DESIGN OF ACTIVE FILTERS INDEPENDENT OF 
FIRST- AND SECOND-ORDER OPERATIONAL 
AMPLIFIER TIME CONSTANTS EFFECTS

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ABSTRACT

A PRACTICAL METHOD OF DESIGNING ACTIVE FILTERS 
IN WHICH THE TRANSFER FUNCTION IS INDEPENDENT OF 
BOTH FIRST- AND SECOND-ORDER OPERATIONAL AMPLIFIER 
TIME CONSTANT EFFECTS IS PRESENTED. NEITHER 
MATCHED OPERATIONAL AMPLIFIERS NOR A TUNING PRO- 
CEDURE DEPENDENT ON AN ACTIVE PARAMETER IS REQUI- 
RED. THE ACTIVE PORTION OF THESE FILTERS IS UNIVER- 
SAL AND READILY INTEGRABLE SINCE IT IS COMPRISED 
OF CONVENTIONAL OPERATIONAL AMPLIFIERS AND RESIS- 
TORS. THE METHOD CAN BE USED TO DESIGN A FILTER 
WITH ANY REALIZABLE TRANSFER FUNCTION OF ANY 
ORDER. 

A NEW FILTER OBTAINED FROM THIS METHOD IS 
INTRODUCED AND EVALUATED BOTH THEORETICALLY AND 
EXPERIMENTALLY. THE SIGNIFICANT IMPROVEMENTS IN 
FILTER PERFORMANCE OF THIS NEW FILTER IS DEMON- 
STRATED IN THIS EVALUATION.

INTRODUCTION

The response of most active filters employing 
operational amplifiers (OP AMPS) that are designed 
to operate at high frequencies and/or high Qs 
changes significantly if the OP AMPS used in 
the design are replaced with devices of the same type 
but with slightly different characteristics. 
These changes in the response of the active filter are 
a result of the departure of the magnitude and 
phase characteristics of the OP AMPS themselves 
from the ideal values.

During the last few years, research efforts 
in active filter design have been directed towards 
topological configurations that are less depend- 
ent upon the parameters of the OP AMPS than were 
previous designs. A host of active filters have 
appeared in the literature [1] - [7], many of 
which perform better than the designs of ten years 
earlyer.

Recently several configurations have appeared 
in the literature [1], [3], [7] - [9], in which 
first-order OP AMP time constant effects have 
been eliminated. Some of these circuits [8], [9] 
however, require either matched OP AMPS or a cumber- 
some active-parameter-dependent tuning procedure 
to remove these first-order effects.

It was recently shown by Geiger and Budak [1] 
that the active sensitivity function (sensitivity 
with respect to the OP AMP time constant) is a 
figure of merit for comparing the OP AMP related 
performance of active filters. Several filters 
[1], [3], [7], in which the active sensitivities 
of the poles and zeros vanish have been introduced. 
The poles and zeros of these zero active sensitiv- 
ity designs are independent of first-order OP AMP 
time constant effects. In addition, the transfer 
function itself is independent of the first-order 
time constant effects for the circuits presented in [3] and [7]. The active sensitivity filters 
do not require either matched OP AMPS or an active 
parameter-dependent tuning procedure to eliminate 
the first-order effects.

Geiger and Budak [1] also presented criteria 
necessary to eliminate second-order as well as 
first-order time constant effects without require- 
ing matched OP AMPS. No filters presented in the 
literature to date are independent of both first- 
order and second-order time constant effects.

In this paper a method of designing active 
filters is introduced in which both the first and 
second derivatives of the transfer function with 
respect to the OP AMP time constants vanish. This 
is achieved by imposing constraints on the gain of 
the amplifiers to eliminate both first- and second- 
order time constant effects in any filter employ- 
ing these amplifiers. Using these constraints a 
new amplifier is synthesized. The ensuing filters 
require neither matched OP AMPS nor an active- 
parameter-dependent tuning procedure.

A bandpass configuration employing the pro- 
posed amplifier is introduced. A performance 
evaluation of this filter confirms the reduced 
OP AMP dependence of the new design over that of 
existing state of the art filters. Experimental 
results presented agree favorably with the theo- 
retical development of the new filter.

The proposed amplifier can be used to design 
active filters with any realizable pole-zero 
assignment. The results presented for the band- 
pass situation are representative of the general 
case.

ACTIVE FILTERS WITH ZERO FIRST & SECOND DERIVATIVES

A general active filter employing a single 
amplifier with gain A(s) is shown in Fig. 1. 
Assume the A(s) amplifier is constructed 
from resistors and three internally compensated 
OP AMPS which are ideal except for a frequency 
dependent gain given by the expression [11]
where the OP AMP time constant $\tau_1$ is the reciprocal of the bandwidth product of the $i$th OP AMP and is ideally zero. The OP AMP time constants are not assumed to be identical. If $T(s)$ is the transfer function of any filter employing $A(s)$ it can be shown that all first- and second-order derivatives of $T(s)$ with respect to all OP AMP time constants will vanish provided $A(s)$ is expressible in the form

$$A(s) = \frac{\prod_{i=1}^{3}(s^2 + \frac{a_i}{\tau^2} + s^2\frac{\tau^2}{\tau^3})}{\prod_{i=1}^{3}(s^2 + \frac{a_i}{\tau^2} + s^2\frac{\tau^2}{\tau^3} + s^2\tau^2\tau^3)}$$

where the $a_i$'s are real constants with magnitudes less than or equal to unity and $\tau_0$ is the dc gain of the $A(s)$ amplifier and may be either finite or infinite.

**Fig. 1** General Active Filter

**ZERO FIRST AND SECOND DERIVATIVE AMPLIFIERS**

A new amplifier along with the corresponding gain $A(s)$ is shown in Fig. 2. Note that the gain expression agrees with the functional form required by (2) to eliminate first- and second-order time constant effects in the transfer function of any filter employing this amplifier as the active device. As can be seen, the amplifier of Fig. 2 has ideally infinite gain. The infinite gain amplifier of Fig. 2 is readily integrable and universal in the sense that it may replace conventional OP AMPs in many existing filter configurations. The zero sensitivity property if unaffected in the input leads of any of the OP AMPs are interchanged. For example, reversing the $+$ and $-$ inputs on $A_i$ results only in a sign change in front of the transfer function.

**Fig. 2** Zero Second Derivative Amplifier

**SOME NEW FILTERS WITH ZERO TRANSFER FUNCTION SECOND DERIVATIVES**

For the purpose of easy comparison with existing designs the new filter presented in this paper ideally realizes a second-order bandpass transfer function. It should be emphasized, however, that any realizable transfer function of any
order can be synthesized with the amplifier of Fig. 2. The results given here are to be interpreted as being representative of the general case.

The circuit shown in Fig. 3 is a second-order bandpass configuration in which both the first and second derivatives of \( T(s) = \frac{V_0}{V_1} \) with respect to the \( s \) of the OP AMPS vanish. This configuration has been chosen for this presentation because its topological structure is similar to that of some well-known configurations and the passive sensitivity expressions are identical to their well-known counterparts.

The circuit of Fig. 3 uses the amplifier of Fig. 2 with the + and - leads of \( A_1 \) reversed. Diode \( D_3 \) is necessary for stability with some OP AMPS. The parameters \( \alpha \) and \( \beta \) must be picked so that the parasitic filter poles are in the left half-plane [18].

The transfer function of this configuration is

\[
T(s) = \frac{V_0}{V_1} = \frac{s^2 + s^2 \left( \frac{2}{R_1 C_1} \right) + s^2 \left( \frac{1}{R_1 C_1} \right) + \frac{1}{R_1 C_1}}{s^2 + s^2 \left( \frac{1}{R_1 C_1} \right) + \frac{1}{R_1 C_1}}
\]

where

\[
\omega_0 = \frac{1}{\sqrt{R_1 C_1 C_2}}
\]

and

\[
Q = \frac{1}{2} \frac{R_1}{\sqrt{R_1}}.
\]

**FILTER EVALUATION**

A plot of the transfer function magnitude of this filter appears in Fig. 4 for values of \( \tau_n = \tau_{\omega_0} \) of .025 and .05.

In this evaluation all OP AMPS are assumed identical. This assumption is not essential but rather used for convenience.

The merit of the new filter is best established by a comparison with previous state of the art designs. A discussion of the performance of existing designs was presented by Geiger and Budak [1].

**EXPERIMENTAL RESULTS**

The circuit of Fig. 3 with \( \alpha = .2 \) and \( \beta = 1 \) was used to realize a filter with \( Q = 10 \) and \( \omega = 27 \text{KHz} \) when the OP AMPS are ideal. The resulting filter was evaluated experimentally using both 741 (measured \( GB = 1.0 \text{ MHz} \pm 1 \)) and 356 (measured \( GB = 4.15 \text{ MHz} \pm 10 \% \)) type of OP AMPS. A summary of the experimental results is included in Table 1.

The close agreement between theoretical and experimental results is obvious from this comparison. The performance of the filter using 741's designed for a center frequency of 27 kHz \( (\tau_n = 0.27) \) emphasizes the usefulness of these filters. Notice also that changing \( GB \) by more than 400\% (i.e., using a 356 rather than a 741) does not significantly affect the filter performance and may well be a better indication of performance than the comparison to the theoretical characteristics which rely on the absolute accuracy of the measured component values as well as the absolute accuracy of the frequency counter used in the experimental evaluation.
### Table 1

<table>
<thead>
<tr>
<th>Theoretical</th>
<th>Experimental</th>
<th>$%$ Error</th>
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<tbody>
<tr>
<td>$f_0$</td>
<td>26.963kHz</td>
<td>26.898kHz</td>
</tr>
<tr>
<td>$q$</td>
<td>9.41</td>
<td>7.64</td>
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### CONCLUSIONS

It has been shown that it is possible to design active filters with zero first and second transfer function derivatives with respect to the parameters of the OP AMPS. This was attained by first establishing the constraints on the gain of amplifiers necessary to obtain these properties and then synthesizing an amplifier which satisfied the constraints. This new amplifier is both universal and readily integrable.

A novel second-order bandpass circuit possessing these zero first and second transfer function derivative properties has been introduced. This circuit is less dependent upon the parameters of the OP AMPS at low frequencies than previously existing designs. In addition, in the 100 kHz range this circuit performs well using low-cost conventional OP AMPS whereas the performance of most previously existing active filters employing the same operational amplifiers is generally considered inadequate. These improvements in performance are attained without requiring either matched OP AMPS or an active parameter dependent tuning procedure. Experimental results confirmed the predicted performance of the new filter.

The new amplifier can be used to synthesize a filter with any prescribed realizable pole-zero assignment. These filters have the zero first and second transfer function derivative property and offer performance improvements similar to those of the bandpass configuration presented.

### REFERENCES


