

## FULLY INTEGRATED VOICEBAND FILTERS

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This paper will describe design techniques to achieve a high performance CCD voiceband filter which meets all specifications required for telecommunications applications. The design techniques include the following:

- double-split electrode technique
- balanced charge sensing technique
- compatible input/output scheme
- minimum phase filter design.

The paper will describe the role of each of the above techniques in meeting the required performance specifications of telecommunications systems.

The double-split electrode technique (1,2) will be described in detail and shown to be essential in the design of high performance CCD transversal filters. The key features are reductions of clock sense line capacitance and consequent reduction in common mode signal, and noise pickup, and noise gain. Other features of the approach include reduced sensitivity to gain error and reduced tap quantization error.

Closely tied in to the performance of double-split electrode structure is the sensing technique. Since the middle segments of the double-split electrodes are clocked separately from the sensing segments, the sensing circuit must clamp the outer segments to the same level as the clocked segments. Total symmetry is essential in order to maintain clock noise rejection and minimize offsets at the filter output. Methods of achieving this will be discussed.

A compatible input/output scheme is required to ensure that high linearity can be maintained as well as accurate control on device gain. The filter components must be arranged so that all parameters are functions of ratios of device structures which track during fabrication. This is an important requirement especially where absolute gain variations are limited to  $\pm 1$ dB. The components pertaining to obtaining maximum performance will be discussed.

Finally, the advantages of minimum phase design (3) will be related to telecommunication requirements and CCD transversal filter design criteria. It is shown that minimum phase requires less tolerance and less transfer efficiency to realize the same magnitude response as linear phase filters.

The performance measurements on a fully integrated double-split electrode, minimum phase, low pass filter will be discussed. The filter was fabricated using double-poly silicon gate n-channel MOST process. Some of the measured parameters on this filter were:

Dynamic range	>80dB
Linearity	>50dB
Gain tracking	<.1dB
Filter response passband	$\pm 1$ dB
stopband	<-40dB

The CCD transversal approach is shown to be an attractive approach for making high performance integrated filters for voiceband filters. The filters have been successfully integrated with a PCM voice codec (4).

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#### REFERENCES

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