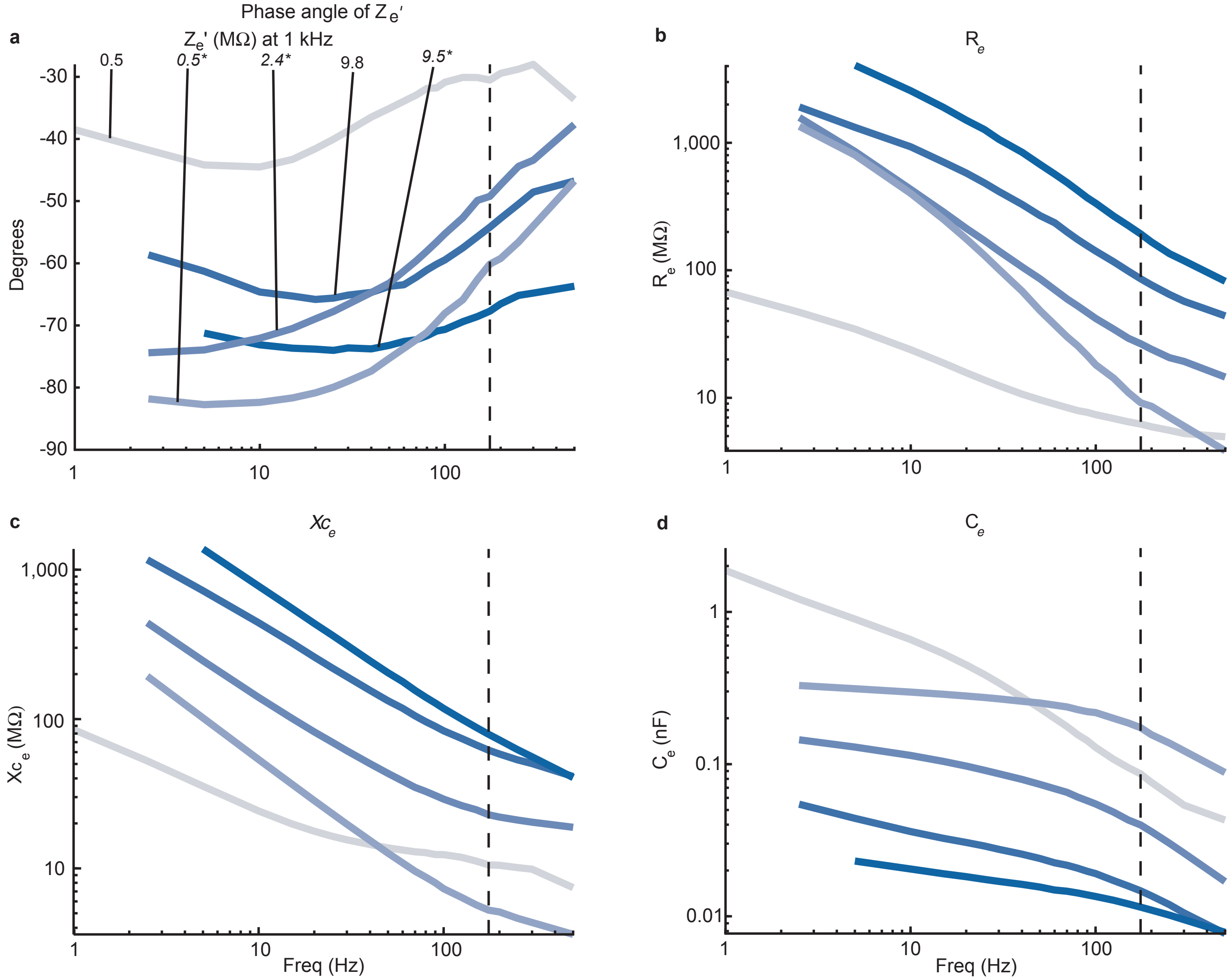

Figure S1. Estimations of Re and Ce. Grey-to-blue lines show data recorded in dilute saline using the low input impedance head-stage for electrodes with low-to-high measured impedance values at 10 Hz. The manufacturer specified 1 kHz impedance values for each electrode is indicated in A. Values in italics and followed by an asterisk denote data from a glass insulated electrode. The vertical grey dashed line denotes the point where data was obtained from the LFP channel, and data to the right was obtained from the spike channel. Because a recorded electrode-amplifier circuit induced phase shift is needed for these estimations to be meaningful, the results are only shown for the lower input impedance head-stage data over lower frequency ranges where these phase shifts tend to exist in the data. Frequency is shown on a log scale. For a list of the exact frequencies tested, please see the Signals used subsection in the Methods section. A: The phase angle of Ze', based on the recorded amplitudes and phase shifts with each electrode and our estimation of Za'. B and C: The resistance (Re) and capacitive reactance (Xce) at the electrode tip based on the phase and magnitude of Ze', ignoring possible subtle contributions of the electrolyte resistance, Rs. D: The capacitance (Ce) at the electrode tip giving rise to Xce. Both Re and Ce increase as frequency decreases, and the overall phase of Ze' decreases towards -90 degrees.

The data shown here are the values accounting for the series input capacitance and the non-zero impedance of the reference electrode. Accounting for these effects did not appreciable affect the estimataion of electrode impedance magnitude (Figure 3 and 4) even at low frequencies, but it did quantitatively affect the estimation of the phase angle of electrode impedance despite preserving the same qualitative nature of the changes in this value across frequencies. The electrode phase angle values we report here should be taken as rough estimations to present the qualitative behavior and general range of this value for the electrodes we tested. Our estimation of this was found to vary systematically with different manipulated Za' values with the same electrode, spanning a range of up to 15 degrees. The values shown here rely on the data shown in Figures 4 and 5, using only data from the parallel configuration with unmanipulated Za' values.

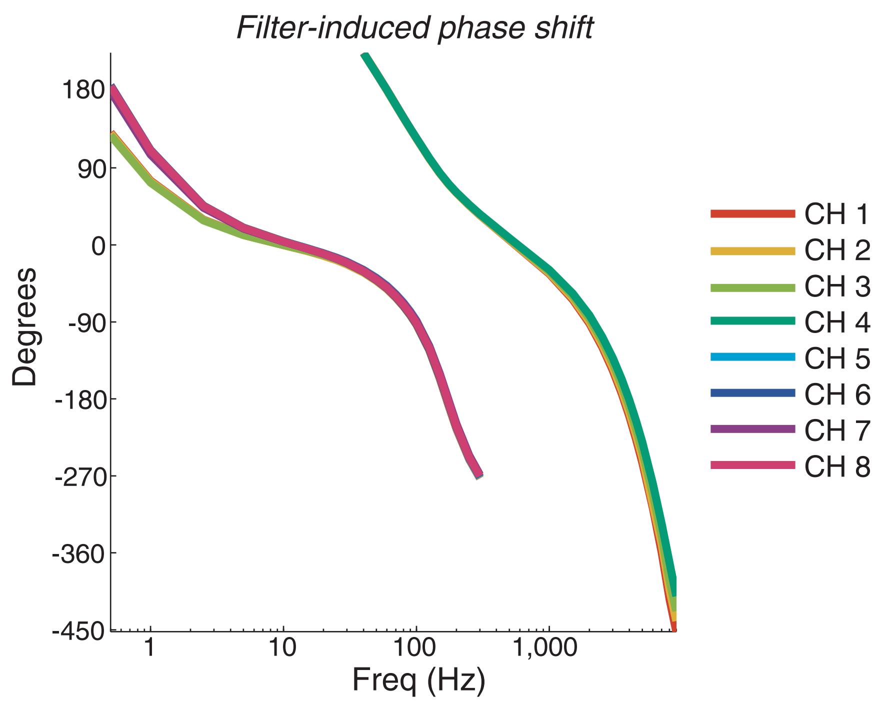

Figure S2. Phase differences across channels. The phase response is shown for 8 LFP channels and 4 spike channels from sinusoidal signals of varying frequencies split 8 ways and sent directly to the head-stage for simultaneous recording. Due to the limitations of the equipment, only 4 spike channels could be recorded as continuous signals. The path of the signal to each input channel of the head-stage was verified to be of negligible impedance. (<1 Ω) for each channel. At very low frequencies, the phase shifts for channels 1-3 are substantially lower than the phase shifts for channels 4-8, though the data for some channels nearly overlap and are difficult to see. Additional gain differences between channels were noticed as well. Frequency is shown on a log scale. For a list of the exact frequencies tested, please see the Signals used subsection in the Methods section.

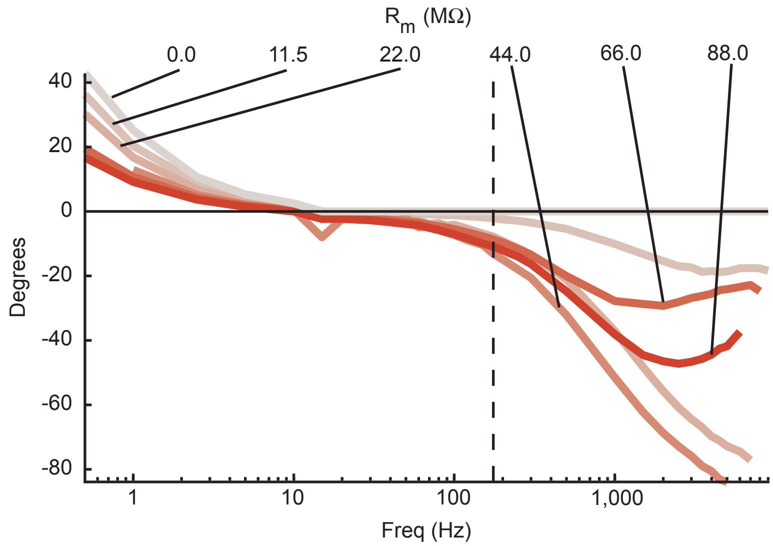

Figure S3. Electrode-amplifier circuit induced phase shifts using different metallic resistors. Phase shifts are shown for signals recorded with the low input impedance headstage after subtracting the phase shifts induced by the system filters (see Figure 7). A positive phase means that the recorded signal leads the actual signal. Frequency is shown on a log scale. For a list of the exact frequencies tested, please see the Signals used subsection in the Methods section. The vertical grey dashed lines denote the points on each plot where data to the left corresponds to the LFP channel data and data to the right corresponds to the spike channel data. Lines are colored from grey-to-red as the value of each resistance changes from low to high, with the precise values used for each line indicated.

Signals recorded across metallic resistances (R_m) largely follow the phase shifts induced by the analog filters alone, with some deviation from this at high frequencies (>300 Hz) and very low frequencies (<10 Hz) resulting from a shift in V_{in} that is described by equation 2. The high-frequency deviations in phase are negative-going and increase in magnitude as the metallic resistance increases, suggesting as expected that the effects of the parallel amplifier input capacitance and shunt capacitance causes Z_a' to be more capacitive than Z_e' which is purely resistive for these recordings.

At very low frequencies, the R_m-dependent phase deviations are caused by the series input capacitance. This series capacitance was introduced to the head-stage to AC-couple it, meaning that the headstage provides additional high-pass filtering to block the lowest frequency signal components going down to a frequency of zero (DC). This capacitance acts on the input before the point in the circuit where the voltage is amplified, effectively adding a constant capacitance to the effective electrode impedance even when no input load before the head-stage is present. Being capacitive, it creates a large impedance only at low frequencies, which as expected causes a positive phase shift over these frequencies when R_m is zero as shown. Adding increasingly large resistive input loads causes the phase angle of the effective electrode impedance to become more similar to the phase angle of the amplifier input impedance that is resistive at low frequencies, and this positive phase shift decreases as expected. Our determination of electrode amplifier input impedance measures the entire impedance from the amplifier's input to ground and so includes the effect of this series capacitance raising the input impedance at very low frequencies as shown in Figure 2, even though this capacitance ultimately results in increased signal degradation over these frequencies.