Replacing Passive Components to Improve Sound Quality

by Paul J. Stamler

From reading circuit design texts, one would think that a capacitor is just a capacitor and that different types are interchangeable in practical use. In fact this isn't so; capacitors differ drastically in engineering performance, and their sonic impact varies too. Capacitors ("caps" for short) don't act like pure capacitance; at high frequencies, capacitors exhibit inductive behavior, so their impedance actually rises with increasing frequency; a pure capacitor's impedance would fall. At the transition frequency where the device changes from capacitative to inductive behavior, there is a minimum impedance that can be thought of as a resistance in series with the capacitor. This is called the "equivalent series resistance," or ESR, of the capacitor. In any application, but especially in power supply capacitors, the lower ESR units perform better.

Capacitors also leak. In theory, a capacitor blocks all DC and passes only AC (including audio). In practice, however, a capacitor will pass some direct current; some types, such as film capacitors, pass almost none, while many electrolytics leak a lot. (Incidentally, most power supply caps leak a great deal when the piece of equipment is first turned on; they stabilize after about 30 minutes, and leak less. This is one of the reasons equipment sounds better after it's been warmed up.) Replacing capacitors with low-leakage units is always a good idea. Finally, capacitors exhibit a curious behavior called "dielectric absorption," or "DA." The capacitor acts as though it has a memory; when a charge is placed on the capacitor, then removed, an echo of the charge can reappear on the plates as if by magic. This can lead to audible problems, including smeared bass notes and the muddied rhythms.

Electrolytics: good and bad

Capacitors come in two flavors: electrolytic and everything else. Electrolytic capacitors are very efficient—they pack a lot of capacitance into a small space, compared to other types. Unfortunately, they also pack a lot of dielectric absorption, ESR, and leakages so they need to be used with discretion in audio circuits.

Electrolytic caps are inherently *polar* devices: they are designed to be used with a DC voltage on one end. They're quite particular about which end it's on, too. If you put a negative voltage on the "+" terminal (or vice versa) and leave it for a little while, the capacitor is likely to go BANG and frighten the cat. Electrolytics are also sold in non-polar form; these useful devices simply comprise two polar electrolytics in a single case, connected back to back.

It's been an unfortunate tendency among circuit designers to use polar electrolytic capacitors as coupling caps in audio circuits, even audio circuits that have no DC on either side of the capacitor. This is a bad idea because you subject the capacitor to backwards voltages on half of every cycle of audio. Such a brief reversal won't cause an explosion, but the capacitor will perform in a grossly nonlinear way and it won't sound good. Polar capacitors should only be used when a polarizing DC voltage is present across the cap.
How can you tell? This is the only time I recommend working on anything that is powered up. Working very carefully, turn on the equipment and measure the DC voltage across each electrolytic capacitor with your voltmeter (a digital meter is great, but a cheap VOM from Radio Shack will do fine here too). *Keep your hands away from the equipment!* Use the insulated probes to make your measurements and take care they don't slip and short something.

If you find DC across an electrolytic capacitor, it's okay to replace it with another polar unit, making sure you get the polarity right. If there is no DC, you should replace the cap with a non-polarized electrolytic. Incidentally, most equipment that's powered by an outboard power supply, or "wall wart," has DC on its coupling caps and can be used with high quality polar caps.

There are two large families of electrolytic capacitors: those made with aluminum foil and those made with tantalum foil. Aluminum electrolytics, the most common, are usually cylindrical, while tantalums are often shaped like little balloons with wires coming out one side. I'll be dogmatic about this: tantalum capacitors *stink* for audio use: they should never be used in any signal-carrying circuit. They sound tubby in the bass, harsh and gritty in the top end, and compressed in their dynamics—mirroring their poor engineering performance in such factors as dielectric absorption. If you find them in your equipment, replace them forthwith. You'll hear the improvement. (One exception: a 1F tantalum capacitor is often used at the output of a voltage regulator chip. Leave it there.)

Aluminum electrolytics are more common these days. They come in several performance levels, but the common or garden-variety aluminum cap is only so-so for audio use. DA and ESR tend to be high and the transition frequency (from capacitative to inductive behavior) can be as low as 5kHz, leading to dubious audio performance.

Fortunately, in the last decade a new generation of high-quality aluminum electrolytics has been developed, of which an excellent example is the Panasonic HFQ series. These capacitors boast good ESR and DA performance in a reasonably-sized package and don't cost as much as earlier high-performance electrolytics. They're easily obtainable from Digi-Key Electronics (see the address list at the end of the article) or other Panasonic parts distributors. You can use them to replace any aluminum or tantalum cap, provided you match capacitance values. Space permitting, I'd try to use at least a 35V cap everywhere. Make sure you install the cap with the "+" marking in the right direction (you marked the board before you removed the old one, right?).

Non-polar electrolytics have also become easier to find in the last decade; the Panasonic Bi-Polar series, also available from Digi-Key, will do a good job in many audio applications. I would replace every polar electrolytic that has no polarizing voltage across it with a non-polar unit, again maximizing the voltage if possible.

When you upgrade capacitors, you may find that the leads are spaced farther apart on the new capacitors than on the old and that when you bend the leads inward to fit them into the holes on the circuit board, they may touch other components and cause shorts. You can prevent this by slipping a short length of "spaghetti" insulation over the lead before you bend it.

The rest of the capacitors

Most caps found in audio equipment aren't used for coupling or power supplies, but for signal shaping. These smaller caps vary in quality as much as electrolytics and can benefit just as much from upgrading.

Ceramic disc capacitors were among the first small caps available and they're still used in a lot of equipment, especially guitar amps. They sound terrible, adding a screechy and gritty quality to the high frequencies that's quite unpleasant. They're also microphonic: a ceramic disc can pick up vibrations from the air or through the cabinet and add them (distorted) to the signal. When you find them in audio circuits it's a good idea to replace them with polystyrene (best) or polypropylene capacitors.

As always, there are a few exceptions. Ceramic discs are excellent for bypassing radio frequencies to ground; they're often found connected between the ground side of an input Jack and the chassis to help keep radio frequency junk out of the system. If you find ceramic discs used this way, leave them there. Ceramic discs are also sometimes used on circuit boards between the power supply pins and ground to keep radio garbage out of the active circuits. You can replace the ceramic discs with stacked film or polypropylene caps, but keep the discs around-if the new units aren't as effective, you may need to put the old ones back in.

Mica capacitors are even older than ceramic discs and aren't used much anymore. They behave a lot like ceramic discs and I replace them with polystyrenes when I find them.

Paper capacitors were often found in equipment built before 1980 and they're still used in a lot of guitar amps. They tend to sound a little harsh on the top, muddy on the bottom, and vague in the midrange. It's usually a good idea to replace them with polypropylenes, although in a guitar amp you should keep the paper caps around in case you don't like the change. (Guitar amps, after all, are *supposed* to add tonal colorations, and your tastes may be different from mine.)

Polyester capacitors (Mylar, to use the DuPont trade name) have replaced paper capacitors in most applications; when a piece of equipment or a speaker says it uses "film" capacitors, they usually mean polyesters. They're not bad, but the bass tends to be tubby and the top end vague; they should be replaced with polypropylenes or (in small values) polystyrenes.

A special class of polyester capacitors is called "stacked film." These were designed as replacements for ceramic discs in bypass applications and tend to be quite compact. I do like them for bypassing, but polypropylene is better in circuits that actually handle audio. There are stacked polypropylenes on the market, but they're expensive and hard to find.

Polypropylene capacitors are a mainstay for audio upgrades. Their quality is excellent, they're reliable, and there are now quite a few sources for them. For low voltage work, the 50V ECQ-P series from Panasonic (available through Digi-Key) is excellent, but they only go up to 0.47pF. Old Colony Sound Labs, Mouser Electronics, Parts Connection, and Welborne Labs (see addresses at end of article) all offer a variety of larger polypropylenes at prices ranging from reasonable to astonishing. A word of caution: polypropylene is an inefficient material for making capacitors, and polypropylene caps tend to be larger than polyesters of a similar value. Before you order, be sure the replacements will fit inside your case!

Polypropylenes come in two types: film and foil, and metallized. The film and foil types are excellent, but big; the metallized units are smaller, but some listeners say they don't sound quite as good. (I remain agnostic on that point.) You should avoid using metallized polypropylenes in tube circuits that place high DC voltages across them as they have a reputation for shorting out.

Finally, polystyrene capacitors are the best you can buy easily. (Teflon caps are reputed to be even better, but unless you're NASA you probably can't get them in small quantities.) They are only available in small values (up to about 0.05F), and they're easy to damage with a soldering iron, but they sound wonderful: clean and clear, with lots of detail and no treble grunge. Mallory and Mial polystyrenes are available from Newark and other large distributors, and other polystyrenes are carried by Parts Connection and Welborne Labs.

Wrapping up the caps

What's the bottom line on capacitors? Should you replace everything with polystyrenes and polypropylenes? Well, nice job if you can do it, but a lot of audio circuits use large to very large capacitors (say, 100-1000F) for coupling, and you'd be hard-pressed to replace all of these with polypropylenes on a reasonable budget, not to mention the problem of fitting them into the case.

So one has to compromise. I replace all electrolytic coupling caps (aluminum or tantalum) with Panasonic HFQ units (if there's a DC voltage across them) or Panasonic Bi-Polar caps (if there isn't). I always try to use at least a 35V cap, space permitting. Similarly, I replace all power supply caps with Panasonic HFQs, again using larger voltage ratings when possible. I replace paper and polyester caps with polypropylenes (or, value permitting, polystyrenes) and ceramic discs and micas in audio circuits with polystyrenes. I usually leave ceramic discs in power supplies or input bypasses alone.

The scoop on resistors

Until the 1970s, most of the resistors found in audio equipment were carbon composition units, the familiar brown striped cylinders. They are terrible! They usually sport wide resistance tolerances, leading to poor matching between channels. They tend to drift with age so the equipment's performance changes with time. They drift with changing temperatures, too, so equipment can change character radically as it warms up.

Carbon comps also show two behaviors that are particularly noxious in audio applications. Any resistor will generate noise as its molecules vibrate in the ambient temperature. The amount of noise can be predicted by theory (it's proportional to resistance and temperature), but carbon comp resistors are usually much noisier than theory predicts. This "excess noise" is, of course, undesirable in audio circuits.

Carbon comps also exhibit what is called "voltage coefficient," wherein the resistance value changes with the voltage across the resistor. In audio applications, this means that the audio signal effectively modulates the resistances in its path, causing distortion. This shows up as muddy and undefined sound. Tube power amplifiers made with carbon comp resistors are notoriously soft and vague-sounding, with poor stereo imaging; they clean up quite noticeably when you replace the resistors.

These behaviors show up less in higher wattage units, so a common trick in the 1950s was to use a 2W resistor in low-level or high-voltage locations, even though ½W would dissipate the power easily.

The next step up from carbon comps is carbon films, and these have become the most common resistors in consumer and professional audio gear. They share the problems with carbon comps, but to a lesser degree; they also benefit from replacement by better resistors.

Metal film resistors are my standard for high-quality upgrades. In the last ten years, they have become affordable and available, and their performance is excellent: tight tolerances (typically 1-2%), virtually no voltage coefficient or excess noise, and very small drift with time and temperature. Digi-Key carries good ¼W metal films from Yageo (MF series), offering a wide assortment of values for about $0.11 a piece in small quantities. If you're replacing ¼W resistors, these will do a good job; however, I try to replace ¼W with ½W units wherever space permits. Old Colony Sound Labs, Parts Connection, and Welborne Labs offer ½W metal film resistors in standard values at somewhat higher prices (about $0.40 ea.); I try to use those when possible. (Of course, ½W resistors should always be replaced with ½W or higher.)

Metal oxide resistors are not quite as good as metal films and usually come only in 5% tolerance, but they are readily available in 1W and 2W ratings. I use them to replace 1W and 2W carbon camps; the Yageo and Panasonic units available from Digi-Key are fine.

Wirewound resistors are seldom found in modern equipment, but they were used occasionally in older gear. Unless they are blown up, I leave them alone they usually work fine.

In the last decade, a new breed of ultra-high quality, ultra-expensive resistors has appeared, mostly in high-end audio gear. These fancy resistors ($3.00-9.00 a piece!) are available from Parts Connection and Welborne Labs; they have excellent reputations, but I've never used them, so can't offer advice.

In summary, I replace all small 1/8 - ½W) resistors with ½W metal films of equal value (or the closest obtainable. I replace higher wattage carbon comps with metal oxides.

What would I expect to gain from these upgrades? A clearer, cleaner, sharper sound, with better spatial definition and less vagueness. I'd also expect a tighter, punchier bass and a sweeter, less "electronic-sounding" treble. Finally, because of the tighter tolerances on the resistors, I'd expect better matching between the two channels, a minor improvement, but nice.

Digi-Key
701 Brooks Ave. So.
Thief River Falls, MN 56701

800-344-4539, Fax 218-681-3380

Mouser Electronics
958 N. Main St.
Mansfield, TX 76063
800-992-9943

Old Colony Sound Lab
PO Box 243
Peterborough, NH 03458-0243
603-924-6371, Fax 603-924-9467

Parts Connection
2690 Brighton Rd.
Oakville, ON L6H 5T4
Canada
800-769-0747

Welborne Labs
PO Box 260198
Littleton, CO 80126
303-470-6585, Fax 303-791-5783