Looking Beyond the Magnitude of Impedance to Phase

The second effect of high ESR is that it causes a phase shift away from the expected ideal of 90 degrees between voltage and current at all frequencies.

Some designers assume that if the resonant frequency is high compared to the frequency of interest, all will be well—the capacitor can be used up to the natural self-resonant frequency or, when the capacitor maker does not give that information, as high a frequency as possible as long as the impedance curve remains fairly linear in appearance. This is not a valid assumption for many capacitor applications, however. It can be true for power-supply by-passing, but for many circuit applications, the useful frequency range of the capacitor is limited by its phase response rather than its impedance. The phase response is degraded well below the capacitor's natural or self-resonant frequency when series losses are added. These losses may arise from the construction of the capacitor itself, or they may arise externally, usually from wire or cable losses and the driving source impedance.

Phase Response

In Figures 2 and 3, we show that filter circuits (e.g., loudspeaker crossovers, RIAA equalization, D/A filters, etc.) cannot be thoroughly designed without integrating the actual, measured in-circuit performance of the capacitors (and inductors as well) into the over-all system design.

Figure 2 shows the phase/magnitude of a 4.4 mfd/100v bi-polar electrolytic capacitor. The capacitor itself has a resonance at 450 kHz with 1-inch lead length, which looks as if it is well out of the audible range. But because of the capacitor's high ESR, phase was down 5 degrees to −85 at only 4.0 kHz and −10 degrees at 14 kHz. When this capacitor was measured in-circuit (with 12 inches of circuit wire), the phase had degraded from −89 degrees at 100 Hz to −85 at approximately 800 Hz, and −55 degrees at 10 kHz! If this designer had doubled the lead length from the capacitor to the load, phase would have begun to sour at a very low frequency, even though the resonance would still be at a relatively high frequency!

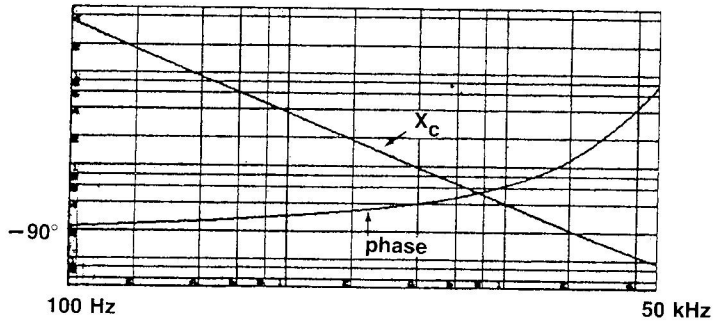

FIGURE 2A:

A 4.4 mfd/100v bi-polar electrolytic with 1-inch lead lengths. X_C appears usable over the audio range. However, phase response is degraded owing to high ESR.