Technical Article

Understanding the Difference between Capacitors, Capacitance and Capacitive Drop Power Supplies

TEXAS INSTRUMENTS

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Knowing the difference between a capacitor's rated value and its actual capacitance is key to ensuring a reliable design. This is especially true when considering high-voltage capacitors used in capacitive drop power supplies for equipment like electricity meters, since losing too much actual capacitance may result in insufficient power to support the application.

With a capacitive drop power supply, the high-voltage capacitor is typically the largest (and one of the more expensive) components in the circuit. When sizing capacitors, it is essential that the actual capacitance can support the load current that the design requires.

Figure 1 shows the existing capacitance values of capacitors available from a capacitor manufacturer, Vishay. Let's assume that your design calculations show that your design requires a 1-µF capacitor (90 V_{AC_RMS} at 60 Hz and 5 V_{OUT} @ 25 mA). Considering the available capacitors, you might choose a 1.2-µF capacitor to accommodate the manufacturer's tolerance of 20%. However, taking into consideration the capacitor's tolerance and aging effects, you may see a 50% reduction in the actual capacitance of your capacitor over time. In other words, in the worst-case scenario, the 1.2-µF capacitor you chose may only have 0.6 µF of capacitance at its end of life.

ELECTRICAL DATA AND ORDERING INFORMATION

U_{RAC} (V)	CAP. (µF)	DIMENSIONS w x h x l (mm)	MASS (g) (3)	CATALOG NUMBER F339X1... AND PACKAGING						
				LOOSE IN BOX					TAPED REEL	
				SHORT LEADS			LONG LEADS			
				l_t = 3.5 mm + 1 mm/- 0.5 mm (≤ 10 mm) or 3.5 mm ± 0.3 mm (≥ 15 mm)	l_t = 5.0 mm ± 1.0 mm	SPQ	l_t = 25.0 mm ± 2.0 mm	SPQ	Ø = 500 mm (1)(2) H = 18.5 mm; P_0 = 12.7 mm	SPQ
	PITCH = 22.5 mm ± 0.4 mm; d_t = 0.80 mm ± 0.08 mm; C-TOL. = ± 20 %									
	0.10	6.0 x 15.5 x 26.0	2.4	41033MIP2T0	41033MIM2T0	300	41033MII2B0	250	41033MI02W0	600
	0.15			41533MIP2T0	41533MIM2T0		41533MII2B0		41533MI02W0	
	0.22	7.0 x 16.5 x 26.0	2.9	42233MIP2T0	42233MIM2T0	200	42233MII2B0	250	42233MI02W0	500
	0.33	8.5 x 18.0 x 26.0	3.8	43333MIP2T0	43333MIM2T0	200	43333MII2B0	250	43333MI02W0	450
	0.47	10.0 x 19.5 x 26.0	6.8	44733MIP2T0	44733MIM2T0	200	44733MII2B0	200	44733MI02W0	350
	0.68	12.0 x 22.0 x 26.0	7.8	46833MIP2T0	46833MIM2T0	150	46833MII2B0	200	46833MI02W0	300
	0.82	12.5 x 22.5 x 26.5	7.8	48233MIP2T0	48233MIM2T0	140	48233MII2B0	400	48233MI02W0	300
	PITCH = 27.5 mm ± 0.4 mm; d_t = 0.80 mm ± 0.08 mm; C-TOL. = ± 20 %									
	0.22	9.0 x 19.0 x 31.5	5.5	42233MKP2T0	42233MKM2T0	100	42233MKI2B0	150	-	-
	0.33			43333MKP2T0	43333MKM2T0		43333MKI2B0			
	0.47			44733MKP2T0	44733MKM2T0		44733MKI2B0			
	0.68	11.0 x 21.0 x 31.0	7.4	46833MKP2T0	46833MKM2T0	100	46833MKI2B0	125		
	1.0	13.0 x 23.0 x 31.0	9.2	51033MKP2T0	51033MKM2T0	100	51033MKI2B0	125		
	1.5	18.0 x 28.0 x 31.5	16.1	51533MKP2T0	51533MKM2T0	100	51533MKI2B0	100		
	2.2	21.0 x 31.0 x 31.0	20.3	52233MKP2T0	52233MKM2T0	50	52233MKI2B0	75		

Figure 1. Sample range of high-voltage capacitors available from manufacturer Vishay

Wait, aging is an issue? If the application is expected to work for 10-plus years, it is not unreasonable to assume that film capacitors may lose ~25% of their capacitance over the lifetime of the product, due to operating temperature, load current and humidity. Table 1 shows a prediction of the total capacitance after considering worst-case tolerance and aging.

Table 1. Tolerance and aging effects on actual capacitance

Capacitor (μF)	Worst-Case Initial Capacitance (μF)	10-Year Aging (μF)
0.1	0.8	0.06
0.15	0.12	0.09
0.22	0.176	0.132
0.33	0.264	0.198
0.47	0.376	0.282
0.68	0.544	0.408
0.82	0.656	0.492
1	0.8	0.6
1.5	1.2	0.9
2.2	1.76	1.32

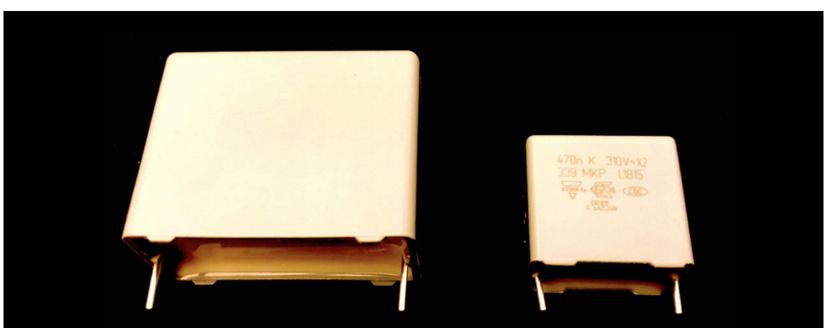
Considering the effects of the tolerances, the best choice to support a 25-mA load at 5 V_{OUT} in a traditional capacitive-drop architecture is a 2.2-μF capacitor, but comes with serious size implications. Is there a better way?

One way to mitigate the effects of capacitance loss due to aging is to simply use a lower-value capacitor. For example, if you used a step-down converter to reduce a DC-rectified 20 V down to 5 V, with perfect efficiency you could maintain 25 mA at the 5-V output, but you would only need to size the high-voltage capacitor to support 6.25 mA. To clarify – in the above example, if a linear power solution required 1 μF, a four-time reduction in voltage will yield a four-time increase in load current capability. In this example, 1 μF reduces to 0.25 μF.

Looking at the same derating for tolerance, you would calculate the need for a 0.3-μF capacitor, yet the next available capacitor has a value is 0.33 μF. Add to that the aging effects, and the next available capacitor you should consider is actually 0.47 μF.

The only problem with a DC/DC step-down converter in applications like electricity meters is that they tend to require a very high level of tamper immunity. Preventing external magnetic fields from impacting the design's additional circuitry requires Hall-Effect sensors or a tamper-proof enclosure, which adds additional cost.

One way to resolve the issue of the oversized capacitor and still support tamper immunity is to use a nonmagnetic step-down converter. TI's TPS7A78 voltage regulator requires no transformers or inductors to produce a nonisolated low-voltage output. The TPS7A78 reduces a 2.2-μF capacitor to 0.470 mF, guaranteeing 25 mA of load current over the life of the product. Figure 2 compares the area and volume of the two capacitors.



Cap μF	w	l	h	Area (mm^2)	Volume (mm^3)
0.47	5	18	10.5	90	945
2.2	18	31.5	27.5	567	15592.5

Figure 2. Area and volume comparison of two high-voltage capacitors

So why do smaller capacitors matter? The obvious answer is the overall solution size. But the less obvious benefits are standby power and efficiency. Reducing the amount of capacitance required by four times reduces standby power from ~300 mW down to ~77 mW. Adding the intelligent clamp circuit behind the TPS7A78 supporting a 25-mA load cuts down the total standby power to ~15 mW.

Knowing how to minimize the capacitor to ensure enough capacitance saves cost for both the manufacturer and the consumer when using capacitive drop power supplies.

Additional resources

- To learn more about LDOs, check out the e-book, LDO Basics.
- See how to use a switcher in the application report, Cap Drop Offline Supply for E-Meters.