Electronic Supplementary Material (ESI) for Lab on a Chip

Impedance measurement technique for high-sensitivity cell detection in microstructures with non-uniform conductivity distribution

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ESI:

A. Differential based impedance measurement technique:

Resistance model:

$$\begin{cases} R_{bc} = R_0 + 3\Delta R \\ R_{ac} = kR_0 + 4\Delta R + \Delta R_C \end{cases}$$

Output signal:

$$V_{out} = V_{in} R_f \frac{(R_{ac} - R_{bc})}{R_{ac} R_{bc}}$$

Output signal when ΔR=ΔR$_C$=0:

$$V_{out0} = V_{in} \frac{R_f}{R_0} \frac{k-1}{k}$$

Output signal variation:

(S1) $$\Delta V_{out} = V_{out} - V_{out0} = V_{in} R_f \left[\frac{(k-1)R_0 + \Delta R + \Delta R_C}{(R_0 + 3\Delta R)(kR_0 + 4\Delta R + \Delta R_C)} - \frac{k-1}{kR_0} \right]$$

(S2) $$|\Delta V_{out}|_{noise=0} = \left| V_{in} \frac{R_f}{R_0} \left[\frac{(k-1)R_0 + \Delta R_C}{(kR_0 + \Delta R_C)} - \frac{k-1}{k} \right] \right| = \left| V_{in} \frac{R_f}{kR_0} \left[\frac{-\Delta R_C}{(kR_0 + \Delta R_C)} \right] \right|$$

(S3) $$|\Delta V_{out}|_{signal=0} = \left| V_{in} R_f \left[\frac{(k-1)R_0 + \Delta R}{(R_0 + 3\Delta R)(kR_0 + 4\Delta R)} - \frac{k-1}{kR_0} \right] \right| \approx \left| V_{in} \frac{R_f}{kR_0} \left[\frac{-R_0 \Delta R (3k^2 - 4)}{(R_0 + 3\Delta R)(kR_0 + 4\Delta R)} \right] \right|$$

(S4) $$SNR_{diff,asym} = \frac{|\Delta V_{out}|_{noise=0}}{|\Delta V_{out}|_{signal=0}} \approx \left| \frac{\Delta R_C}{(kR_0 + \Delta R_C)} \frac{(R_0 + 3\Delta R)(kR_0 + 4\Delta R)}{R_0 \Delta R (3k^2 - 4)} \right|$$

Approximation of equation (S4) for $R_0 >> \Delta R, \Delta R_C$:

(S5) $$SNR_{diff,asym} \approx \left| \frac{\Delta R_C}{\Delta R (3k^2 - 4)} \right|$$

B. Division based impedance measurement technique:

Resistance model:

$$\begin{cases} R_{bc} = R_0 + 3\Delta R \\ R_{ac} = kR_0 + 4\Delta R + \Delta R_C \end{cases}$$

Output signal:

$$V_{out} = A_{div} \frac{R_{bc}}{R_{ac}}$$

Output signal when ΔR=ΔR$_C$=0:

$$V_{out0} = \frac{A_{div}}{k}$$

Output signal variation:

(S6) $$\Delta V_{out} = V_{out} - V_{out0} = A_{div} \frac{R_0 + 3\Delta R}{kR_0 + 4\Delta R + \Delta R_C} - \frac{A_{div}}{k} = A_{div} \frac{(3k-4)\Delta R - \Delta R_C}{k(kR_0 + 4\Delta R + \Delta R_C)}$$

(S7) $$|\Delta V_{out}|_{noise=0} = \left| A_{div} \frac{-\Delta R_C}{k(kR_0 + \Delta R_C)} \right|$$

(S8) $$|\Delta V_{out}|_{signal=0} = \left|A_{div}\frac{(3k-4)\Delta R}{k(kR_0+4\Delta R)}\right|$$

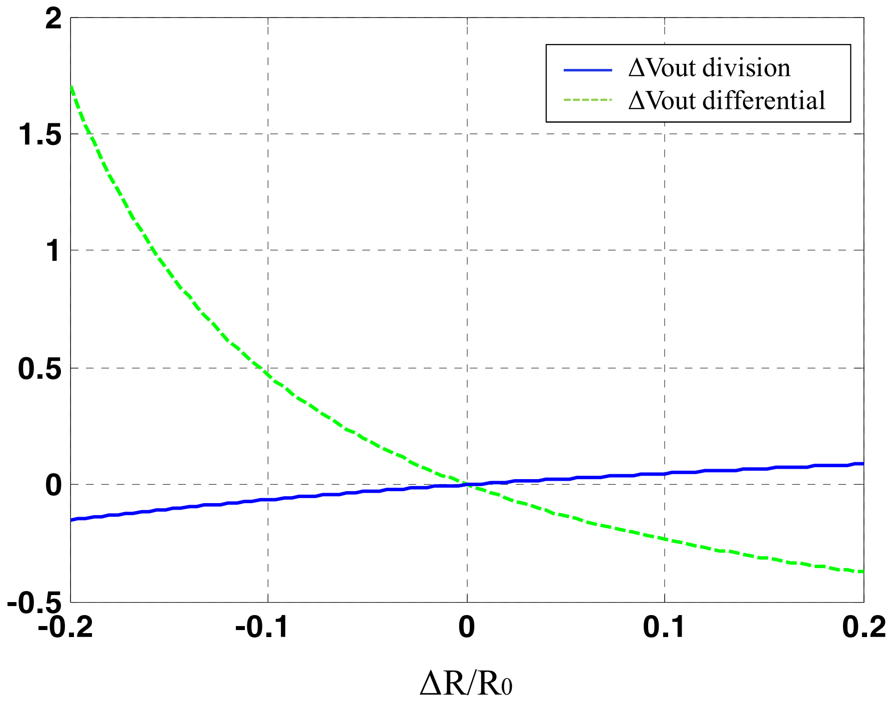
(S9) $$SNR_{div,asym} = \frac{|\Delta V_{out}|_{noise=0}}{|\Delta V_{out}|_{signal=0}} = \left|\frac{\Delta R_C}{(kR_0+\Delta R_C)}\frac{(kR_0+4\Delta R)}{(3k-4)\Delta R}\right|$$

Approximation for $R_0 >> \Delta R, \Delta R_C$:

(S10) $$SNR_{div,asym} \approx \left|\frac{\Delta R_C}{\Delta R(3k-4)}\right|$$

C. ΔVout comparison

Equation (S1) and (S6) varying $\Delta R/R_0$ with: Vin =1V, R_f = 20kΩ, k=3, R_0=16.2kΩ, A_{div} =1, $\Delta R_C/R_0$ = 0.01.

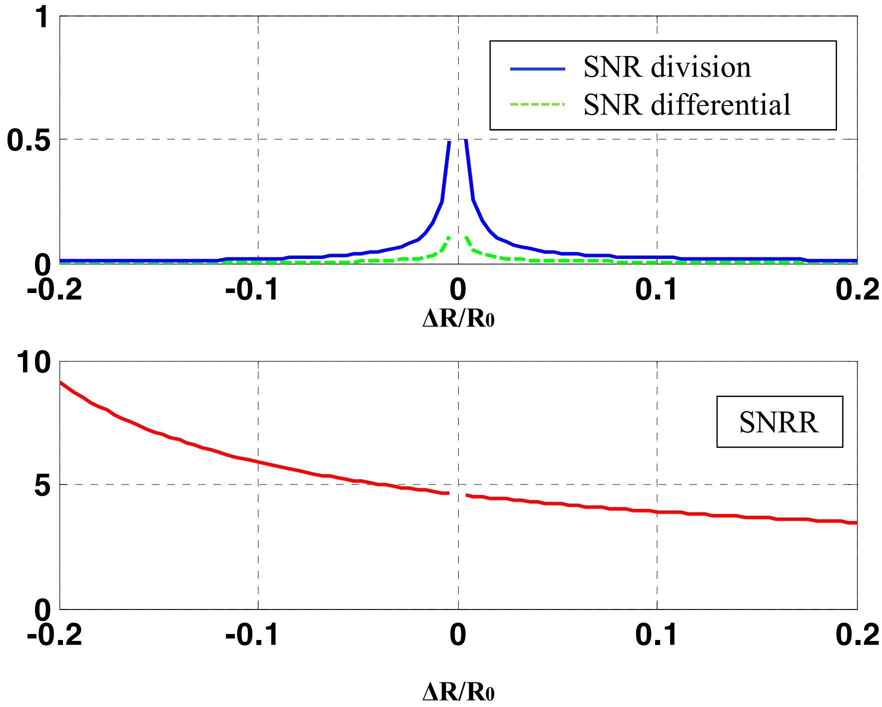


D. SNR comparison

In the top figure, equation (S4) and (S9) are plotted against $\Delta R/R_0$ with: Vin =1V, R_f = 20kΩ, k=3, R_0=16.2kΩ, A_{div} =1, $\Delta R_C/R_0$ = 0.01.

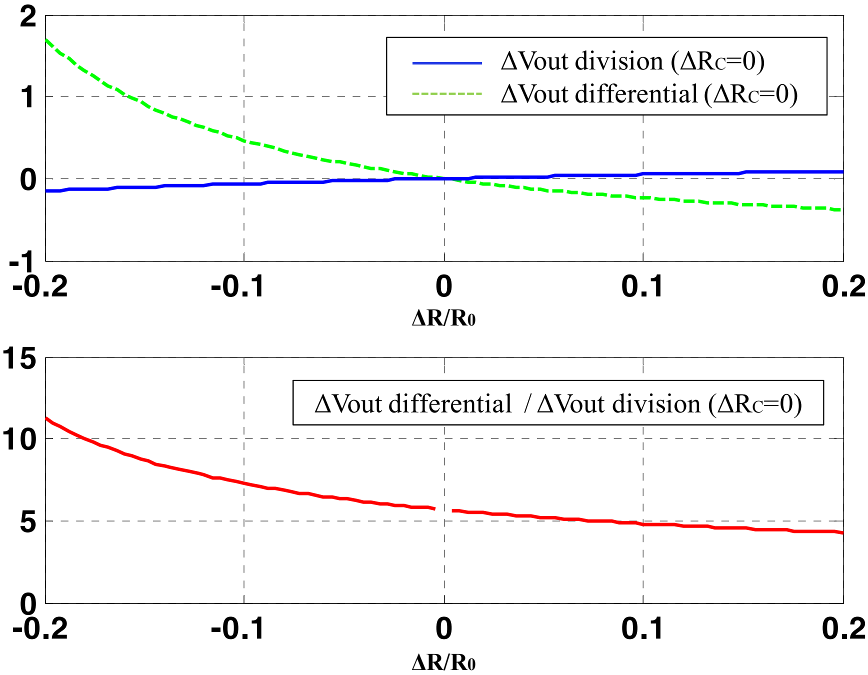
In the bottom figure, SNRR = SNRdivision/SNRdifferential.

For $\Delta R/R_0$=0 the two graph are not defined because the two SNR are not defined.



E. Noise to noise comparison ($\Delta R_C/R_0=0$)

In the top figure, equation (S1) and (S6) are plotted against $\Delta R/R_0$ with: Vin =1V, R_f = 20kΩ, k=3, R_0=16.2kΩ, A_{div} =1, $\Delta R_C/R_0$ = 0.
In the bottom figure, the ratio of the two curves shows that for $\Delta R_C/R_0$ in the range [-20%; 20%] with the division approach the noise-induced variation is attenuated of a factor which goes from 4.29 to 11.23.
For $\Delta R_C/R_0$ in the range [-10%; 10%], the noise attenuation factor goes from 4.8 to 7.2.
For $\Delta R_C/R_0$ in the range [-5%; 5%], the noise attenuation factor goes from 5.2 to 6.3.



SUPPLEMENTARY FIGURES:

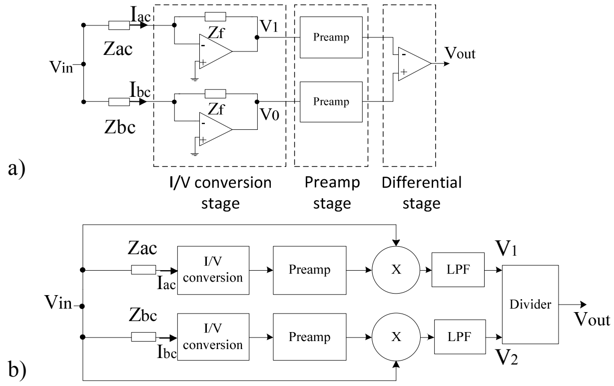


Fig. S1 a) Diagram of the differential circuit used to compare the two impedances in the microchannel. b) Block diagram of the proposed custom circuit which includes an I/V conversion stage, a preamplifier, an analog multiplier, a low-pass-filter and an analog divider.

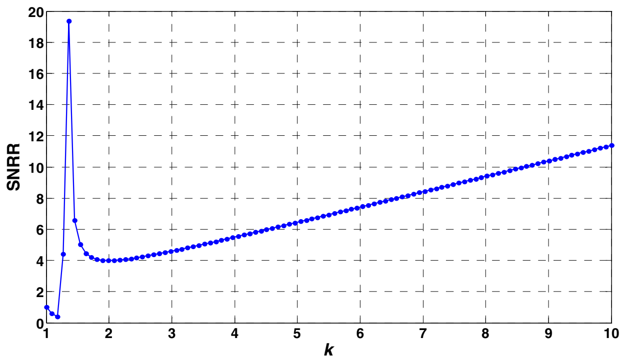


Fig. S2 The SNRR ratio (SNR_{div}/SNR_{diff}) as described by equation (ss) varying k in the range [1:10]. For k = 3 the S/S ratio is 4.6 which means 4.6 times higher efficiency using the proposed approach.

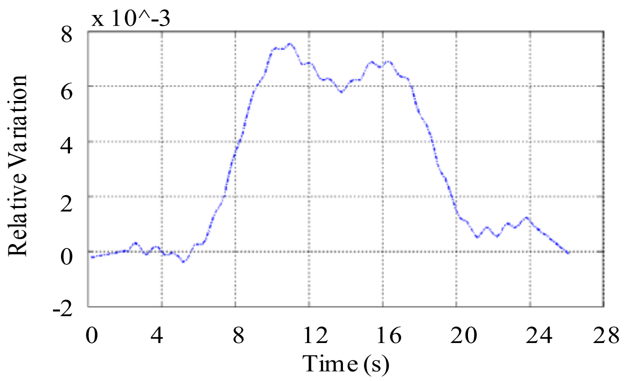


Fig. S3 Relative output signal variation due to two consecutive cells being detected.