

## Filter tuning system using fuzzy logic

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We can conclude from Table 1 that the noise reduction factors of the two alternatives are almost the same, while, as was mentioned earlier, the comb alternative suggested in this Letter is far more efficient (low complexity structure).

**Conclusions:** A mixed configuration of a simple to implement ESS scheme in FSFs was introduced. The suggested scheme replaces the error feedforward structure with a comb-ESS structure which achieves substantial noise reduction while minimising the complexity of the error spectrum shaping network, thus making it very attractive to implement.

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### Filter tuning system using fuzzy logic

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*Indexing terms:* Fuzzy logic, Fuzzy set theory, Filters, Tuning

The authors describe an expert system approach for tuning filters using fuzzy logic. The proposed system adjusts the filter components in order to meet the given window specifications. The system is described and experimental results are presented for a lowpass filter implemented with OTAs.

**Introduction:** Specifications in the design of an analogue filter are often expressed by window constraints. Fig. 1 shows a typical window. Fitting the frequency response within window constraints is achieved through well established approximation techniques such as Butterworth, Chebychev, etc.

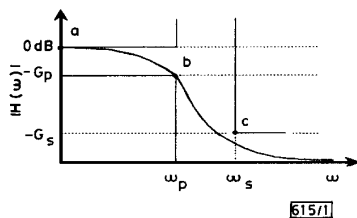


Fig. 1 Magnitude window specifications for filter design

However, when these approximations are implemented in hardware their frequency response may not meet the specifications due to component variations. A solution to this problem is to include a tuning system as in [1, 2]. This system will adjust some of the components until the filter meets the specifications. The design of such system is complicated for the following reasons:

(i) The adjustable components usually produce nonlinear changes in the frequency response of the filter.

(ii) The variation of one component modifies several characteristics of the filter.

(iii) The implemented circuit contains parasitic components and other nonideal effects.

The proposed system uses a fuzzy logic approach taking advantage of the fact that a window specification can allow any curve as long as it is within the window. Therefore, when the filter is tuned it does not have to match exactly the approximation curve because the filter is tuned to fit within the window. Once it is within the window the system can move the filter to approximate the desired function (optimisation process).

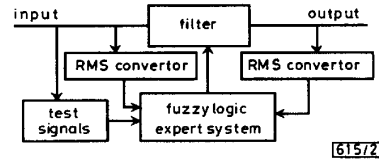


Fig. 2 Filter tuning system

**Filter tuning system:** The proposed method consists of an expert system which allows the tuning of the filter based on the same procedure that an expert would use in practice. A fuzzy logic system of this type requires the measurement of variables to be controlled. In our case, we need to measure the magnitude of the input and output signals. In practice a frequency response plot is obtained by using measurement equipment. The system is simplified by using the minimum number of measurement points in the frequency response. For a second order filter we determined that we need to know the frequency response at only three points:  $|H(0)|$ ,  $|H(\omega_p)|$ , and  $|H(\omega_s)|$ . Therefore, three sinusoidal test signals are applied at the frequencies previously mentioned. Fig. 2 shows the system diagram.

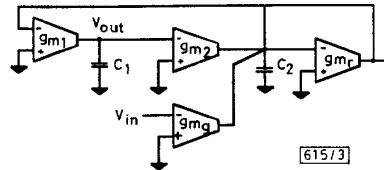


Fig. 3 Second order biquadratic lowpass filter

**Filter:** The case study was a second order lowpass filter implemented with OTAs [3]. Fig. 3 shows the circuit. The transfer function is as follows:

$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + s\frac{g_{m1}}{C_2} + \frac{g_{m2}g_{mr}}{C_1C_2}} = \frac{A\omega_0^2}{s^2 + s\frac{\omega_0}{Q} + \omega_0^2} \quad (1)$$

The main advantage of using OTAs for this type of application is that the transconductance can be programmed by the current supplied to the OTA, allowing the filter parameters to be changed. This can readily be seen in eqn. 1. Even though the relation between the supplied current and the transconductance is logarithmic, the system can tune the filter correctly regardless of the nonlinearities. It can also be seen in eqn. 1 that by modifying one component several filter parameters are changed, e.g. if either  $g_{m1}$  or  $g_{m2}$  are changed, the filter parameters  $\omega_0$ ,  $Q$  and  $|H(0)|$  are also changed. The tuning procedure considers the dependence that exists between the controllable attribute and the filter parameter.

**Expert system:** In classical logic, sets are defined in a crisp manner, i.e. an element either belongs to a set or does not belong to it. In fuzzy logic, a membership value between '0' and '1' is assigned to each of the elements of the set, where '0' means that an element does not belong to the set and '1' means that the element totally belongs to the set. Fig. 4 shows a set of membership functions used to quantify the deviation of the curve from the window spec-

ifications in the passband, i.e. to quantify the points  $|H(0)|$  and  $|H(\omega_p)|$ . For example suppose the magnitude at some frequency is  $-1$  dB; this point will be close to zero with membership  $2/3$  and close to  $G_p$  with membership  $1/3$ , see Fig. 4. Similar membership functions were used to measure  $|H(\omega_s)|$ . For a Butterworth filter with maximum attenuation in the stopband, the frequency response curve should pass through points  $a$  and  $b$  in Fig. 1. The membership functions were designed to approximate a Butterworth filter with maximum attenuation in the stopband. For this case the frequency response should be close to zero for  $|H(0)|$  (see Fig. 4) and close to  $G_p$  for  $|H(\omega_p)|$ . The proposed system will try to meet these requirements with the constraint that  $|H(\omega_s)|$  must be less than  $G_s$ . Notice that the membership functions have crisp transitions at  $0$  dB and at  $-G_p$ . The window specifications are given with crisp limits. A set of 45 rules were developed to perform the circuit adjustment. This set was obtained by recording the empirical procedures realised by an expert system.

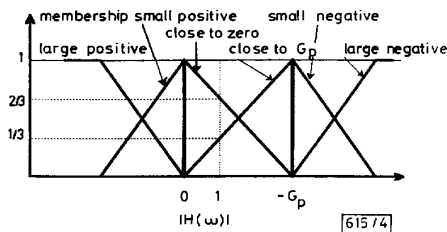


Fig. 4 Membership functions to quantify magnitude in passband

The system processes the fuzzy logic quantities by using the Tagaki and Sugeno if-then rules [4]. The conjunction *and* is computed by obtaining the maximum of the membership values of the variables. The consequence of each rule is a constant term (a singleton). Thus, the defuzzified output is calculated as the weighted average of the individual rule's output. Once the output is obtained the system modifies the filter parameters accordingly. The system then applies the test signals again and repeats the same process until the frequency response is within the window. A control section applies the test signals sequentially and records the magnitude measurements. The expert system was implemented using a digital computer.

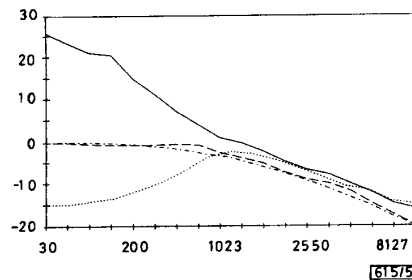


Fig. 5 Experimental results of tuning system

— (i) untuned  
 - - - (i) tuned  
 ..... (ii) untuned  
 - . - . (ii) tuned

**Results:** Fig. 5 shows the results for two different initial conditions of the filter. The output shown was obtained when the filter response met the window constrains. For curve (i) the system tuned the filter after 14 iterations. For curve (ii) the system tuned the filter after nine iterations. If the system continues iterating it tries to approach the optimum points.

**Conclusion:** The proposed system is able to tune second order filters and approximate them to have maximum attenuation in the stopband. This system implementation is intended to show that

fuzzy logic can be used to tune filters or to tune other electronic circuits or systems provided the availability of a manual procedure.

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### Fast motion estimation with spatial transformation

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Indexing terms: Motion estimation, Image processing

A fast search method for motion estimation with spatial transformations is introduced. While the fast method reduces the number of transformation mappings with a displacement of  $\pm 8$  pixel/frame from about  $7 \times 10^9$  to 486, its peak-to-peak signal to motion-compensated noise ratio is, on the average, 3 dB better than that of the conventional full-search block-matching algorithm.

**Introduction:** Motion estimation based on the block-matching algorithm (BMA) is popular due to its simplicity and efficiency. However, the block-matching method assumes that the motion of each is independent of the others and contains purely uniform translational motion. Hence, any rotational or complex motions cannot be tracked efficiently. In block matching with spatial transformation (BMST) [1], complex motions are compensated for by mapping the current block of pixels onto a quadrilateral in the previous frame using transformations defined by a set of mapping parameters [2]. The parameters of the spatial transformation are obtained by solving a set of equations relating the co-ordinates of the current block to the best-matched quadrilateral in the previous frame [2]. Similar to the BMA, the best-matched quadrilateral is found by displacing each vertex of the previous block, so that the minimum distortion inside a search window is identified. The application of the full-search method in finding the minimum distortion is computationally intensive, because the four vertices of the quadrilateral have to be displaced independently. In this Letter, a fast method for reducing the computational load is presented.

**Computational load:** The search for the best-matched quadrilateral in the previous frame requires the appropriate displacement of the quadrilaterals' vertices. With the full-search method at the vertices of the quadrilateral and constrained to a maximum displacement of  $\pm v$  pixel/frame, there are  $(2v + 1)^2$  possible displacements for each vertex. For four vertices, there are  $((2v + 1)^2)^4 = (2v + 1)^8$  possible quadrilateral candidates. The mapping count increases at an exponential rate of 8 and, for  $v = \pm 8$  pixel/frame, it approximates to  $7 \times 10^9$  mappings per search block. This quadrilateral count is reduced by employing fast-search techniques at the vertices. Similar to the conventional BMA, logarithmic step-search methods can