1 Introduction

Potential instability, ringing and nonlinear phase of classical IIR notch filters, are among the motivations to consider FIR notch filters instead of IIR filters. This paper focuses on two approaches deriving a FIR filter from an according second order IIR filter, both presented in [RKJ01], Section 2.3. The derived FIR filter inherits good properties like low delay but also bad ones like nonlinear phase both close to the corresponding IIR.

At first sight, one gets rid of numerical instability and ringing. At second sight, numerical instability is just shifted from filter execution to filter design (where it may be acceptable). Still the design algorithm as such keeps simple, simpler at least as compared with other approaches as e.g. [RJK94], but they must be carried out with special arithmetic and is thus still quite time and memory consuming.

Also ringing is not really removed, but its length is bounded and tied to the order of the FIR filter.

For fixed notch frequency, the IIR filter essentially has a single parameter, the radius of the poles which must be less than 1. Depending on the field of application, the acceptable width of the notch is bounded and so the radius must be close to 1. This is exactly what causes numerical instability and ringing with little damping. So motivation to replace the IIR filter by a FIR filter is for the critical parameter values. To keep up quality, the FIR filter must approximate its according IIR filter well enough, which requires some minimum order and this in turn is the length of its "ringing". Besides the width of the notch, the field of application may restrict the length of ringing. For example in an ECG application the QRS complex ("heart beat") may cause ringing and this must at least be damped enough until the next beat comes. Since the segment immediately after the QRS complex is particularly significant for diagnosis, much quicker damping is vital. This may cause an unsolvable conflict for the derived FIR filter as much as for the original IIR filter: the radius must be smaller than one for quick damping of ringing but close to 1 to obtain a tight notch.

The idea to replace an IIR notch filter by a derived FIR filter has been introduced in [RJK97]. The approach advocated there is to decompose the filter into a FIR part which eliminates the notch frequency and into the IIR part which compensates outside the notch so that the complete IIR filter leaves frequencies apart from the notch frequency essentially unaltered. Then the IIR part is replaced by a FIR filter approximation, just computing the impulse response and cutting off somewhere. The composition of the two FIR filters, which is again a FIR filter, eliminates the notch frequency still completely, as does the original IIR filter, but compensation outside the notch is degraded so that it perturbs frequencies remote from the notch frequency. Worse than that, increasing the filter order cannot resolve that problem. This effect is the stronger, the tighter the notch is, i.e. when numerical instability begins to be an issue. Since [RJK97] presents punctual performance results in terms of the frequency domain with relatively broad notch, this effect is not observed in that paper.

Section 2.3 in [RKJ01] takes up the approach suggested in [RJK97], restates the results and adds a second approach, just taking the IIR filter as a whole, computing the impulse response and cutting off somewhere directly. Of course, the resulting FIR filter may not be expected to eliminate the original notch frequency completely, but this filter turns out to be a "weak" kind of notch filter in the sense that the amplitude at the notch frequency is reduced by a factor tied to the filter order. In contrast to the first approach, the filter preserves frequencies apart from the notch frequency quite well and fitting can be improved increasing filter order whereas there seems to remain ripple close to the notch frequency. The tighter the notch, the less damping on the notch frequency. So as for the first approach, the deficiencies of the filters are apparent in a parameter domain not observed in [RKJ01].