

SAMOC Simulation of a Second-Order Bandpass Filter

A major application of SC (switched-capacitor) networks is to implement filters. Since an SC circuit can be fabricated by CMOS technology in a single chip, SC implementation of filters can dramatically decrease the filter size which was traditionally caused by coil inductors or later by large resistance area in active RC circuits. SAMOC is not equipped with frequency domain analysis routine. However, Matlab can generate and analyze signals for filter analysis. The estimation of a transfer function of SC filter can be done by feeding a white noise signal and calculating the ratio of power spectral density of the output and input signals. That is, the power spectral density of the input white noise is

$$V_{in}(s) = 1 \quad (1)$$

so that the transfer function

$$H(s) = V_{out}(s) / V_{in}(s) = V_{out}(s). \quad (2)$$

From (2), the transfer function of a filter can be obtained by observing the power spectral density of the output signal while a white noise is the input. Since this estimation is a statistical result, the larger the sampling space is the more objective the results would be. For this reason, a very long series of random input is used.

SAMOC can neither generate white noise signals nor estimate the power spectral density of signals. Therefore, the signal generation, spectrum estimation and data visualization are finished by using Matlab.

A bandpass SC filter is illustrated in Fig. 1. It contains 8 ideal switches, 4 capacitors and one OPAMP. The transfer function derived by SC network theory is:

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{-f_c(C_a / C_1)s}{s^2 + sf_c(C_b / C_1 + C_b / C_2) + f_c^2(C_a / C_1)(C_b / C_2)} \quad (3)$$

SAMOC simulation of SC networks can be performed by feeding a series of signals into V_{in} and record the output from V_{out} .

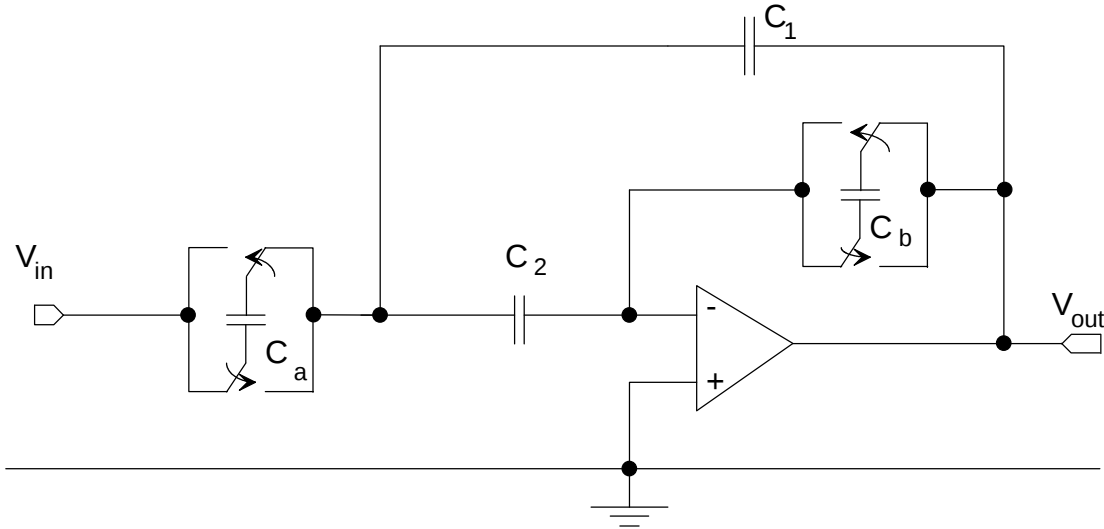


Fig. 1 An SC implementation of a second-order bandpass filter.

A series of signals contains 10000 random values created by Matlab function `randn()` are fed into V_{in} and the output V_{out} evaluated by SAMOC is recorded and send back to Matlab. The capacitors C_a , C_b , C_1 and C_2 have the same size 1f Farad. The power spectral densities of both signals are estimated by the `psd()` function included by the Matlab signal processing toolbox. The power spectral density (psd) of the input and output signals are plotted in Fig. 2 (a) and (b) respectively. The transfer function of the bandpass filter is estimated by the ratio of power spectral densities of two signals and is plotted in Fig. 2 (c). The x-axis value (0-600) is for plot resolution. In power spectral densities of discrete time signals, the range of x-axis is from 0 to π . The scaling of the x-axis can be adjusted by varying the sampling rate.

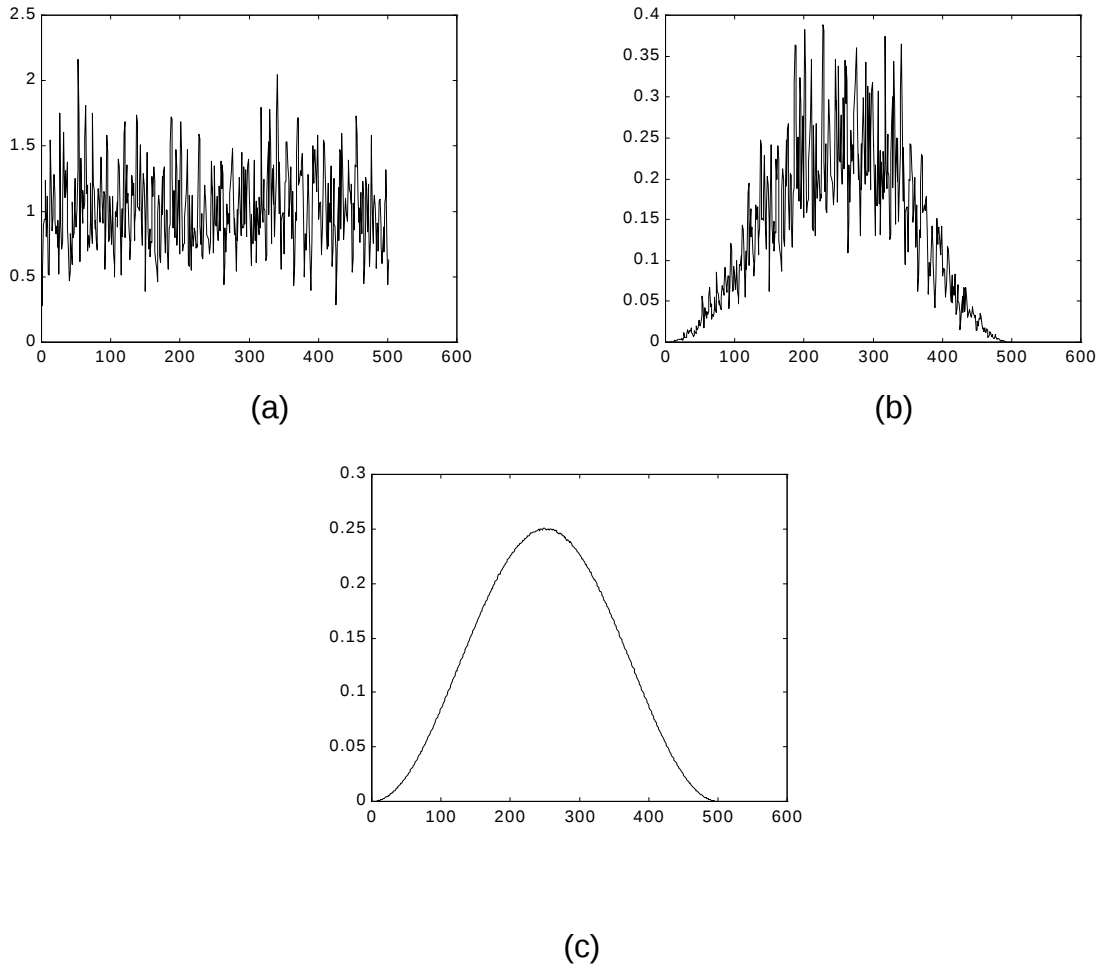


Fig. 2 Power spectral densities of input and output signals and their ratio.

If the clock frequency f_c are set to be 1k Hz, then transfer function of the filter is

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{-1000s}{s^2 + 2000s + 10^6} \quad , \quad (4)$$

and the theoretical transfer function can be visualized by `bode()` routine in Matlab. Fig. 3 is the frequency domain behavior of the transfer function in (4). Note that the maximum gain of the filter is equal to the switching frequency f_c .

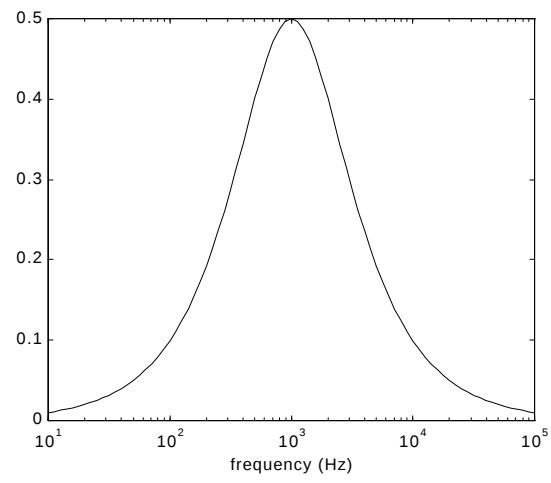


Fig. 3 Transfer function of the second order bandpass filter