A 'Z' PLANE LERNER SWITCHED CAPACITOR FILTER

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ABSTRACT

This paper discusses the design of a switched capacitor filter that optimizes both amplitude and phase response simultaneously. Conceptually derived from a Lerner function, the filter architecture is efficient and simple.

SUMMARY

In 1964 Lerner[1] discribed a passive filter with linear phase in the passband and sharp cut-off skirts in the stop band. The transfer function of this filter type inherantly optimizes phase and amplitude response without having to add any allpass sections for delay correction. In present high performance data communications, such response is necessary. Hence, we have modernized the Lerner filter by re-working the 's' plane transfer function, converting it to the 'z' plane and deriving and implementing an integrated Switched Capacitor Filter (SCF) with band-pass response. A further advantage of this filter is that the architecture is parallel, potentially resulting in faster settling times than a cascaded network. Additionally, it is relatively simple to design an SCF using these structures and can therefore, reduce custom design cycle time. This building block can be used in an automated filter design CAD package.

Lerner's 's' plane transfer function is based on a pole residue summation rather than the conventional pole zero cascaded representation. In the Lerner function shown (eq. (1)), note the alternating polarity of the residues and that all the poles are on a line to the left and parallel to the imaginary axis. The last two terms of the equation are the corrector poles that smooth transition from the passband to the stop band. The polarity of the corrective residues is the opposite of the boundary terms of the summation that they are next to.

Equation (2) shows the previous equation that we re-arrange into a summation of bandpass functions multiplied by a simple first order function. As long as the pole and zero of the simple function is far enough below the desired passband of the Lerner function, its effect will be to only attenuate the bandpass functions summation. The boundaries of the passband are defined by the corrector poles location.

Equation (3) is the mapping of equation (2) that is used to design the 'z' plane Lerner SCF. Since in our design, the first order multiplier can be ignored, the active poles are arranged on a circle concentric to the unit circle spaced at equal angles with exception to the corrector poles, being placed at half angle increments. There are six complex pole pairs of this type on the chip.

$$(1)\quad H(s)=\overbrace{\sum_{k=n_L}^{n_h}\left[\frac{b(-1)^k}{s-j2ka+b}+\frac{b(-1)^k}{s+j2ka+b}\right]}^{\text{main pole-residues}}\overbrace{\pm\left(\frac{b/2}{s-j(2n_h+1)a+b}+\frac{b/2}{s+j(2n_h+1)a+b}\right)\pm\left(\frac{b/2}{s-j(2n_L-1)a+b}+\frac{b/2}{s+j(2n_L-1)a+b}\right)}^{\text{corrector pole-residues}}$$

$$(2)\quad H(s)=\frac{s+b}{s}\,2\left[\sum_{k=n_L}^{n_h}\left(\frac{bs(-1)^k}{(s-j2ka+b)(s+j2ka+b)}\right)\pm\frac{b/2\,s}{(s-j(2n_h+1)a+b)(s+j(2n_h+1)a+b)}\pm\frac{b/2\,s}{(s-j(2n_L-1)a+b)(s+j(2n_L-1)a+b)}\right]$$

$$(3)\quad H(z)=\frac{1-e^{-bT}z^{-1}}{1-z^{-1}}\,2\left[\underbrace{\sum_{k=n_L}^{n_h}\left(\frac{b(-1)^k(1-z^{-1})}{(1-e^{-bT}e^{j2kaT}z^{-1})(1-e^{-bT}e^{-j2kaT}z^{-1})}\right)}_{\text{'main bandpass 'pole residue generators'}}\underbrace{\pm\frac{b/2\,(1-z^{-1})}{(1-e^{-bT}e^{j(2n_h+1)aT}z^{-1})(1-e^{-bT}e^{-j(2n_h+1)aT}z^{-1})}\pm\frac{b/2\,(1-z^{-1})}{(1-e^{-bT}e^{j(2n_L-1)aT}z^{-1})(1-e^{-bT}e^{-j(2n_L-1)aT}z^{-1})}}_{\text{'corrector bandpass 'pole residue generators'}}\right]$$

In our Lerner SCF the bandpass sections used are relatively popular [4,5] and straight forward to implement by matching coefficients from the bandpass terms of equation (3) to the 'z' transform shown at the bottom of Figure 1. Scaling can then be performed on each section to maximze dynamic range with the aid of a simulator such as Switcap [6]. Figure 2 shows the complete filter. Summing the bandpass functions is performed by grouping equal weighted positive and negative residue terms together, clocking them into a single capacitor at opposite clock phases. Each pair of bandpass functions is summed by a capacitor of value C_s, whereas the corrector pole bandpass functions are summed by a capacitor value of 1/2 C_s to correspond to the needed residue values. The output of the complete filter is the sampled and held value of the summation. This is accomplished by capacitors Cf_s and Cd_s having virtually the same capacitance so that a previous cycle's charge stored on Cf_s is "deintegrated" by Cd_s.

FIG 2

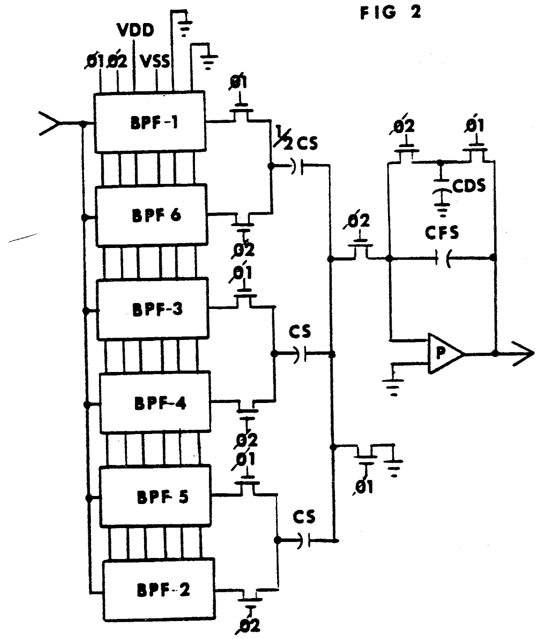
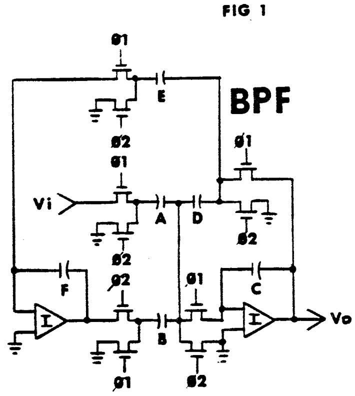


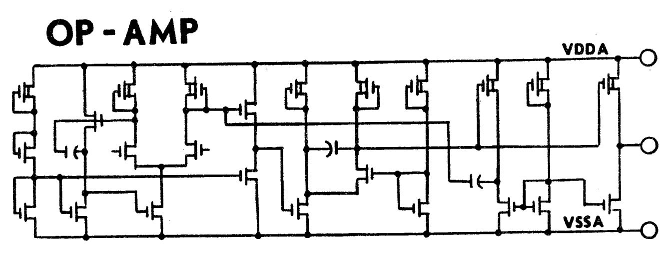
FIG 1



$$H(Z) = -FA\,\frac{1-Z^{-1}}{CFZ^{-2}+(BE-FD-2CF)\,Z^{-1}+FD+CF}$$

Fabrication of our filter was done in a depletion-enhancement n-channel process with a minimum channel length of 8u for the op-amp and 6u for all other circuits. The capacitors were formed as a poly-gate oxide-N^+ implant structure. Figure 3 shows the basic op-amp used throughout the chip. Figure 4 shows the chip layout and the filter response curves. The die photo is pictured in Figure 5 with some performance data.

FIG 3



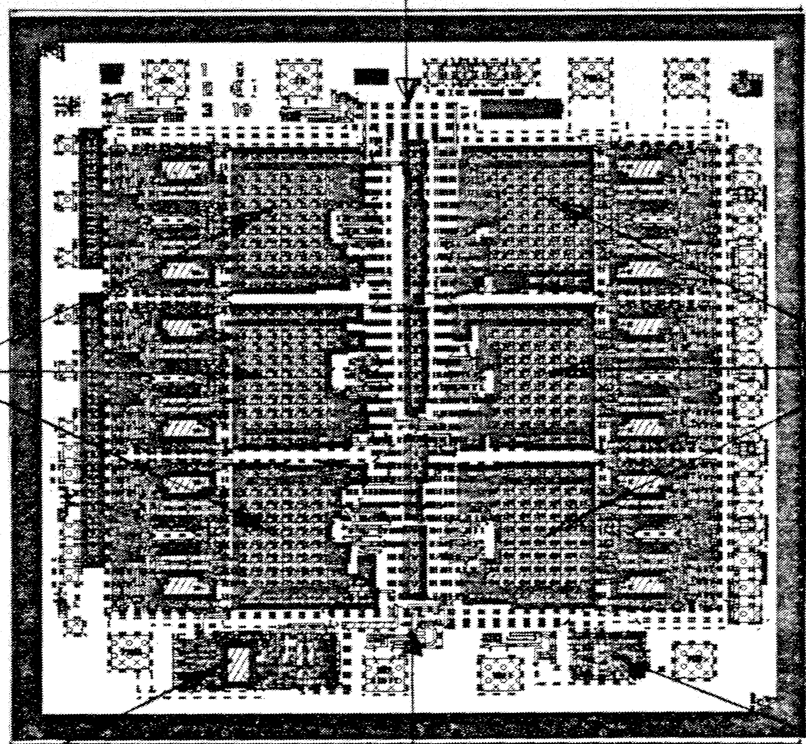
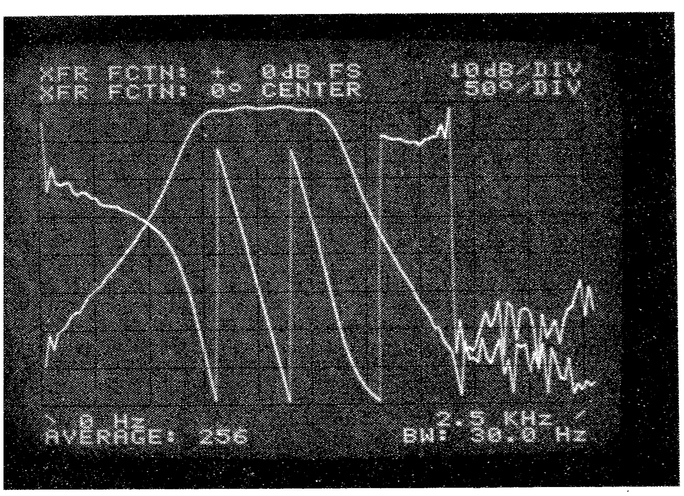
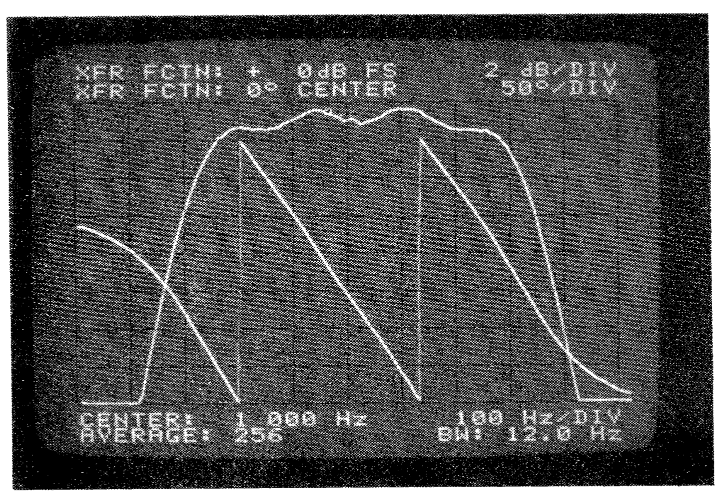


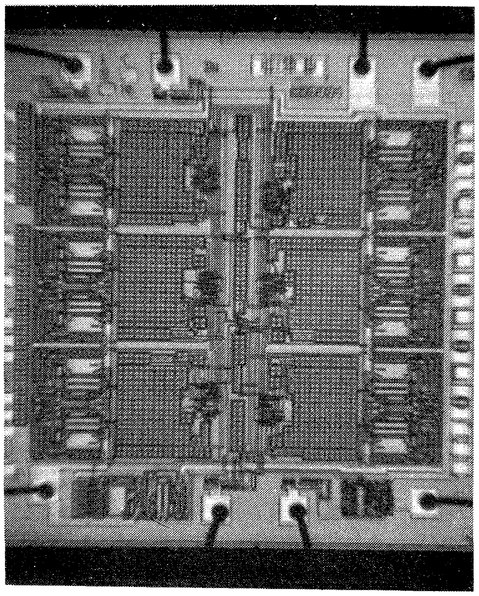
FIG 4



OVERALL RESPONSE



PASSBAND RESPONSE



V_{DD}	+5V
V_{SS}	-5V
V_{BB}	-5V
Passband	1 octave defined by -6db points
Passband center	1 KHz @ f-clock = 54.5 KHz
Passband noise	50u V/vHz
V_{DD} PSRR @ 2.5 KHz	-52 db
V_{SS} PSRR @ 2.5 KHz	-39 db
Die Size (includes test devices)	103 x 108 (mils)

FIGURE 5

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B I B L I O G R A P H Y

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