INTRODUCTION

The initial concept of the frequency-response masking technique was introduced by Neuvo, Cheng-Yu and Mitra (1984). It was shown that the complexity of a linear phase FIR filter can be considerably reduced by using the cascade connection of an interpolated FIR (IFIR) filter and a properly designed FIR filter. The IFIR filter transfer function is obtained by replacing the unit delay $z^{-1}$ with the delay block $z^{-M}$, where $M$ is an integer. In this way, the frequency response of the IFIR filter is made periodic. The FIR filter in the cascade is used to eliminate (mask) the images from the IFIR filter frequency response. Two years later, Lim (1986) proposed a complete approach for the application of frequency-response masking technique in designing narrow-band and arbitrary-band linear phase FIR filters. It was shown that the approach given in (Lim, 1986) results in a linear phase FIR filter with a small fraction of nonzero coefficients, and thus is suitable for implementing sharp filters with arbitrary bandwidths. The arithmetic complexity is considerably smaller in comparison with the arithmetic complexity of an optimal FIR filter having the equivalent frequency response.

This approach is applied later to IIR filters by Johansson and Wanhammar (1997, 2000). The overall filter is composed of an IIR periodic model filter and its complementary periodic filter, and FIR linear-phase masking filters. In this way, the arbitrary-band filter can be designed. For a narrowband filter, the cascade of a periodic filter and masking filter can be used.

The frequency-response masking approach is suitable for digital filters with sharp transition bands. Compared to the classical single-filter design, this technique offers the advantage of lower coefficients’ sensitivity, higher computation speed and lower power consumption.
Recently, the application of frequency-response masking approach has been extended to filter banks to achieve a sharp band-separation with reduced computational complexity (Furtado, Diniz, Netto, and Saramäki, T. 2005; Rosenbaum, Lövenborg, and Johansson, 2007).

In this chapter, we review the frequency-response masking techniques for narrow-band and arbitrary bandwidth IIR filters. We demonstrate through examples that very selective characteristics can be obtained using relatively low-order sub-filters. In this way, stable, low-sensitive filters are obtained.

**NARROWBAND FILTER DESIGN**

The frequency-response masking technique can be used for a narrowband filter design. The principle is very simple: the narrow-band filter is obtained as a cascade of a periodic model filter and a masking filter. Figure 10.1 illustrates the cascade connection of the periodic model filter $G(z^M)$ and the masking filter $F(z)$, and Figure 10.2 indicates the concept of the narrowband filter design.

Design starts from the model filter $G(z)$ and its frequency response $G(e^{j\omega})$, illustrated in Figure 10.2 (a). We call this filter a model filter. Replacing each delay in the model filter by $M$ delays, the periodic model filter $G(z^M)$ is obtained. The frequency response of the periodic model filter $G(e^{jM\omega})$ is sketched in Figure 10.2 (b). The periodic spectra (images) produced by $G(e^{jM\omega})$ can be eliminated by the masking filter. For a low-pass filter design, the masking filter is a low-pass, indicated by $F_L(e^{j\omega})$ in Figure 10.2 (c). The cascade of $G(e^{jM\omega})$ and $F_L(e^{j\omega})$ produces a desired narrowband lowpass filter $H_L(e^{j\omega})$, Figure 10.2 (d).

For a bandpass filter design, the masking filter has to be the bandpass as shown in Figures 10.2 (e) and 10.2 (f). If a highpass characteristic is required, only $F(z)$ has to be a highpass. Therefore, for narrowband filters, the transfer function $H(z)$ is expressed in the form

$$H(z) = G(z^M)F(z) \quad (10.1)$$

We can arbitrarily choose FIR or IIR transfer functions for $G(z)$ and $F(z)$.

The important outcome of the proposed approach is that the transition band of the overall filter is $M$ times smaller than that of the model filter. This effect is produced by the replacement of every delay in $G(z)$ by $M$ delays. Consequently, the passband bandwidth is also reduced by the same factor. Hence, this method is only suitable for narrowband design.

This masking technique provides the implementation of a sharp narrowband characteristic using filters with much wider transition bands. The specifications for masking filtering may be additionally relaxed by using the multistage implementation of $F(z)$, as shown in Figure 10.3.

The overall transfer function for the structure of Figure 10.3 is given by

$$F(z) = \prod_{k=1}^{R} F_k \left( z^{M_k} \right) \quad (10.2)$$

Periodic filters $F_1, F_2, ..., F_R$ from Figure 10.3 are designed to subsequently remove the images from the frequency response. It is shown in (Johansson & Wanhammar, 1996) that for masking filters $F_1(z), F_2(z), ..., F_R(z)$ the halfband filters can be used. Configurations based on the use of halfband masking filters achieve an improvement in the computational efficiency.
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