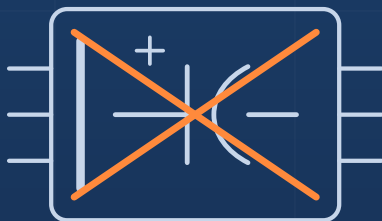


7 CAPACITORS YOU SHOULD NEVER USE

CAPACITOR SWAP GUIDE

Seven capacitors that drift out of spec, fail certification, or catch fire in a product. And exactly what to use instead.



MnO₂ TANTALUM
SHORTS AND IGNITES



POLYMER TANTALUM
NO OXIDIZER INSIDE

PREPARED BY
JOHN TEEL

DOC NO.
CAP-07

REV
A

SOURCE
[PREDICTABLEDESIGNS.COM](https://predictabledesigns.com)

Capacitor Swap Guide

Seven capacitors that fail in a product, and exactly what to use instead.

Capacitors are the most common part in your product, and the part nobody thinks about. They rarely get a second look, so the same seven mistakes show up in schematic after schematic that I review. One of them will fail safety certification outright, three of them make a product flaky in ways you can never reproduce on the bench, and one of them can catch fire when it fails, which is why some engineering teams have banned it from every board they build.

Each entry explains why the capacitor fails in a product and gives you exactly what to use instead. The list follows the same countdown as the video, starting with the parts that fill a cheap assortment kit and ending with the one that ignites. You do not need to memorize any of the part types or numbers, because they are all here.

The Guide at a Glance

#	NEVER USE	USE INSTEAD	WHAT IT COSTS YOU
7	Y5V or Z5U ceramics	X7R or X5R, and C0G for precision	82% of the value lost
6	0201 or 0402 with no space need	0603 as the default package	Defects and DC bias loss
5	Ceramic on an LDO that needs ESR	Tantalum or electrolytic with ESR	Oscillation and resets
4	X7R or X5R in a precision circuit	C0G, also called NP0	Timing off by 30% or more
3	Cheap electrolytic next to heat	105C, 5,000-hour parts, kept cool	Dries out, then reboots
2	Regular cap in an X or Y position	X2 on the line, Y1 on the barrier	Failed safety certification
1	Tantalum without heavy derating	Polymer tantalum, same footprint	A fire on your board

Every swap above is spelled out in its full entry, so keep reading before you release the schematic.

#7

Y5V and Z5U Ceramics

DIELECTRIC

WHY IT FAILS IN A PRODUCT

- The letter code on a ceramic capacitor tells you how it behaves over temperature, and for Y5V and Z5U the answer is badly. If you have ever bought one of those cheap capacitor assortment kits, there is a good chance most of it was one of these two.
- A Y5V capacitor is allowed to lose up to 82% of its capacitance across its rated temperature range, and Z5U is not much better at 56%. That 10uF cap you put on a regulator output might be acting like a 2uF cap inside a hot enclosure.
- These dielectrics also lose a big chunk of capacitance from DC bias, so the two effects stack on top of each other. Your bulk filtering and decoupling capacitors end up specified around a number the circuit never actually sees.

WHAT TO USE INSTEAD

THE SWAP	WHY IT MATTERS
Use X7R or X5R for decoupling and bulk capacitance	X7R stays within plus or minus 15% across its whole temperature range, which is a number you can actually design around.
Use C0G for anything small and precise	A class 1 ceramic holds its value anywhere the exact capacitance matters.
Check the dielectric code on every ceramic	The code is on the datasheet, and it is the only way to find out what a kit part actually is before it goes on a production board.

They cost a little more

X7R and X5R cost a little more than the parts in an assortment kit, but a 10uF cap that is still close to 10uF inside a hot enclosure is the difference between a filter that works and one that was specified around a number the circuit never sees.

#6

An Ultra-Small Package When Space Is Not Tight

PACKAGE SIZE

WHY IT FAILS IN A PRODUCT

- An 0402 is only 1mm long, and an 0201 is 0.6 by 0.3mm, which is basically a speck of dust. Drop one and it is gone, hand soldering an 0201 is nearly impossible, and reworking one on a finished board takes a microscope and a very steady hand.
- Even in mass production, the smaller the part, the more you invite defects like tombstoning, where one end of the part lifts off its pad during reflow, and solder bridging between pads that are almost touching. Some lower-cost assembly houses will not place 0201 parts at all or charge extra for them, and any rework on parts that small costs more per board.
- Squeezing a large value into a tiny package also hurts the circuit electrically because of DC bias. A 10uF ceramic in an 0402 was measured with almost no voltage across it, and on a normal 3.3V rail it can lose more than half of its value, so it is now doing the job of a 3 or 4uF cap.

WHAT TO USE INSTEAD

THE SWAP	WHY IT MATTERS
Default to 0603 for general-purpose capacitors	Go smaller only when you truly need the space or the better high-frequency performance that a smaller package gives you.
Check the DC bias curve at your operating voltage	Murata, TDK, and Samsung all publish DC bias data and have free online tools that show this curve for most of their capacitors.
Move up a package when the loss is too much	If the curve shows more loss than you can live with, step up to an 0603 or 0805, or try a different part number with a better curve.

Where DC bias bites you

A switching regulator or a bulk filter counts on a certain amount of capacitance for ripple, transient response, or stability. High-value ceramics use a dielectric that gets less effective as the voltage goes up, and squeezing 10uF into a tiny package means very thin layers, so the capacitance drops fast even at low voltages.

#5

A Ceramic Cap on an LDO That Needs ESR

REGULATOR STABILITY

WHY IT FAILS IN A PRODUCT

- Every capacitor has a little bit of resistance inside it called ESR, and some older linear regulators depend on that resistance to stay stable. Their control loop was designed when the output capacitor was always a tantalum or an electrolytic, and the ESR in those parts acts like a built-in damper for the loop.
- Put a ceramic capacitor on one of those regulators, with almost no ESR, and the loop can start oscillating. That shows up as a noisy output, a regulator that runs hot, or a microcontroller that resets for no obvious reason.
- The classic example is the LM1117, which asks for an output capacitor with an ESR between 0.3 and 22 ohms, and a typical ceramic capacitor sits far below that.

WHAT TO USE INSTEAD

THE SWAP	WHY IT MATTERS
Check the datasheet for the exact regulator	Most newer, higher quality LDOs are built to be stable with a low-ESR ceramic, but plenty of older designs are still out there.
Give an ESR-dependent regulator a tantalum or an electrolytic	Pick a part with an ESR inside the range the datasheet calls for.
Pick a ceramic-stable LDO if the transient dip matters	Any time the load current jumps, it flows through the ESR and creates a momentary dip in the output, so check the load transient response in the datasheet before you commit.

The trade an old regulator makes

A regulator that depends on ESR gives up some transient response to get its stability. When I was designing LDOs at TI, almost all of them were built to be stable with a low-ESR ceramic output capacitor, and most newer, higher quality LDOs are the same.

#4

X7R or X5R Where a C0G Belongs

PRECISION

WHY IT FAILS IN A PRODUCT

- X7R and X5R are class 2 ceramics, built to pack a lot of capacitance into a small size at the cost of some accuracy. For decoupling and bulk filtering that trade is exactly what you want, but anywhere the exact capacitance value matters it will wreck your design.
- X7R does not hold a value, it holds a range. You start with a tolerance of 10 or 20%, add about 15% of drift over temperature, then the DC bias loss, and then aging, because these dielectrics slowly lose capacitance just sitting on the shelf. Stack it all up and a filter corner or a timing interval can move by 30% or more.
- Class 2 ceramics are also piezoelectric, meaning they physically flex when a voltage is applied, and the reverse is true too. Vibration or even a tap on the board shows up as a voltage spike in your signal.

WHAT TO USE INSTEAD

THE SWAP	WHY IT MATTERS
Use C0G anywhere the exact value matters	That means RC timing circuits, oscillators, crystal load capacitors, active filters, and anything in a precision analog signal path.
Expect stability of about 30ppm per degree C	C0G, also called NP0, is a class 1 ceramic built for accuracy instead of size. It has no DC bias effect, no piezoelectric effect, and it barely ages.
Keep X7R for bulk and decoupling	Use X7R where you need bulk, and C0G anywhere the exact value matters.

What the swap costs

You can get C0G up to around 100nF in small packages and higher in larger ones. In the pF to low nF range where most timing and filter circuits live, it only costs a few cents more than X7R.

#3

General-Purpose Electrolytics Next to Anything Hot

LIFETIME

WHY IT FAILS IN A PRODUCT

- Aluminum electrolytic capacitors have a lifespan, and it is shorter than most people think. The cheap general-purpose ones might have only a 2,000-hour endurance rating at 85C.
- An electrolytic has liquid inside it, and that liquid slowly evaporates through the seal, faster when it is hot. Every 10C increase in temperature roughly cuts the life in half, so at 85C that 2,000-hour rating is less than three months of continuous operation.
- On a lot of boards these capacitors end up right next to a hot linear regulator, a power resistor, or a switching transistor, inside an enclosure with no airflow. When one finally dries out, the ESR climbs, the ripple gets worse, and you get a product that works for a year and then starts rebooting or humming.

WHAT TO USE INSTEAD

THE SWAP	WHY IT MATTERS
Use 105C parts with a 5,000-hour rating or better	This usually adds a few cents at most. Electrolytics are one of the few parts on a board that wear out over time, so plan for that from the start.
Keep them away from heat sources in the layout	Dropping the capacitor temperature to 45C takes that same rule of thumb to an estimated 32,000 hours, a little under four years of always-on use.
Replace it with a ceramic or a solid polymer aluminum	In a lot of low-voltage circuits that do not depend on ESR, a ceramic does the job, and a solid polymer aluminum still ages but has no liquid to dry out.

Do the math

Every 10C roughly cuts the life in half. A 2,000-hour part at 85C lasts less than three months of continuous operation, and the same part at 45C lasts about 32,000 hours.

#2

A Regular Cap Where an X or Y Cap Belongs

SAFETY

WHY IT FAILS IN A PRODUCT

- If your product plugs into the wall, there are two common spots where a regular capacitor becomes a shock and fire hazard. The first is across the incoming AC line, between line and neutral, where a capacitor keeps noise from getting into or out of your product.
- The second is a capacitor that crosses from the AC side over to the low-voltage side to reduce conducted emissions. It sits right on the isolation barrier, which is the only thing keeping mains away from everything the customer can touch.
- A capacitor across the line sees every surge and spike the power grid throws at it, and a regular film or ceramic capacitor was never tested for that. If it fails as a short across the line, you get a fault current that can start a fire, and if the one crossing the barrier shorts, mains voltage ends up on the side your customer is touching.

WHAT TO USE INSTEAD

THE SWAP	WHY IT MATTERS
Use an X2 capacitor across the line	An X-rated capacitor is tested to survive those surges. Because it sits between line and neutral, the danger if it fails is fire rather than shock, so the standard tests for exactly that.
Use a Y1 capacitor across the barrier	A Y-rated capacitor is built and tested so that a short circuit is extremely unlikely, and Y1 is the grade rated to bridge the barrier on its own. Together they cost well under a dollar.
Keep the safety approvals on file	The approvals are documented by the manufacturer, and a certification lab will want to see them.
Or keep mains out of the enclosure entirely	If this sounds like a risk you would rather avoid, a pre-certified external adapter takes it off your board.

Certification warning

Put a standard capacitor in either of those spots and the product fails safety certification, no matter how well the rest of the design was done.

#1

Solid Tantalum Capacitors Without Heavy Derating

FIRE RISK

WHY IT FAILS IN A PRODUCT

- This is the one capacitor on the list with a fire risk baked into its chemistry, even in a low-voltage circuit with no mains anywhere near it. A traditional solid tantalum uses manganese dioxide for one of its internal layers, and that is an oxidizer.
- When one of these capacitors fails, it usually fails as a short circuit, and if enough fault current is available, that spot heats up until the oxidizer and the tantalum react and the part ignites. These parts often fail right at power-up, when the inrush surge hits a tiny weak spot in the dielectric.
- A 16V tantalum on a 12V rail looks fine on paper, but under a proper derating rule it is way over the line, which is why some engineering teams have banned tantalums entirely.

WHAT TO USE INSTEAD

THE SWAP	WHY IT MATTERS
Use a polymer tantalum in the same footprint	Polymer replaces the manganese dioxide with a conductive polymer, so there is no oxidizer inside. It can still fail as a short, but that short is far less likely to turn into a fire.
Run polymer at 80 to 90% of the rated voltage	A manganese dioxide part has to stay at or below half of the rated voltage, and closer to a third on any rail that may see a surge.
Keep a derated traditional tantalum only where it still has a job	Polymer has higher leakage current, so an ultra-low-power standby circuit may still call for a heavily derated traditional part, and so does the output of an old regulator that needs ESR.
If you truly must use a manganese dioxide part, protect it	Derate it, put some resistance in series to limit inrush, and treat it as the most dangerous component on your board, because it probably is.

Cheap insurance

Polymer tantalums usually cost somewhere in the tens of cents per part in volume, which is cheap insurance against a fire.

The Six Capacitor Filters

Every capacitor on your schematic gets judged on the same six filters once it is inside a customer's product. Run your bill of materials through this list before you release the design.

1 Dielectric

Every ceramic on the board is X7R, X5R, or C0G, and nothing is Y5V or Z5U.

2 Package

General-purpose parts are 0603 unless you truly need the space, and every high-value ceramic was checked on its DC bias curve at the real operating voltage.

3 Stability

Every regulator output capacitor has an ESR inside the range its datasheet calls for.

4 Precision

Every timing, oscillator, crystal load, filter, and precision analog capacitor is C0G.

5 Lifetime

Every electrolytic is a 105C part rated for 5,000 hours or better, kept away from heat, or replaced with a ceramic or a solid polymer aluminum.

6 Safety

Any capacitor across the line is X2, any capacitor across the isolation barrier is Y1, and any tantalum is a polymer or a heavily derated part with inrush limiting.

Get a second set of eyes before you order boards.

Which of these seven capacitors is hiding in your schematic is exactly the kind of thing that gets caught in a review inside the Hardware Academy, where you can get help from me and other experienced engineers on your schematic, your layout, and everything else it takes to get to production.

PredictableDesigns.com/academy