Abstract — The Farrow structure provides an effective means of implementing a variable fractional delay filter. In the literature, the design of Farrow filters is invariably formulated as a weighted least-squares problem, or similar. However, this design approach does not often yield satisfactory group-delay responses. This paper presents a design formulation that addresses this shortcoming directly. It also explores a more generalised form of the Laguerre-Farrow filter.

I. INTRODUCTION

Fractional delay (FD) filters have found applications in many signal processing fields, including communication, speech processing, and array processing. These filters allow the user to delay sampled signals by amounts that are not integer multiples of the sampling period. An excellent discussion on the various design methods for fractionally delay filters can be found in the tutorial article [1].

In many advanced applications there are demands for the delay to be continuously variable during the operation of the filter. These filters are known as variable fractional delay (VFD) filters. VFD filters are very useful in applications such as time-delay estimation, speech coding, signal interpolation, and sampling rate conversion. Published works include variable filter banks for audio signal processing [2], adaptive noise reduction [3], reduction of channel timing-error effects in time-interleaved AD converters [4], modelling of music instruments, speech coding and others wherever new samples need to be interpolated [1], wireless radio optimisation [5], multi-mode transmultiplexers [6], fractional delay Hilbert transform filters [7], and IIR variable delay filters [8]. All of the above-mentioned publication had one thing in common and that is the use of the Farrow structure [9] as the foundation of their designs.

In this paper, the discussion will include a reformulation of the optimum design problem to allow frequency response shaping. It also shows the generalization of the conventional Farrow structure to incorporate Laguerre filters [8]. Laguerre filters are higher order forms of the unit delay elements of an FIR filter. By replacing the unit delays with Laguerre filter sections, extra degrees of freedom are introduced into the design. It will be shown that this extra freedom can yield a better design.

II. THE LAUERRE-FARROW STRUCTURE

A. The Conventional Farrow Structure

The celebrated Farrow structure is shown in Fig. 1. It consists of $M$ parallel FIR filters, whose coefficients are fixed, and a multiplier chain through which the user adjusts the filter delay $\delta$. It can be readily shown from Fig. 1 that the Farrow filter has transfer function

$$H(z, \delta) = \sum_{k=0}^{K} \sum_{m=0}^{M-1} b_{k,m} \delta^m z^{-k}$$

(1)

Fig. 1. The conventional Farrow structure

One view of the Farrow structure is that it is simply a $K$-tap FIR filter whose coefficient are each an $(M-1)$th order polynomial in $\delta$. In other words, with an appropriate choice of filter coefficients $b_{k,m} \in \mathbb{R}, \ k = 0, 1, \ldots, (K - 1), \ m = 0, 1, \ldots, (M - 1)$, the Farrow filter aims to approximate, as closely as possible, over a range of delays $\delta$, the ideal variable fractional delay filter whose frequency response is given by

$$H_f(e^{j \omega}, D, \delta) = e^{-j(D-\delta)\omega}$$

(2)

where $D$ is the nominal, or bulk, delay of the filter. Methods to design the $M$ fixed FIR filters are summarized in [1].
REFERENCES


