is ESR?

ESR is an undesirable capacitor property initially determined by the manufacturing process. An ideal capacitor has 0 Ohms ESR. But we live in the real world. All capacitors have some ESR. ESR is the sum of all series resistances in a capacitor. ESR is lumped together and represented by a resistor in series with a capacitor as shown in Fig 1.

ESR includes:

- DC Lead Resistance
- DC Plate Resistance
- DC Connection Resistance
- All other DC Resistances
- AC Dielectric Resistance

ESR measurement requires specialized equipment like the Capacitor Wizard<sup>®</sup> which is specifically designed to measure ESR. 100kHz is the industry preferred frequency of measurement however ESR is NOT FREQUENCY DEPENDENT.

### Why Test for ESR?

High ESR can cause many circuit problems even though the capacitance may be correct! High ESR can cause:

- Overheating, explosion:
- Undesired phase shifts:
- RC time constant changes:
- Unwanted current limiting:
- Weird timing issues:
- Loss of power output:
- Reduction of filtering ability

In the words of Jim Brown, a Capacitor Wizard<sup>®</sup> owner, "If you don't use an ESR meter you are **JUST WASTING YOUR TIME!**"

### What are good/bad ESR values?

Electrolytics follow these *general* rules:

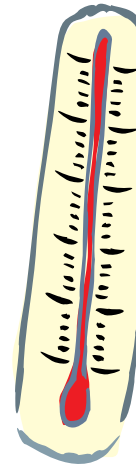
- 1) The higher the capacitance, the **lower the normal ESR**.
- 2) The higher the voltage, the **higher the ESR**.

It is our opinion that capacitors with ESR of 10 ohms and up are nearly always bad. ESR under 0.5 ohms is nearly always good. Values in between require comparison to a known good part or some knowledge of the circuit. **Experience is the best teacher.**

If you are working on a switching power supply you know the ESR should be low, less than 0.5 ohms no matter what the voltage. 1 or 2 ohms ESR would be highly suspect.

Don't worry, with a little experience you will quickly become an expert! You will be amazed at the number of bad capacitors you find!

### Temperature and ESR



An interesting property of electrolytic capacitors is the inverse temperature co-efficient. As temperature increases ESR decreases. As temperature decreases ESR increases.

Think about the possible failure scenarios. A symptom could be: "The equipment doesn't work when cold but gets better when warmed up." Remember

ESR decreases as a capacitor warms and increases as it cools. So it makes sense that freeze spray could be used to increase the ESR enough to cause a malfunction and locate the offending capacitor. Test capacitors at room temperature when using the Capacitor Wizard<sup>®</sup>.



### Electrolytic Capacitors

Electrolytic capacitors have the highest ESR failure rate. Why?

- Copper/aluminum junctions break
- Wet electrolyte dries
- Excessive heat / temperature cycling
- Overvoltage / overcurrent / abuse
- Chemistry changes
- Age

## Let's Test a Capacitor!

### First Measure ESR

We know the capacitors in figure 2 are bad because we can see they are **puffed out the top**. Let's confirm the 1000uf 16v is bad. ESR test results from the Capacitor Wizard® (Fig 4) show 2 ohms. We would expect a good 1000uf 16v capacitor to test below 0.5 Ohms. **This part is BAD due to high ESR.**



Fig 2: Bad Caps

### Measure Capacitance

Capacitance should be near 1000uf. It is only 339uf. The part is also **BAD** due to low capacitance. But even if the capacitance was near 1000uf the part is **still bad due to high ESR**. If a part fails the ESR test you don't need to check capacitance. **REPLACE IT!**



Fig 3: Fluke 87-V Multimeter



Fig 4: Capacitor Wizard® Cap1B



Fig 5: A low ESR capacitor. 680uf 50v  
ESR > 0.050 Ohm.  
Nichicon PW series  
Part # UPW1H681MHD

### Nichicon Iytic App Notes:

<http://www.nichicon.co.jp/english/products/pdf/aluminum.pdf>

### Buy Only Low ESR Caps

A capacitor's physical construction and chemistry determine ESR. Although the actual construction and chemistry is a closely guarded secret, capacitor manufacturers and distributors provide ESR ratings in their catalogs. Today you **must consider ESR** when selecting replacement capacitors, especially in switching power supplies and similar equipment.

I buy locally from Electronic Supply or mail order from **Mouser Electronics (Mouser.com)**. Mouser has **no minimum charge**, a large component inventory and their prices are the best in the country. The low ESR part shown in Fig 5 only costs \$0.80! I would consider the Nichicon **"PW"** series for:

- Miniature sized,
- Low impedance (ESR)
- High reliability

Designed for switching power supplies.

### My ESR Story

Over the years ESR has been a large problem with capacitors yet most technicians knew nothing about it! I didn't know about ESR until 1995. Now I know what was wrong with those mystery capacitors that always tested good yet substitution proved otherwise.

Years ago I repaired my fax machine. I saved the bad cap I found. 10uf 16v. It had passed a capacitance test every time but I had substituted it and knew it was bad. I had spent hours & hours on that simple repair before I tried substitution. I kept the part knowing someday I would be able to solve the mystery.

Today I know the problem was high ESR. The "good" capacitor had 20 ohms ESR! Consequently the whole power supply shut down. It was impossible to troubleshoot except by measuring part values or part substitution! Measuring capacitance misled me and cost me hours of time. Buy an ESR meter and save yourself time and grief!

### In Conclusion

This has been a brief introduction to ESR and it's detrimental effects on electrolytic capacitors and the electronics surrounding them. It is intended to show the technician the necessity of measuring ESR. I follow this rule: "If in doubt REPLACE."

Thanks for watching!  
Doug Jones