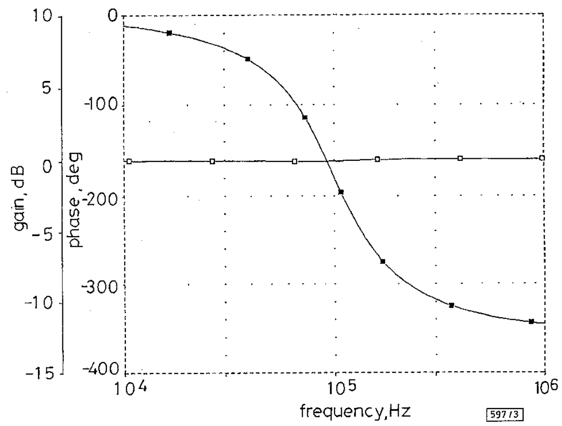

Fig. 3 *Simulated result of allpass response*

□ $|T(j\omega)|$, ■ $\angle T(j\omega)$

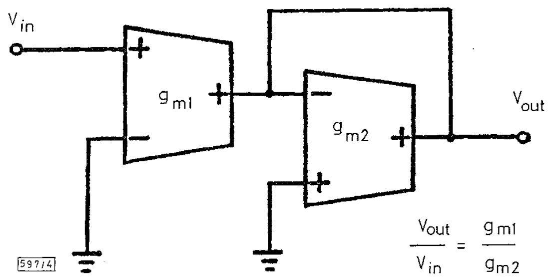

Fig. 4 *Voltage proportional block with OTAs*

electronically tuned. The simulated responses with PSPICE have been quite good over a wide frequency range.

The proposed circuit may be applied to the realisation of high-order transfer functions. Work on this subject will be presented in the near future.

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Current-mode companding √x-domain integrator

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Indexing terms: Integrating circuits, Current-mode circuits

Log-domain integrators and filters are considered to be a promising alternative in the area of low-voltage filtering applications. The authors present the MOS strong inversion analogue, a √x-domain integrator. Simulation results demonstrate the viability of this new approach.

Introduction: The on-going trend towards lower supply voltages has resulted in a decrease in the dynamic range of filters designed using conventional circuit techniques. A possible solution is instantaneous companding [1]. Using this approach, the capacitance voltage swings will be smaller than the input signal swings. Consequently, the supply voltage will be less restrictive with respect to the maximal input signal.

The translinear principle is an elegant realisation principle for companding integrators and filters [2, 3]. The filters of this class are often called log-domain or translinear filters, they exploit the exponential characteristic of the bipolar transistor, both for performing an expanding V-I conversion of the capacitance voltages and for realising multiplication and division of currents. The input and output signals are currents, and log-domain filters can be described completely in terms of currents [4], which accounts for the classification 'current-mode'.

In an IC process where bipolar transistors are not available, the exponential behaviour of the MOS transistor in the weak inversion region enables the realisation of translinear filters. However, as weak inversion operation is limited to low current levels, these MOS filters can only be used for low-frequency applications. In this Letter, it is shown that the large-signal behaviour of the MOS transistor operating in the strong inversion region can also be exploited to realise a current-mode companding integrator.

Operation principle: Realising a current integrator basically comes down to implementing a differential equation, given by

$$K\dot{I}_{out} = I_{in} \quad (1)$$

where K is a constant with dimension [s] and the dot represents differentiation with respect to time.

If the output current is the drain current of an MOS transistor the quadratic-law model states that

$$I_{out} = \frac{\beta}{2}(V_{GS} - V_{th})^2 \quad (2)$$

where β, V_{GS} and V_{th} are the transconductance factor, the gate-source voltage and the threshold voltage of the MOS transistor, respectively.

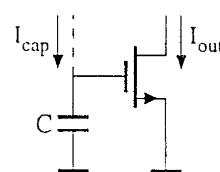

Fig. 1 *Definition of* I_{cap}

The derivative $\dot{I}_{out}$, can be calculated from this equation and an expression containing the (voltage-mode) terms $\dot{V}_{GS}$ and $(V_{GS} - V_{th})$ will result. As currents are the information-carrying signals in eqn. 1, it is more interesting to describe $\dot{I}_{out}$ in terms of currents. The term $(V_{GS} - V_{th})$ can be eliminated by applying eqn. 2. The term $\dot{V}_{GS}$ can be rewritten into a current if we associate it with the current I_{cap} through a capacitance C, across which the voltage V_{GS} is applied. This is illustrated in Fig. 1. Thus, the derivative $\dot{I}_{ut}$ becomes

$$\dot{I}_{out} = \frac{\sqrt{2\beta I_{out}}}{C} I_{cap} \quad (3)$$

At this stage, we define the integration constant K in eqn. 1

$$K \triangleq \frac{C\sqrt{I_o}}{I_a\sqrt{2\beta}} \quad (4)$$

where I_o and I_a are two DC currents.

Now, $\dot{I}_{out}$ can be eliminated from eqns. 1 and 3, yielding

$$\sqrt{I_{out} I_o} I_{cap} = I_a I_{in} \quad (5)$$

which is a current-mode algebraic equation.

The interpretation of this equation is very important. eqn. 5 states that if we are able to implement this algebraic equation, where I_{cap} is defined by the subcircuit in Fig. 1, we have actually realised a current-mode companding integrator, of which the transfer function is given by

$$I_{out} = \frac{\sqrt{2\beta} I_a}{C\sqrt{I_o}} \int I_{in} dt \quad (6)$$

Note that the unity-gain frequency, following from eqn. 6, is linearly tunable by the DC current I_a, owing to the judicious definition of the integration constant K.

Circuit description: In [5] the concept of translinear circuits was generalised to include MOS transistors operating in the saturation strong-inversion region. Strong inversion translinear circuits can be used for realising theoretically process- and temperature-independent current-mode transfer functions. Consequently, this circuit principle can be applied to implement eqn. 5, thus yielding the $\sqrt{x}$-domain integrator, analogous to the term log-domain, shown in Fig. 2. The circuit consists of two translinear building blocks, a $\sqrt{x}$-circuit and a multiplier-divider circuit [5], the subcircuit shown in Fig. 1 and some current mirrors for interconnection purposes. The back gates of all transistors have been connected to the supplies. The output current of the $\sqrt{x}$-subcircuit is $1/2\sqrt{(I_o I_{out})}$. The output of the multiplier/divider is $I_{in} I_a / \sqrt{(I_{out} I_o)}$, which is equal to I_{cap} according to eqn. 5. This current is fed to the capacitance, and I_{out}, the output current of the integrator, is fed back to the $\sqrt{x}$-subcicuit.

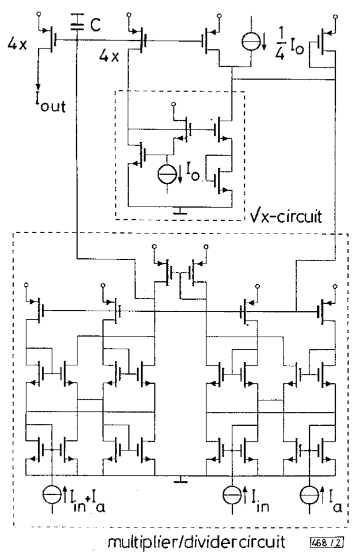

Fig. 2 *Strong inversion translinear integrator*

If linear tunability is not important, the currents I_o and I_a can be chosen to be equal. In this case the input current is limited to $|I_{in}| < 2\sqrt{(I_o I_{out})} - I_o$.

Simulation results: Simulations were performed for the companding integrator shown in Fig. 2, based on a 2.5µ IC process. The aspect ratio of all transistors was 50/10µm. The DC currents I_a and I_0 were 5µA. The integration capacitance was 100pF. For biasing purposes the integrator was enclosed in a unity feedback configuration, which results in a first-order low-pass filter, with a cutoff frequency of $\sqrt{(2\beta I_o)}/(2\pi C)$.

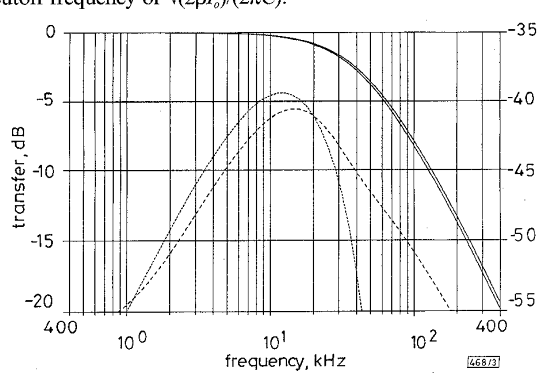

Fig. 3 *Large-signal transfer function and harmonic distortion*

——— transfer function
– – – – HD2
- - - - - HD3

A nonlinear analysis simulation was carried out to obtain the large-signal transfer function and the harmonic distortion components. The input signal of the filter was a sine wave, superponed on a 5µA DC current, which was necessary for biasing the output transistor of the integrator. The simulation was performed twice, once for a sine wave with a 100nA amplitude, and once for an amplitude of 4.5µA, which is 90% of the DC input current.

The results are depicted in Fig. 3. The simulated cut off frequency was 45kHz, corresponding to the calculated value. The difference in transfer function between the two simulations is very small. The harmonic distortion components are displayed on the second y-axis, for the simulation with an amplitude of 4.5µA.

Conclusions: An MOS tunable current-mode $\sqrt{x}$-domain integrator analogous to the class of log-domain filters has been presented. The proposed integrator exploits the quadratic law of the MOS transistor operating in strong inversion and saturation, both for performing an expanding V-I conversion of a capacitance voltage, and for implementing current-mode algebraic equations, according to the generalised translinear principle. Simulation results of a first-order low-pass filter have been shown to demonstrate the principle.

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Analysis of interferometric images using the Hough transform

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Indexing terms: Hough transforms, Image processing

The Hough transform is adapted to determine fringe spacings and orientations of noisy interferometric images consisting of one or more superimposed Young fringe patterns. These measurements are used to calculate the deformation of concrete under stress, and are part of an investigation into the impact of traffic flow on bridge stability.

Introduction: A specklegram is a double-exposed negative produced from two speckle patterns of a specimen, such as a concrete column, taken before and after deformation. It consists of corresponding point pairs separated by a distance which is the product of the deformation and the magnification of the system. When the negative is illuminated with an unexpanded laser beam, Young fringes are produced, which are analysed to determine their spacing. Each measurement is part of a map of displacement or deformation.

Method: Image analysis techniques are commonly used in fringe analysis, e.g. Fourier transforms, autocorrelation and intensity maximisation along radial strips [1, 2]. These methods may not be suitable when the quality of the data is low. The Hough transform