A DIGITALLY PROGRAMMABLE V-I CONVERTER FOR APPLICATION IN MOSFET-C FILTERS

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Abstract- A digitally controlled V-I converter is presented. The basic element of the converter is a MOSFET-only current divider [1]. The results of a practical implementation with discrete op-amps, resistors and integrated transistors are discussed. The programmable V-I converter proposed in this work can be readily applied to MOSFET-C continuous-time amplifiers, filters and oscillators.

Introduction

Continuous-time filters are needed for many signal processing applications such as for antialiasing and reconstruction. One of the most successful methods to integrate continuous-time filters uses the so-called MOSFET-C structures [2]. These continuous-time filters are derived from classical active-RC filters, with the resistors being replaced by MOS transistors operating in the triode region. Special techniques [2,3] have been developed in order to reduce the harmonic distortion due to transistor nonlinearities. MOSFET-C filters also suffer from high variability of the frequency response owing to process deviations, thermal variations and/or aging, requiring adjustment of component values in order to keep the frequency response within acceptable limits. Usually, the output conductance of the MOSFET, controlled by the gate voltage, is adjusted in order to get the desired frequency response. However, this strategy of tuning changes the operating point of the MOS transistors, degrading the linearity of the filter.

In this paper we propose the application of MOSFET-only current dividers (MOCD) [1] in MOSFET-C filters. This technique allows obtaining digital programmability without requiring much silicon area. Moreover, the proposed technique does not require changes in the gate voltage, avoiding degradation in the linearity of the filter. Tuning methods such as those presented in [4-6] are readily applied to the method proposed here.

Principle of the method

The proposed scheme of the digitally controlled V-I converter is based upon the structure shown in Fig. 1 [2] which, assuming matched transistors, allows eliminating the even nonlinearities of the differential output current (I_1-I_2). In our proposal, M_1 and M_2 are replaced by MOCDs, represented in Fig. 2. The output current of the MOCD is a fraction, selected by a digital word, of the input current. This programmable current divider has two big advantages over other digitally programmed dividers: (i) MOSFET's perform simultaneously as elements of the divider network and as switches and (ii) the impedance of the current attenuator is independent of both the number of bits and of the attenuation factor. Moreover, the high linearity of this current division technique [1] has been proved adequate for analog signal processing.

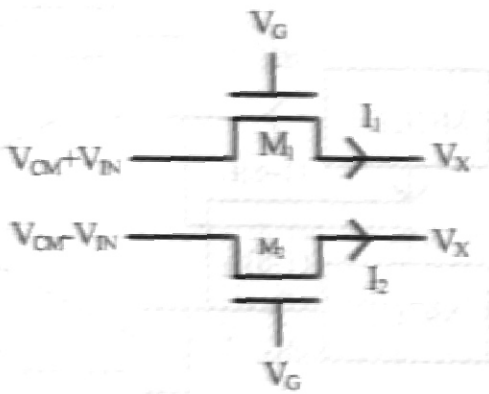

Fig. 1. Structure of an MOS linear V-I converter

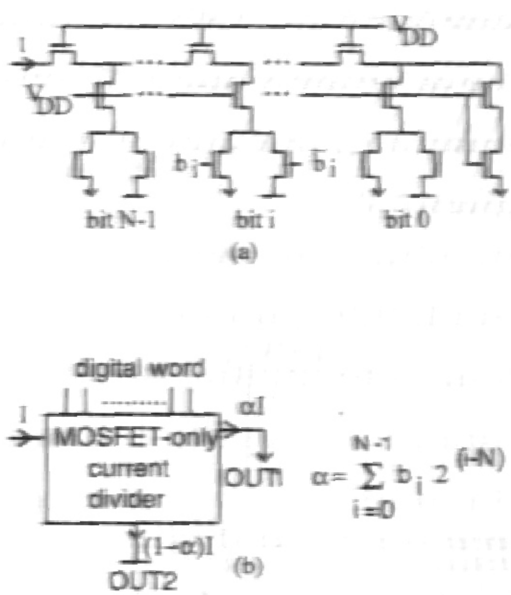

Fig. 2 -(a) MOSFET-only binary current divider and (b)its symbol.

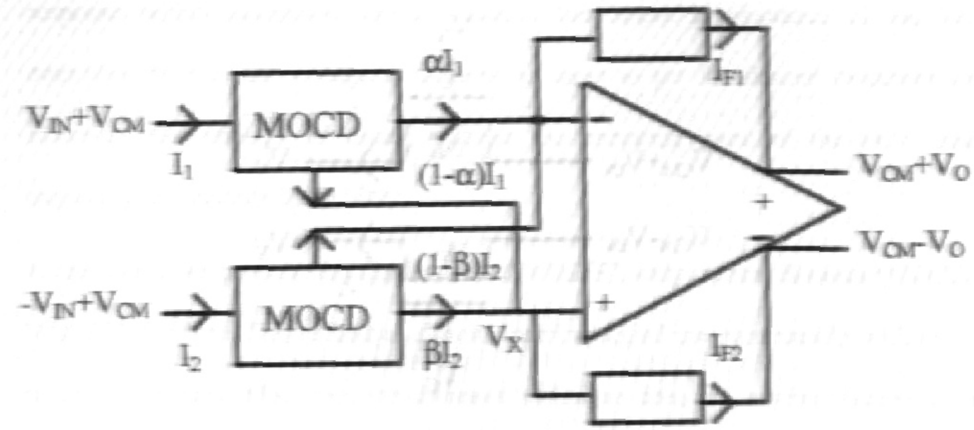

Fig. 3 - Proposed structure of the digitally programmable V to I converter for applications in MOSFET-C filters

The proposed scheme for applications in MOSFET-C filters is shown in Fig. 3. The elements in the feedback loop can be resistors or capacitors [2]. In the scheme shown in Fig. 3, the gate voltage is kept constant at V_{DD}. Let us assume the I-V characteristic of the MOSFET in the triode region is given by [7,8]

$$I_D = \frac{Kn}{2}\frac{W}{L}\left[(V_P - V_S)^2 - (V_P - V_D)^2\right] \quad (1)$$

where the parameter V_P is the pinch-off voltage given by $V_P=(V_G-V_{TO})/n$, being V_{TO} the threshold voltage and n the slope factor [7-8]. $K=\mu C'_{OX}$ is the transconductance parameter. The application of eqn. (1) to the structure shown in Fig. 3 leads to the following expression for the differential output current:

$$I_{F1} - I_{F2} = -2(2\alpha - 1)Kn\frac{W}{L}V_{IN}(V_P - V_{CM}) \quad (2)$$

assuming matched MOCDs and $\alpha=\beta$. Note that, in this case, $V_P=(V_{DD}-V_{TO})/n$ and the differential output current does not depend on V_X. It should be also observed that the equivalent aspect ratio [8] of the MOCD is one half the aspect ratio of a single transistor of the association shown in Fig. 2.

Our analysis of the output current of the V-I converter has been limited to the the results obtained from eqn. (1), a simplified description of the MOS output characteristic. Analytical results for the harmonic components of the output current, obtained from more elaborated expressions, can be found elsewhere [2].

Generation of the common-mode voltage

In order to get the maximum voltage swing, the common-mode voltage has to be equal to half the pinch-off voltage V_P, the limit of the drain voltage to keep a MOSFET in the triode region. Assuming the I-V characteristic of the MOSFET is given by eqn. (1), a bias voltage equal to $V_P/2$ is obtained at the intermediate node of the series association of equal transistors shown in Fig. 4. Note that, for the bias conditions shown, the topmost transistor in Fig. 4 is in the saturation region while the others operate in the triode region [8]. Fig. 5 illustrates the curves of both the output current and the voltage at the intermediate node shown in the series association of Fig. 4. For the transistors chosen, $V_P=4V$ for $V_G=V_{DD}=5V$.

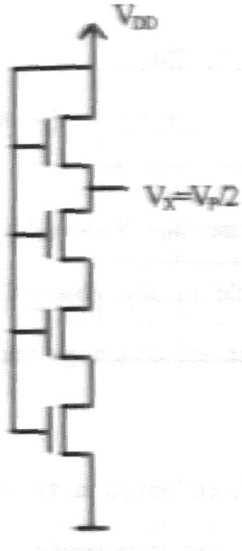

Fig. 4 - Voltage divider for the generation of the common-mode voltage

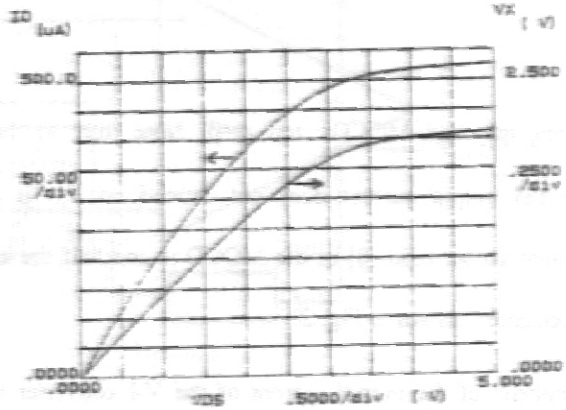

Fig. 5 - Output characteristic of the series connected MOSFETs In Fig. 4

Experimental results

In order to validate the proposed method, we have built an amplifier with discrete op amps, resistors and two identical, but from different chips, MOCD networks of two bits each one. The MOCDs are make up with NMOS transistors for which W=36μm and L=5μm. The transfer function of the amplifier, selected by equal digital words in the two current attenuators, is shown in Fig. 6 for voltage gains of -2, -1, 1, 2. The voltage gains are scaled by a ratio dependent upon the MOS network parameters and the external resistance values. Fig. 7 displays the outputs of the balanced op amp while Fig. 8 shows the output of a differential amplifier whose inputs are those shown in Fig. 7

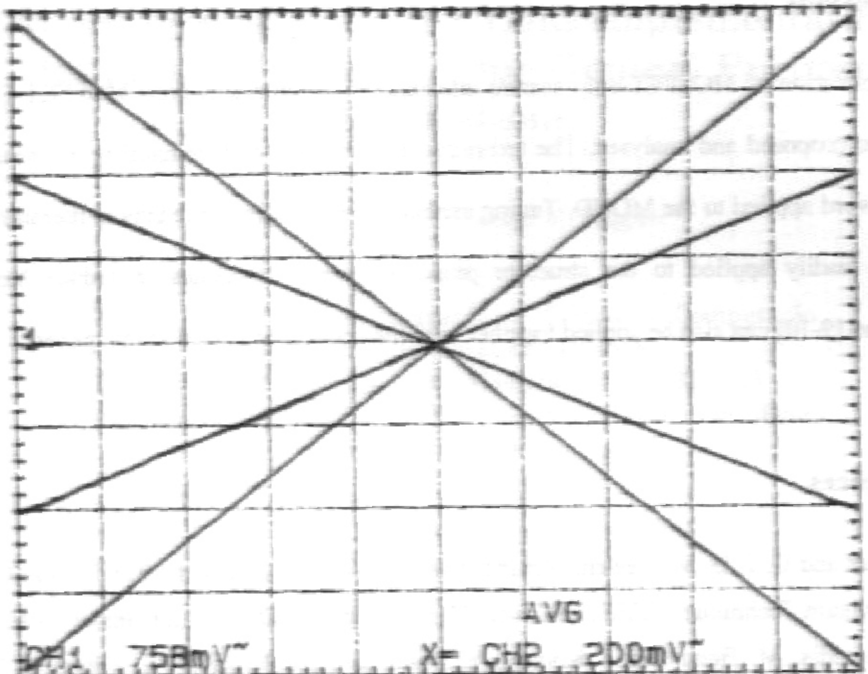

Fig. 6 - Transfer functions of the digitally programmable amplifier with voltage gains of -2, -1, 1,2.

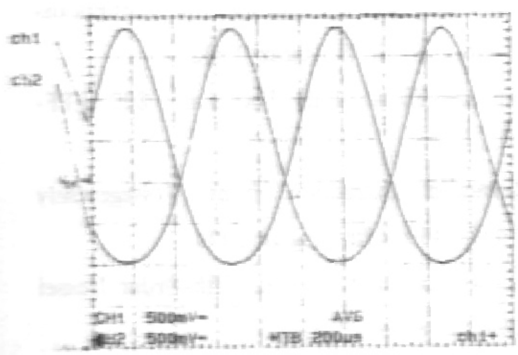

Fig.7 - Output voltages of the balanced op amp

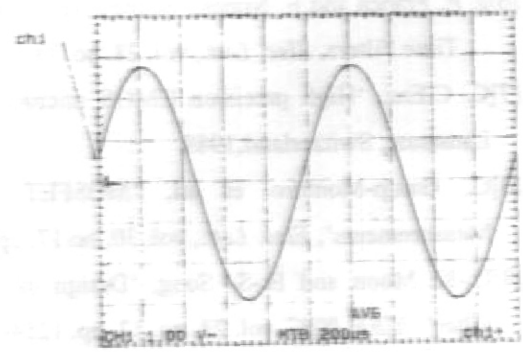

Fig. 8 - Output voltage of the differential-to-single ended amplifier

Conclusions

The application of MOSFET-only current attenuators in continuous-time MOSFET-C filters has been proposed and analysed. The technique allows easy programmability by means of a digital word applied to the MOCD. Tuning methods presented in the technical literature [4-6] can be readily applied to the structure proposed here. Techniques to reduce harmonic distortion [9-10] can also be applied together with the scheme proposed in this paper.

References

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