# LOW FREQUENCY OPERATION OF NARROW BAND CCD TRANSVERSAL FILTERS

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ABSTRACT

The use of CCD's in acoustic signal processing applications requires large total time delays to obtain low frequency correlations. The maximum delay is ultimately limited by the storage time of the CCD well. This paper describes the performance of a 1.0 Hz low pass transversal filter with on chip delays in excess of one second. To achieve a 1.0 Hz passband with less than 1.0 dB band pass ripple and stopband suppression greater than 50 dB, the 101 filter stage filter was designed to be clocked at 100 Hz. The analytical design of the filter is further described, and measurements of device performance based on current available data are presented.

## I. INTRODUCTION

Charge coupled device CCD delay lines can be used to accurately delay samples of analog signals. While it has been shown that CCD's operate well in the mid-frequency range (1.0 kHz < f < 10.0 mHz), measurements of their performance below 1.0 kHz have been previously neglected. However, this is the frequency region of interest in acoustic signal processing applications such as matched filtering or beamforming to optimize the detection of acoustic signals propogating through the ocean. The device discussed in this report was designed to operate at clock frequencies as low as 100.0 Hz, providing on chip time delays in excess of 1.0 second. A split electrode lowpass transversal filter was chosen as the vehical for this study because its design and operation are understood[1] for f > 1.0 kHz.

## II. DEVICE DESCRIPTION

The CCD transversal filter chip shown in Fig. 1 contains two CCD delay lines compatible with the double layer polysilicon process. One delay line forms a .240" x .060" 1.0 Hz transversal filter using a set of tap weights to configure the split electrodes. The second delay line is .240" x .012" and exists primarily to cancel the differential mode clocking noise and dark current contribution to the main filter output. This auxiliary channel is also weighted and can be used as a 10.0 Hz lowpass filter without noise cancellation.

The tap weight coefficients were selected by a computer program which determined the best equi-ripple approximation to the (ideal) desired lowpass filter frequency response. The impulse response and therefore the weighting coefficients can then be determined by sampling the inverse discrete Fourier transform of the calculated response. Several runs of this program have generated the set of curves in Fig. 2, relating the stopband suppression in dB (R) to the number of delay stages (N) and the transition bandwidth ($bw_t$) of such filters. A point of inflection of these curves occurs when

$$bw_t \approx \frac{1}{N\tau} \qquad (1)$$

where $\tau$ is the delay per stage. This occurs because narrow band filters have transition bandwidths equal or greater than the filter bandpass. From Fig. 2, 101 stages were chosen to achieve 55 dB band stop suppression at the expense of a 200% transition bandwidth. It is interesting to note that for these filters should a transition at less than 100% be desired, choices for N > 90 should be avoided as they have very little effect on R and thus only waste silicon real estate. The analytical frequency response due to the calculated weighting coefficients is shown in Fig. 3.

## III. EXPERIMENTAL RESULTS

A photograh of the impulse response of the filter with $f_c$ = 1.0 kHz is shown in Fig. 4, with the corresponding frequency response for $f_c$ = 1. 0 kHz and f = 438 Hz plotted in Fig. 5. The observed 3 dB cutoff for the curve with $f_c$ = 1.0 kHz is $f_{3\ dB}/f_c$ = .0165 compared with the theoretical value of .0175. At the lower frequency, $f_{3\ dB}$ has shifted to $f_{3\ dB}/f_c$ = .0198 due to dark current contributions of the signal at lower frequencies. At higher input frequencies the rolloff becomes independent of the clock frequency.

The frequency response has not been measured at lower clock frequencies, nor the ultimate value of the stopband suppression been measured due to limitations in the technique used to obtain this preliminary data. The fact that $f_{3\ dB}$ is extremely close to the analytical value for both clock frequencies suggests the usefullness of this design approach for low frequency narrow passband filters. The measured band stop suppression R > 40 dB indicates these filters will be useful for the matched filtering applications discussed previously.

While the frequency response has not yet been obtained at $f_c$ = 100.0 Hz, an estimate of the filter performance at this clock frequency is made by observing the output signal of the delay line as the total delay time on the chip $t_d = n\tau$ is increased. The result shown in Figs. 6a - 6c indicates that a useful output signal is detected from the output diffusion of the CCD delay line as $t_d$ approaches 1.0 second.

## IV. DISCUSSION

It is clear that CCD's can play a major role in obtaining analog delay even as the clock frequency is decreased and thus $t_d$ increased to 1.0 sec. It can be expected in the future that as semiconductor material and IC processing improves, even long delay times will be possible without serious degradation of device performance. Thus low frequency correlations to the tenths of Hz will become available.

## REFERENCE


1. R. D. Baertsch et. al. IEEE Trans. Elect. Dev., (Feb. 1976).


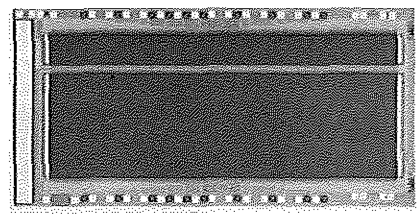

Fig. 1 The NOSC-013 Transversal Filter Chip

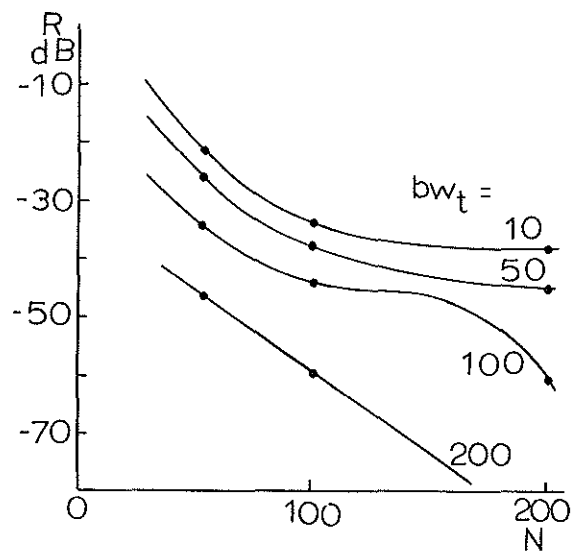


Fig. 2 Narrow Band Filter Design Curves

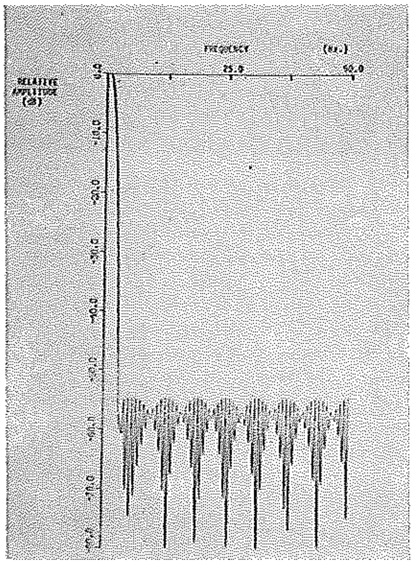

Fig. 3  Low Pass Filter Analytical Frequency Response

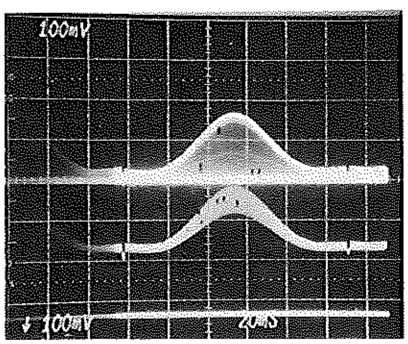


Fig. 4  Transversal Filter Impulse Response, $f_c$ = 1.0 kHz

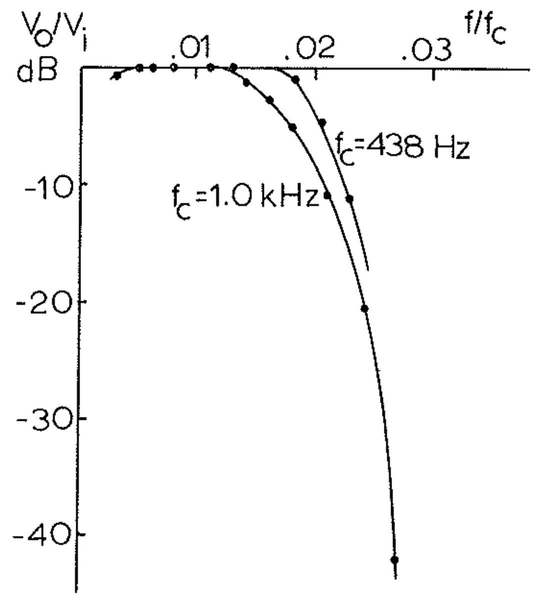


Fig. 5  Measured Frequency Response of the Transversal Filter

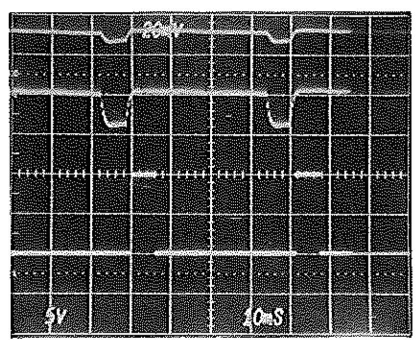


Fig. 6a  33.33 msec delay

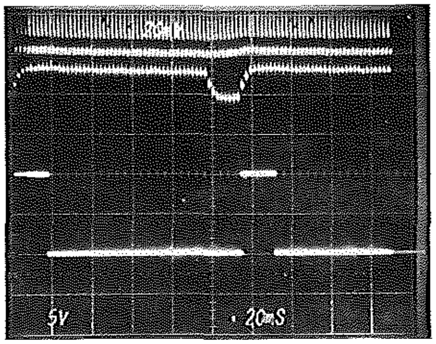


Fig. 6b 212.1 msec delay (2x input)

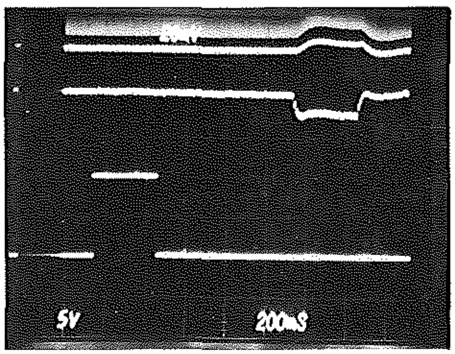


Fig. 6c 1.01 second delay