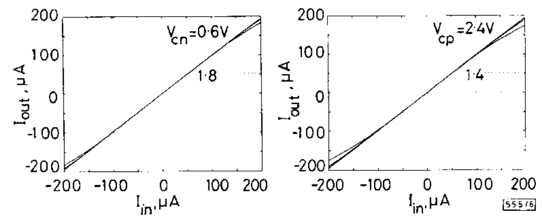

Fig. 6 *I_{out} against I_{in}*

Tuning control voltages V_{cn} and V_{cp} also affect the dynamic range of the circuit owing to finite output conductances. In Fig. 6, plots of I_{out} against I_{in} for several V_{cn} and V_{cp} values are depicted. In the Figure, a linear relationship is observed between I_{out} and I_{in} for $I_{in} \leq 100\mu A$.

Conclusion: A new current-mode damped integrator is proposed. The circuit operates at low supply voltages since only two transistors exist from supply to ground rail. Using two control voltages, the corner frequency of the integrator can be tuned.

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Digitally programmable V-I converter for application in MOSFET-C filters

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Indexing terms: Digital circuits, Transconductors, Switched capacitor filters

A compact digitally controlled V-I converter is presented. The basic element of the V-I converter is a MOSFET-only current divider (MOCD) [1]. The programmable V-I converter proposed in this work can be readily applied to MOSFET-C continuous-time amplifiers, filters and oscillators.

Introduction: One of the most successfull techniques for integrating 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 replaced by MOS transistors operating in the triode region. Special techniques [2] have been developed to reduce the harmonic distortion caused by transistor nonlinearities. MOSFET-C filters suffer from high variability of the frequency response owing to process deviations, thermal variations and aging. This high variability requires the tuning of component values to keep the frequency response within acceptable limits. Usually, the tuning is performed on the output conductance of the MOSFET, which is controlled by the gate voltage. However, this tuning strategy changes the operating point of the MOS transistors, degrading the linearity of the filter.

We propose the application of MOCDs [1] in MOSFET-C filters. This design technique allows digital programmability without requiring much silicon area, as compared to the conventional implementation. Tuning the response of the filter does not require changes in the gate voltage, thus avoiding degradation in the linearity of the filter. Furthermore, tuning strategies such as those presented in [3, 4] can be readily applied to the new structure.

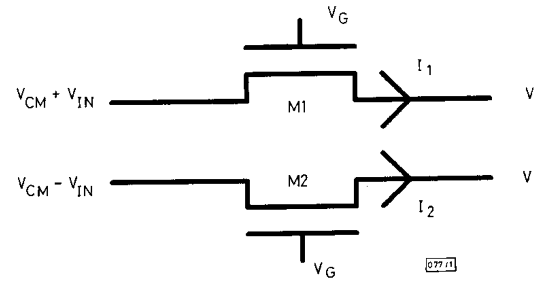

Fig. 1 *Structure of MOS linear V-I converter*

Principle of method: The proposed scheme of the digitally controlled V-I converter is based on the structure shown in Fig. 1 [2]. Assuming matched transistors, the differential output current (I_1-I_2) is free of even nonlinearities. In our proposal, M_1 and M_2 are replaced by MOCDs. The structure of the MOCDs is depicted in Fig. 2. The output current of the MOCD is a fraction, selected by a digital word, of the input current [1]. This programmable current divider has two major advantages over other digitally programmable dividers: (i) MOSFETs 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 the attenuation factor. Moreover, the high linearity of this current division technique [1] has been proved adequate for analogue signal processing.

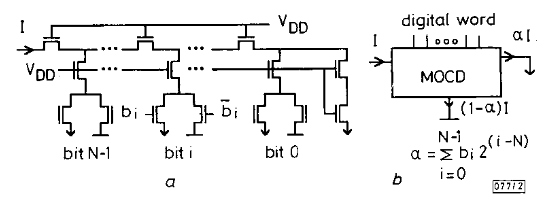

Fig. 2 *MOSFET-only binary current divider and its symbol*

a Circuit diagram
b Symbol

Fig. 3 describes the application of the proposed scheme in MOSFET-C filters. The elements in the feedback loop can be resistors or capacitors [2]. The gate voltages of the MOSFETs are kept constant at V_{DD}.

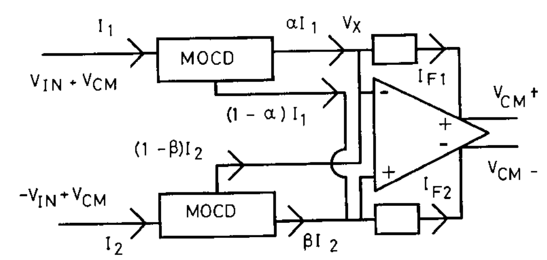

Fig. 3 *Digitally programmable V to I converter for applications in MOSFET-C filters*

We assume that the I-V characteristic of the MOSFET in the triode region is given by [6, 7]

$$I_D = \frac{\mu C'_{ox} n}{2} \frac{W}{L} \left[(V_P - V_S)^2 - (V_P - V_D)^2 \right] \qquad (1)$$

where V_p is the pinch-off voltage given by $V_P = (V_G - V_{TO})/n$, V_{TO} is the zero-bias threshold voltage and n is the slope factor [6, 7]. It has been demonstrated in [5] that the series-parallel association of FETs is equivalent to a single transistor. Therefore, the application of eqn. 1 to the structure of Fig. 3, assuming matched MOCDs and $\alpha = \beta$, leads to the following expression for the differential output current:

$$I_{F1} - I_{F2} = -2(2\alpha - 1)\mu C'_{ox} n \frac{W}{L} V_{IN}(V_P - V_{CM}) \quad (2)$$

In this case, $V_P = (V_{DD} - V_{TO})/n$. The equivalent aspect ratio [5] of the MOCD is half the aspect ratio of a single transistor of the type shown in Fig. 1.

Our analysis of the output current of the V-I converter has been limited to the results obtained from eqn. 1, which is a simplified description of the MOS output characteristics. Analytical results for the harmonic components of the output current, obtained from more elaborate expressions, can be found in [2].

Generation of the common-mode voltage: For maximum voltage swing, the common-mode voltage must be equal to $V_P/2$. V_P is the limit of the drain voltage to keep a MOSFET in the triode region. Assuming that 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 [7]. For this bias condition, the topmost transistor in Fig. 4 is in the saturation region whereas the other transistors operate in the triode region [5].

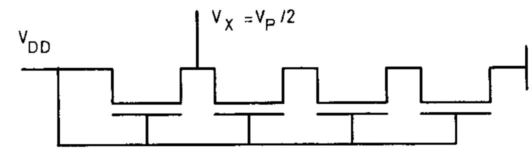

Fig. 4 *Voltage divider for generation of common-mode voltage*

Experimental results: To validate the proposed method, we built an amplifier with discrete opamps, resistors and two theoretically identical (but from different chips) MOCD networks of two bits each. The MOCDs are made up of NMOS transistors [W = 36μm and L = 5μm]. The transfer function of the amplifier, selected by equal digital words in the current attenuators, is shown in Fig. 5 for voltage gains of –2, –1, 1 and 2. The voltage gains are scaled by a factor that depends on the MOS transistor parameters and the external resistance values.

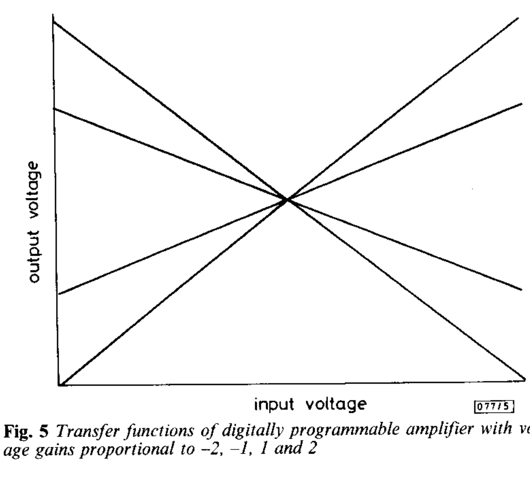

Fig. 5 *Transfer functions of digitally programmable amplifier with voltage gains proportional to –2, –1, 1 and 2*

Conclusions: The application of MOSFET-only current attenuators in continuous-time MOSFET-C filters has been proposed and analysed. The proposed structure allows easy programmability by means of a digital word applied to MOCDs. Tuning methods presented in the technical literature [3, 4] can readily be applied to the structure presented here. Techniques for reducing harmonic distortion [8] can also be applied together with the new scheme.

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Isolated step up/down three-phase AC to DC power supply

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Indexing terms: Switched mode power supplies, Circuit design

A new circuit for providing an isolated DC supply from a three-phase AC source is described. The circuit uses a very simple control scheme to ensure that the current drawn from the AC source is sinusoidal. Unlike previous circuits, the isolation is provided by integration of a second stage converter into the circuit such that pulses of energy are transferred from the input stage to a unique parallel resonant circuit which automatically transfers the energy to the load without any intermediate energy storage. The operation of the circuit is described and some experimental results are given.

Introduction: With forthcoming legislation, it is becoming essential for manufacturers of electronic equipment to ensure that the current drawn from an AC supply contains a low level of low frequency harmonics of the fundamental current. In conventional rectifier circuits the symmetry of the source current waveform is destroyed by the smoothing capacitor. This results in a power factor for the circuit which is <1. Unity power factor can only be achieved when the current drawn from the supply is both sinusoidal and in-phase with the supply voltage. It is desirable to operate as close to unity power factor as possible since this minimises the RMS current drawn from the AC source for the given output power.

Power electronic (active) circuits for sinusoidal rectification have been the subject of extensive research over the last few years and many possible circuits exist. Prior art circuits are common for power factor correction of single-phase AC to DC converters, but circuits are less common for three-phase AC to DC converters. The circuit described in this Letter arose from a need to produce an isolated and controllable DC output, from a three-phase AC