POWER-SUPPLY CAPS

UNFORTUNATELY, I WAS disappointed by the new outboard DAC series (*AE* 4/96–3/97), specifically the choice of power-supply capacitors. With exotic circuits and regulators regularly featured, I'm surprised that no one has given good current information on power supply capacitor selection in your magazine yet.

Panasonic FA series electrolytics have been available for years and have lower ESR than HQ types or any other electrolytic capacitor that I've measured. I have used a Wayne-Kerr electronic multi-bridge to evaluate capacitors for power supplies, and FA-series caps have very low ESR and ESL. The largest physical sizes are the best, good even past 300kHz, the limit of my test equipment. Readers can use the ESR figures in Digi-Key's catalog as a guide.

Panasonic stacked film caps are nearly useless in power supplies. A far better choice is a standard metalized polypropylene (mpp) or aluminum foil and polypropylene film capacitor above a minimal size (below that size the small end terminations raise the ESR by a factor of ten or more). A 50V 0.22µF cap is generally the smallest acceptable by my measurements. Greater capacitance lowers ESR at low frequencies. Higher voltage ratings than necessary do not improve ESR—it would be better to have a capacitor of the same size with a lower voltage rating and more capacitance.

Film capacitor choice for bypassing is very difficult. I've found that I need to test every type on a bridge. The choice cannot be made on purchase price alone. Some modestly priced metalized polyprops have lower ESR than more expensive capacitors.

The Panasonic stacked film caps are not among the better film bypasses. It would be unfair to mention brands I've personally used or avoided because I have not had many to test. However, because a film capacitor is good in the signal path does not mean it is good as a power-supply bypass.

For high-frequency bypasses as in digital circuits, there are some ceramic capacitors designed for low ESR that should be used as close as possible to IC pins. I don't have the equipment to test high frequencies, so I can't comment further.

Finally, I should add that my ears have confirmed everything I've measured on a test bridge—and vice versa. I've replaced some DAC bypasses in my Marantz CD63 with mpps from my junkbox and was disappointed. The bridge showed my junkbox caps had the lowest ESR. I've also tried adding the recommended Panasonic stacked film caps to circuits and heard no difference. The bridge revealed that they did not lower the ESR of the power supply, thus contributing nothing.

Mark Kaepplein
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RE-CAP

After a surprise reading of Mark Kaepplein's "Power-Supply Caps" letter in *AE* 4/98 (p. 42), I decided to look into some current Panasonic electrolytics. The general tone of Mr. Kaepplein's letter seemed to be that *AE* readers have been done a grave disservice by authors recommending inferior, outdated caps. Unfortunately, many of the letter comments don't hold up when held to close scrutiny.

For example, there is the stated conclusion that the FA series "have lower ESR than HQ types or any other electrolytic capacitor that I've measured" (an editorial note here: the assumption is that what was really meant was Panasonic type "HFQ," since that is the high-performance type recommended by Hank Zumbahlen in his DAC project, as well as by myself and others; there actually is no "HQ").

Table 1 is a brief comparison of three capacitor families, Panasonic HFQ, FA, and FC, taken from the most recent Digi-Key catalog data (Jan./March 1999). Data is displayed with the suggested 100kHz ESR specification criterion, and the four values chosen are common to all three families.

It is not at all obvious where the big differences Mr. Kaepplein alluded to are hidden within this data. Yes, there is a slightly lower ESR in the FA and FC types in some (but not all) sizes/values, but nothing to get up in arms about. The FA and FC series do offer a slight edge in sizing options for these values, a possible plus in their favor. But, in equal value, apples-versus-apples cases, you could use any of these caps.

Some actual measured data for HFQ and FC 120µF/25V types is also useful for further perspective (this value/voltage isn't covered by the table, due to nonavailability in the FA family). This particular value/voltage has been used in past *TAA* projects, and illustrates a couple of points.

Figure 1 shows measured impedance curves for HFQ and FC types, over a range of 20Hz to 200kHz. The measured 100kHz ESR is 180Ω and 200mΩ, respectively, both less than HFQ and FC specifications of 200 and 250mΩ. Although the differences aren't huge, in this value/voltage, the HFQ type would actually be preferred in performance terms. *Figure 2* shows what can be done to lower ESR with three parallel FC 120µF/25V units. The 70mΩ 100kHz ESR compares favorably with 330µF/25V single units above.

So, the moral here is that you need first to interpret manufacturer's data with some careful thought. Given that, it is reasonable to conclude that any of the capacitors from *Table 1* are good choices. Also, when seeking low ESR, you should also consider shunt connections, as well as higher-performance families. As for the lowest ESR electrolytic capacitor family, my opinion, as well as my experience, is completely different from Mr. Kaepplein's. Measured data on comparable value units in the Sanyo "Oscon" line shows a 100kHz ESR nearly an order of magnitude lower than the *Fig. 1* 120µF/25V types. Unfortunately, these proprietary types just aren't as readily available.

I urge caution for anyone using ceramics as bypasses, as they have parasitic effects not seen in films. For example, other than the relatively stable NPO ceramic dielectric types (which really aren't practical as bypasses), the cheaper ceramics can exhibit nonlinear voltage effects as well as microphonics (see letters "PCB Possibilities," *AE* 1/98, and "Performance Levels," *AE* 3/98). When using high-K ceramics as bypasses, you need to ensure that the chosen value and ESR, along with the surrounding circuit, is such that the capacitor never sees appreciable terminal voltages. Otherwise, the capacitor's nonlinear capacitance-versus-voltage response can produce spurious responses.

Finally, I have difficulty following the exact reasons Mr. Kaepplein dislikes stacked films so much, and am disappointed that he offers no specific manufacturer's film family alternate, nor any actual performance data or comparisons. Specifics of a component's generic type, the manufacturer model number, and ready sources are bread-and-butter to the home constructor. "Panasonic stacked film caps are nearly useless in power supplies" is obviously an opinion, not a solution offering a viable alternative.

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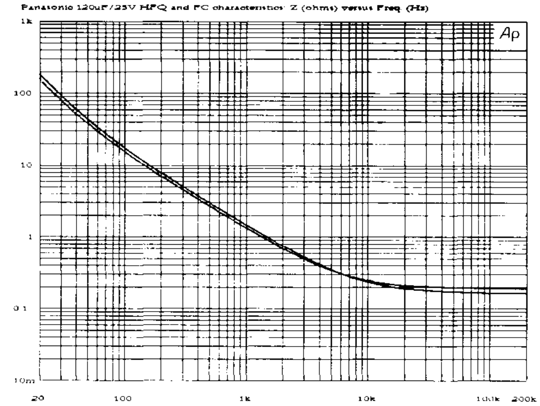

FIGURE 1: Panasonic 120µF/25V HFQ and FC characteristics. Z (ohms) versus frequency (Hz).

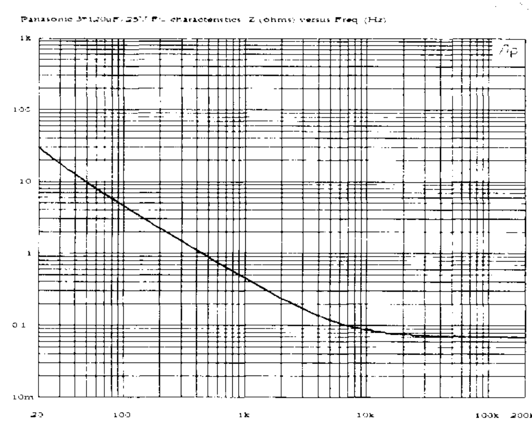

FIGURE 2: Three 120µF/25V FC units. Z (ohms) versus frequency (Hz).

In *AE* (4/98) Mark Kaepplein takes me to task for my choice of caps used as power-supply bypasses. The crux of the argument was the lower ESR of Mr. Kaepplein's chosen capacitor types invalidated the DAC article.

I guess my first question is what aspect of the DAC's performance was he disappointed in? Was it the soundstage, low-level resolution and linearity, noise performance, or just exactly what? I think that judging a design strictly on a component used in the design as opposed to actually measuring and listening to the design is ludicrous.

Has Mr. Kaepplein actually measured or, more importantly, listened to my DAC? My guess is that he has not. Without getting into the meter readers vs. golden ears argument again, isn't the object of the exercises to create an audio experience? As a side note, the old meter readers generally relied on system measurements of THD and frequency response, for example, rather than isolated component analysis on an impedance bridge (i.e., out of circuit).

As for the caps in the power supplies,

TABLE 1

Panasonic type	33µF/25V ESR(mΩ)	1000µF/25V ESR(mΩ)	2200µF/25V (mΩ)	4700µF/25V (mΩ)
HFQ	90	34	21/28(2 sizes)	17
FA	85/90 (2 sizes)	35/38 (2 sizes)	18/22 (2 sizes)	15
FC	85/90 (2 sizes)	38/43 (2 sizes)	22/28 (2 sizes)	15

several factors affected the types of caps selected. ESR was a consideration, as were size, price, and availability. I designed this with the idea that some people would be building copies, which, unfortunately, does not seem to be the case. Because of this objective, however, I tried to use easily available components wherever I could.

With the number of parts on the boards, size became a consideration. The same with cost. In designing a piece of equipment such as this, compromises are often involved. I believe that I made reasonable choices. If Mr. Kaepplein thinks that he could improve on the design, more power to him. But that doesn't mean that my design has no merit.

Commenting on the decoupling caps, the optimum type of decoupler would be a surface-mount MLC (multi layer ceramic), which have very low ESR. The fact that these caps have no leads means that the lead inductance is low. The difficulty is the extremely small size makes them difficult to work with (at least for me).

Perhaps a review of what the individual caps were designed to do is in order. The large-value capacitors can be considered a reservoir of charge, to provide instantaneous current requirements of the circuit. Having the local reservoir close to the circuit minimizes the effects of trace inductance and resistance. The small-value caps are supposed to shunt the noise on the power supply away from the amplifiers.

Remember that the power-supply rejection (PSRR) goes down with increasing frequency. The power supply is very much part of the signal path and must be treated as such. That is the reason that the regulators were designed the way they were. I would be interested in further explanation of Mr. Kaepplein's statement that stacked films are useless in this application. His letter does not include justification for this broad comment.

Mr. Kaepplein writes that he is satisfied with his DAC upgrade. I am happy for him. I am satisfied with my design as well. Even though there might be some "builder bias" in these opinions, I have had many responses on my DAC from third parties who have actually listened to it. I would encourage Mr. Kaepplein to open his mind and listen to the result rather than trash a design he has not heard.

Hank Zumbahlen

CORRECTED VALUES

Some unfortunate errors crept into my letter entitled "RE-CAP" (*AE* 3/99, p. 40). In the last full paragraph in the first column, the second sentence referencing measured 100kHz ESR should read "... 100kHz ESR is 180 and 200mΩ, respectively, ..." In the table at the bottom right of the same page, the first capacitor value/voltage column should be labeled "330µF/25V." All of the tabular data presented is in terms of 100kHz ESR (in mΩ).

On a related note, some time after I collected the above referenced letter's data and sent the letter to *AE*, I tested samples of a new electrolytic capacitor type from Rubycon. These capacitors, type "ZA," are intended to offer "One-Third the Impedance of Conventional Low-Imp Capacitors at 100kHz, 20° C" (a quote from their ad). On the 100µF/25V samples I tested, they did indeed provide that level of impedance, measuring a Z of about 60mΩ at 100kHz (i.e., Z ~⅓ of the Panasonic 120µF/25V HFQ or FC series). While this performance is not quite as good as a comparably sized Oscon capacitor, it is appreciably better than the referenced Panasonics. Information can be obtained from Rubycon America, 4293 Lee Avenue, Gurnee IL, 60031, (708) 249-3450, or http://www.rubycon.com.

Walt Jung