SWITCHED CAPACITOR FILTERS

This invention relates to switched capacitor filters and more particularly to high frequency switched capacitor filters of the type comprising shift register structures combined with feedback and feed-forward arrangements.

As is well known the bandpass function of such filters is dependent on the input capacitances of the filter and is therefore sensitive to stray capacitances at the input side of the filter.

It is desirable that the effects of these stray capacitances be compensated in order that the capacitor values may be minimised while retaining adequate precision of the filter characteristics.

It is thus an object of the present invention to provide switched capacitor filters with means for achieving such compensation.

Accordingly, there is provided a switched capacitor filter including amplifier means provided in a feedback or feed-forward path thereof, said amplifier means having a gain dependent on the ratio of stray capacitance at the input side of the filter to the capacitance of the capacitors used in the filter so as to compensate for errors in filter characteristics which said stray capacitance would otherwise introduce.

In a preferred embodiment of the invention the switched capacitor filter comprises at least one filter amplifier and at least one filter switch coupled together via a filter node which is sensitive to stray capacitances, and in which the amplifier means comprises an operational amplifier having a stray capacitance at its inverting input matching the stray capacitance of said filter amplifier, a switch responsive to a clock signal and substantially identical to said filter switch and connected substantially similarly thereto, and a capacitor matching the total capacitance coupled to said filter node, wherein said switch and said capacitor are coupled between the inverting input and the output of said operational amplifier so that when said switch is open said operational amplifier provides an

amplification of incremental input signal changes determined by said capacitor and by the total stray capacitance at the inverting input, said total stray capacitance being substantially equal to the total stray capacitance at said filter node when said filter switch connected thereto is open.

The amplifier means may, of course, be coupled to a plurality of feedback or feed-forward paths in the filter. Furthermore, a plurality of amplifier means may be provided, if desired.

One embodiment of the invention will now be more fully described by way of example with reference to the drawings of which:

Figure 1 shows diagrammatically a switched capacitor filter of a well-known type; and

Figure 2 shows the filter of Figure 1 with compensation for stray capacitance according to the invention.

High frequency switched capacitor filters can be realised using shift register structures combined with feedback and feed-forward arrangements. Figure 1 shows a simple example of such a filter having a first set of switches (S_1, S_3, S_5) shown closed, responsive to a first clock signal, a second set of switches (S_2, S_4, S_6), shown open, responsive to a second clock signal, a set of unity gain buffer amplifiers (A_1, A_2, A_3, A_4) and a set of appropriately coupled capacitors (C_1, C_2, C_3, C_4, C_5). It will be appreciated that each set of switches must open before the other set closes.

It can be readily shown that the structure of figure 1 generates the bandpass function, in the Z domain:

$$H_{(Z)} = \frac{1}{Z^2 + C_2/(C_1 + C_2)}$$

It will be seen from this expression that the pole positions are dependent on the ratio of the capacitors C_1, C_2. Capacitor C_1 is, however, shunted by the input capacitance of the amplifier A_1 and by any capacitance to ground from the terminal of the switch S_1, connected thereto.

Referring to figure 1 it will be seen that if C_1, for example, is shunted by a stray capacitance C_p then the ratio

$$\frac{C_2}{C_1 + C_2}$$

becomes

$$\frac{C_2}{C_1 + C_2 + C_p}$$

Referring now also to Figure 2, the present invention is based on the realisation that the coefficient may be restored to the ideal value if an amplifier having a gain given by the expression

$$\frac{C_1 + C_2 + C_p}{C_1 + C_2}$$

is inserted in the feedback path from the buffer amplifier A_4 to the switch S_5. It will be noted, furthermore, that said amplifier need provide this gain solely when the switch S_5 is closed. It is therefore possible to use an amplifier having a gain defined by a switched capacitor network comprising a capacitor of value equal to $C_1 + C_2$ and a stray capacitance matching C_p. The amplifier gain may thus be made to adapt automatically to variations in the ratio of the capacitors and stray capacitance.

Figure 2 shows the filter of figure 1 with a suitable compensation amplifier structure provided. The input signal is applied to the non-inverting input of an operational

amplifier A_5. The output of the amplifier is coupled via a switch S_7 responsive to a clock signal, in parallel with a capacitor C_6 to the inverting input. For convenience a ground reference line is included. The stray capacitance to ground from the inverting input of the amplifier and the terminal of the switch S_7 connected thereto is represented in figure 2 by the capacitor C_p.

The operation of the compensation amplifier structure in isolation from the rest of the filter will now be considered. During a first phase of the clock signal controlling the switch S_7, said switch is closed. The input signal is arranged to be at a reference level during this phase. The capacitor C_6 is discharged and the stray capacitance C_p between the inverting input of the amplifier and ground is charged to said reference level. The output voltage is at the reference level.

During a second phase of said clock signal the switch S_7 is open. During this phase the input signal takes up its active level. By the feedback action the stray capacitance C_p at the inverting input will be charged from the reference level to the action level. The charge required will be transferred via the capacitor C_6 across which a voltage will consequently be developed. The amplifier output signal excursion from the reference level will thus be greater than the input level excursion therefrom by the ratio:

$$\frac{C_6 + C_p}{C_6}$$

The switch S_7 can be made identical to those used in the filter and the amplifier A_5 can be readily designed to have substantially the same input capacitance as the filter amplifiers A_1-A_4. The stray capacitance can thus be matched to that occurring at the input node of one of said amplifiers. By making capacitor C_6 equal to the total of

the capacitors connected to such a node there is obtained an amplifier having the gain necessary to compensate for the effects of stray capacitance.

Thus, during the state preceeding that shown in figure 2, the switches S_6, S_7 were closed while switch S_5 was open. The non-inverting input to amplifier A_5 was thus coupled to a reference level and by the feedback action the inverting input and output were constrained to adopt the same level. The capacitor C_2 was thus coupled between the input of amplifier A_1 and a voltage source at the reference level. It will be seen that the conditions were the same as those obtaining in figure 1 during the same state.

In the state shown, suppose that the output voltage of amplifier A_4 differs from the reference level by a voltage V_4. The output of amplifier A_5 will then be shifted from the reference level by an amount

$$\frac{V_4 \ (C_6 + C_p)}{C_6}$$

The charge stored on capacitor C_2 in response to the signal V_4 will thus be

$$\frac{V_4 \ C_2 \ (C_6 + C_p)}{C_6}$$

In the state succeeding that shown in figure 2, the switch S_1 will be open while the output of amplifier A_5 will be again at the reference level. By charge conservation it can readily be shown that the voltage then established at the input to amplifier A_1 in response to the difference voltage V_4 is given by:

$$(V_1)_4 = \frac{V_4\ C_2\ (C_6 + C_p)}{C_6} \times \frac{1}{C_1 + C_2 + C_{p1}}$$

where C_{p1} is the capacitance to ground from the input terminal of amplifier A_1 and the terminal of switch S_1 connected thereto.

As explained, the switches S_1, S_7 may be made identical and the stray capacitances of A_1, A_5 may readily be matched. The total stray capacitances C_{p1}, C_p may thus be made sensibly equal. Making

$$C_6 = C_1 + C_2$$

there is obtained $$(V_1)_4 = \frac{V_4\ C_2}{C_1 + C_2}$$

The feedback ratio from the output to the input is thus established at the desired value independently of the stray capacitance present at the input.

It will be evident that, if so desired, the stray capacitance C_p and capacitor C_6 could be scaled with respect to C_{p1} and C_1, C_2.

It will be appreciated that the described filter only serves to illustrate the technique underlying the invention. In a practical case the compensation amplifier may, if desired, be coupled to a plurality of feedback or feed-forward paths. More than one compensation amplifier may also be used.

CLAIMS

1. A switched capacitor filter including amplifier means provided in a feedback or feed-forward path thereof, said amplifier means having a gain dependent on the ratio of stray capacitance at the input side of the filter to the capacitance of the capacitors used in the filter so as to compensate for errors in filter characteristics which said stray capacitance would otherwise introduce.

2. A switched capacitor filter according to claim 1 comprising at least one filter amplifier and at least one filter switch coupled together via a filter node which is sensitive to stray capacitances, and in which the amplifier means comprises an operational amplifier having a stray capacitance at its inverting input matching the stray capacitance of said filter amplifier, a switch responsive to a clock signal and substantially identical to said filter switch and connected substantially similarly thereto, and a capacitor matching the total capacitance coupled to said filter node, wherein said switch and said capacitor are coupled between the inverting input and the output of said operational amplifier so that when said switch is open said operational amplifier provides an amplification of incremental input signal changes determined by said capacitor and by the total stray capacitance at the inverting input, said total stray capacitance being substantially equal to the total stray capacitance at said filter node when said filter switch connected thereto is open.

3. A switched capacitor filter according to either claim 1 or claim 2 wherein said amplifier means is coupled to a plurality of feedback or feed-forward paths in the filter.

4. A switch capacitor filter according to any preceding claim including a plurality of amplifier means.

5. A switched capacitor filter substantially as hereinbefore described by way of example with reference to Figure 2 of the drawings.