terns. This pattern is produced by interferences between the various modes, each of which is subject to slightly different delays through the fibre (mode dispersion). The position of the individual speckles of the fibre far and near fields is extremely sensitive to small changes in the source wavelength or to physical distortions of the fibre due to changes in the local refractive index.

If a fibre is joined to a fibre similar but with axial or longitudinal misalignments, only the near-field speckles of the common core area or far-field speckles within the numerical aperture of the coupled fibre contribute to the fibre–fibre coupling. Owing to minimal laser wavelength deviation produced by the modulation current (e.g. temperature or refractive-index changes) the attenuation of imperfect splices, connectors or fibre-a.p.d. couplings will be modulated by the transmitted information. This produces harmonic distortions in multimode fibres.

The following example gives an impression of the magnitude of such effects. At the end of a 1 km graded-index fibre, the second harmonic of a 30 MHz carrier could be changed more than 30 dB by slightly bending the fibre.

We observed such laser wavelength deviations when measuring dynamic spectra of a c.s.p. laser during the emission of light pulses with f.w.h.m. of even less than 300 ps. Furthermore, similar chirp effects are described in Reference 3.

Transmission quality: The f.d.m. of the transmitter was alternatively operated with and without coherent carriers.

With coherent carriers we achieved a s.n.r. of 39 dB unweighted and 47 dB weighted (CCIR, Rec. 421-2 Annex III). In this case the interferences consisted mainly of thermal noise and crossmodulation products (as shown in Fig. 2*b*).

To improve the vertical and horizontal hold of the displayed pictures without coherent carriers we had to reduce the r.f. power at the laser diode input by 2 dB. We achieved an s.n.r. of 38 dB unweighted and 43·5 dB weighted only. In this case the interferences consisted of thermal noise and intermodulation as well as crossmodulation products (Fig. 2*c*). We recognise that, owing to the integrating measurement, there is only a small difference in the s.n.r.s in both cases with coherent and noncoherent carriers. The s.n.r. measurement is accomplished over 40 μs within the 64 μs duration of one line. However, the subjective impression of the transmission quality depends on the peak values of the jamming square-wave modulation (Fig. 2*c*). Therefore an adequate subjective quality of the transmitted t.v. pictures could only be reached by applying coherent carriers.

The s.n.r. of 47 dB weighted measured with coherent carriers fulfills the transmission quality of s.n.r. = 46 dB weighted proposed by the German Post Office for subscriber loops of c.a.t.v. systems.

Conclusions: We described an optical transmission link capable of the analogue transmission of 26 t.v. channels with an s.n.r. sufficient for c.a.t.v. subscriber subsets. Special attention is paid to the nonlinearities arising from modal noise in multimode fibres.

Acknowledgment: The project has been sponsored by the German Ministry of Research & Technologie. The authors alone are responsible for the contents.

C. BAACK
G. ELZE
G. GROßKOPF
F. KRAUS
W. KRICK
L. KÜLLER

Heinrich-Hertz-Institut für Nachrichtentechnik
Berlin GmbH, Einsteinufer 37
D-1000 Berlin 10, W. Germany

26th March 1979

References

1 KRICK, W.: 'Improvement of c.a.t.v. transmission using an optimum coherent carrier system', International television symposium, Montreux, May 27–July 1, 1979 (to be published)

2 EPWORTH, R. E.: 'The phenomenon of modal noise in analogue and digital optical fibre systems'. Proceedings 4th European conference on optical communication, Geneva, September 12–15, 1978, pp. 492–501

3 WRIGHT, J. V., and NELSON, B. P.: 'Pulse compression in optical fibres', *Electron. Lett.*, 1977, **13**, pp. 361–363

0013-5194/79/100300-02$1.50/0

DYNAMIC AMPLIFIER FOR M.O.S. TECHNOLOGY

Indexing terms: Active filters, Amplifiers, Field-effect integrated circuits

This letter will demonstrate the feasibility of replacing the static operational amplifiers in switched-capacitor m.o.s. circuits[1,2] by a simple group of switches that acts as a dynamic amplifier.[3] The method is applicable to m.o.s. and c.m.o.s. active-filter circuits such as the ladder filter and biquad, and promises to save static power and chip area by eliminating static o.a.s, as well as reducing $1/f$ noise.

This letter demonstrates the feasability of replacing the static operational amplifiers in m.o.s. switched-capacitor active-filter circuits by a simple group of switches that acts as a dynamic amplifier, saving chip area and static power, and reducing $1/f$ noise. The explanation will be given by demonstrating a switched-capacitor integrator using a static o.a. in comparison with one using the dynamic amplifier. The dynamic amplifier is not limited to integrator applications, however.

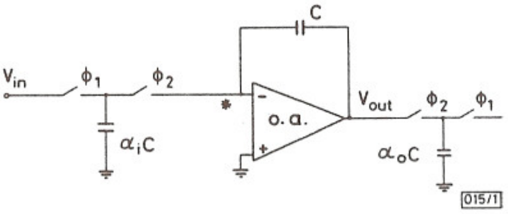

Fig. 1 *Circuit diagram of an m.o.s. technology switched-capacitor integrator, using a static m.o.s. operational amplifier*

Consider the static o.a. switched-capacitor integrator (Fig. 1) having a parallel switched capacitor at the input. The o.a. in this circuit need only have high gain when ϕ_2 is on, because at that time it must cause the transfer of charge from capacitor $\alpha_i C$ to capacitor C, establishing a virtual-ground at node $*$ by feedback action through capacitor C. At the time that it has done this, the output voltage of the integrator, V_{out}, is valid. In the 'lossless differential integrator' (l.d.i.) configuration, V_{out} is sampled during the same time period,[4] ϕ_2 on, to allow the signal V_{out} to be passed to a following integrator, via capacitor $\alpha_o C$.

Consider the equivalent case of operation for the dynamic amplifier ('dynamp') in the switched capacitor integrator, as shown in Fig. 2.

The portion of the circuit inside the broken line is the dynamic amplifier, although its action must be considered with

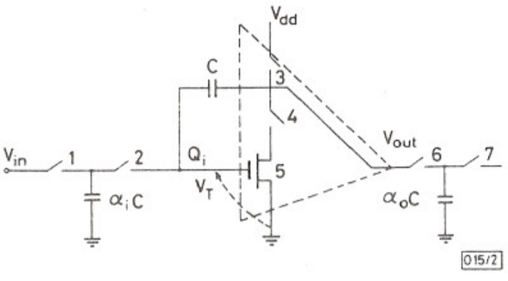

Fig. 2 *Functional circuit of the dynamic amplifier, in the particular context of replacement of a static o.a., in a switched-capacitor integrator*

appropriate timing of the switches external to the broken line as well. Further, the amplifier is only valid in circuits where there is direct capacitive feedback between the output and virtual ground *, a constraint which is common in switched-capacitor circuits.

The general principle of the circuit, in summary, is to create a virtual-ground-like action at the input of a discharge transistor, (switch 5 in the Figure) by using capacitive feedback from the output of this transistor to make it turn itself off. The circuit is then usable in any active-filter circuits where the virtual-ground principle is used, for example integrators, including ladder filters, and state-variable filters or biquads. An example of an amplifier with resistance in the feedback loop as well, rather than a simple integrator, will follow later.

The detailed action of the dynamic amplifier in Fig. 2 is as follows: during the first time period (switch 1 closed), capacitor $\alpha_i C$ is charged by voltage V_{in}. In addition, capacitor $\alpha_o C$ transfers its charge to any following similar circuit (switch 7 closed). The action so far is identical to the various static case.

In the next time period, switches 3, 2 and 6 are closed. The action of switch 3 is to precharge the output node (V_{out}) to V_{dd}. At the same time, switches 2 and 6, being closed, enable capacitors $\alpha_i C$ and $\alpha_o C$ to be precharged as well.

Assume that the virtual node * is floating at V_T, the threshold of m.o.s.t. 5. The precharge action lifts up node * to a voltage above V_T, the value of this voltage being dependent on the previous charge stored on the node and that injected by the input capacitor.

For the amplifier action, switch 3 is now opened and switch 4 closed, and switches 2 and 6 remain closed.

This initiates a discharge of the node V_{out} from V_{dd} toward ground. This couples back capacitively to the virtual node *, lowering its voltage. When the voltage of node * has dropped to the threshold of m.o.s.t. switch 5, V_T, the discharge ends. At this time the node * voltage V_T corresponds to the virtual ground in the static o.a. case. That is, the bias level of the circuit, for V_{in}, V_{out}, and node *, is at V_T of switch 5. This circuit therefore operates at a bias level V_T.

To obtain a dynamic operating range for both input signal and output signal that is symmetrical around the bias level, it is therefore necessary to have a high V_T, which is placed at the centre of the field of operation. It is therefore necessary to have a special ion implantation to adjust the threshold of the discharge transistor to about half the power supply voltage. Other means of increasing V_T, such as substrate bias, are also possible, but ion implantation will allow operating on particular transistors only.

Since node * has now dropped to a virtual 'ground' (bias level V_T), any charge on capacitor $\alpha_i C$ which is different from the bias charge $V_T \alpha_i C$ will have slewed to the feedback capacitor C. The output of the integrator, V_{out}, will at this time be

$$V_{out} = V_T - Q_i/C$$

where Q_i is the total charge that has been input to the integrator summing junction in this and all previous cycles. At this time, switches 2 and 6 open, so that the output capacitor $\alpha_o C$ has observed the appropriate output voltage of the integrator. The cycle is ready to repeat again, with switches 1 and 7 closing as before.

To demonstrate resistive amplifier action in addition to integrator action, consider a switched-capacitor resistor connected across the feedback capacitor as shown in Fig. 4. This switched capacitor should be a series-switched capacitor[1] rather than a parallel one, because the parallel switched capacitor has a delay of one-half clock period, making it not directly usable here. The series-switched capacitor, on the other hand, couples back instantaneously and so fits in with the timing of the dynamic amplifier. In Fig. 4, switch 9 would be driven by the same clock voltage as switches 1 and 7 (see Fig. 3*a*), whereas switch 8 would have the same clock as switches 2 and 6.

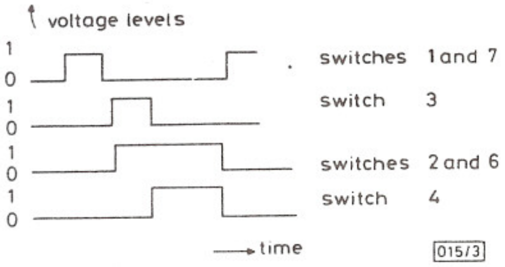

Fig. 3 *Clocks required for this particular realisation of the dynamic amplifier*

Where resistive terminations are to be used in ladder filters,[4] they should preferably be done with series- rather than parallel-switched capacitor resistors. In all other respects, the ladder filter, in versions that have resistive integrator inputs, can be carried over directly to a dynamic-amplifier version.

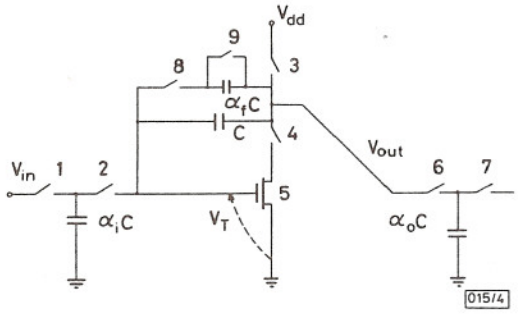

Fig. 4 *Example of low resistive feedback can be incorporated, where d.c. gain rather than integrator action is required*

The advantages of the dynamic-amplifier circuit over switched-capacitor circuits using the static o.a., are that it saves the static power of the o.a., as well as much of the chip area required for the o.a. Also, no $1/f$ noise will be present because the channel of the discharging transistor is going empty at the end of the discharge ($1/f$ noise is proportional to drain current). Thus, good noise performance can be expected. Computer simulations, using typical switched-capacitor integrator parameters, show that effective amplifier gains of greater than 60 dB are readily obtainable with minimal size transistors. Here, amplifier gain is defined by analogy to Fig. 1 to be the ratio of the change in voltage V_{out} to the change in virtual-node voltage, calculated by assuming different charge Q_i stored on the virtual node. In the dynamic amplifier case, Fig. 2, this calculation must be done at the end of the discharge cycle (off-going time of switch 4). From the computer simulation, for example, with discharge transistor of W/L ratio 80/10, feedback capacitor C of 20 pF, input capacitor $\alpha_i C$ of 5 pF, output capacitor $\alpha_o C$ of 5 pF, and 10 V clocks, a gain of 2500 is predicted, for a discharge time (width of switch 4 clock pulse) of 5 μs.

M. A. COPELAND*
J. M. RABAEY

Departement Elektrotechniek
Katholieke Universiteit, Leuven, Belgium

10th April 1979

References

1 CAVES, J. T., COPELAND, M. A., RAHIM, C. F., and ROSENBAUM, S. D.: 'Sampled analog filtering using switched capacitors as resistor equivalents', *IEEE J. Solid-State Circuits*, 1977, **SC-12**, pp. 592–599

2 HOSTICKA, B. J., BRODERSON, R. W., and GRAY, P. R.: 'MOS sampled data recursive filters using switched capacitor integrators', *ibid.*, 1977, **SC-12**, pp. 600–608

3 COPELAND, M. A.: 'Dynamic amplifier for MOS technology', patent pending

4 JACOBS, G. M., ALLSTOT, D. J., BRODERSON, R. W., and GRAY, P. R.: 'Design techniques for MOS switched capacitor ladder filters', *IEEE Trans.*, 1978, **CAS-25**, pp. 1014–1021

* On sabbatical until July, 1978, from Department of Electronics, Carleton University, Ottawa, Canada

0013-5194/79/100301-02$1.50/0