AN IMPROVED DESIGN OF A QUADRATURE DETECTION MULTIFREQUENCY RECEIVER

Vito Cappellini and Enrico Del Re

Istituto di Elettronica, University of Florence and IROE-C.N.R.
Florence, Italy

ABSTRACT

An improved structure for an envelope detection multifrequency receiver, based on digital quadrature filters, is proposed. The receiver uses non-recursive digital filters and exploits a property of non-recursive digital quadrature filters to reduce the required computational complexity by a nominal factor of two with a negligible hardware increase. The interest is outlined of applying the proposed structure in data communications and telephone networks.

INTRODUCTION

Multiple frequency transmissions are used in many data communication systems and mobile communications. M-ary frequency-shift-keying (FSK) modems and signalling in conventional telephone networks are common examples of systems using multiple transmission frequencies. Generally non-coherent detection is preferred at the receiver because it attains the required system performance with an acceptable implementation complexity.

Many approaches for non-coherent digital multifrequency receiver have been proposed: band-pass filtering (Refs. 1-2), use of the Discrete Fourier Transform (Refs. 3-4), tone parameter extraction (Ref. 5), pattern recognition detection (Ref. 6) and envelope detection (Refs. 7-10).

The last solution appears to be one of the most promising and attractive methods from a practical implementation point of view. It can be implemented, for example, by multiplying the receiver waveform with two in-quadrature sinusoids and subsequent low-pass filtering (Ref. 7) or by using two band-pass filters with a 90° phase shift difference (quadrature filters) (Refs. 8-10).

In this paper an improved structure of an envelope detection multifrequency receiver, based on digital quadrature filters, is considered. In Sect. 2 the basic operations of a receiver of this type will be recalled and in particular the advantages of using finite-impulse-response (FIR) digital filters will be pointed out. In Sect. 3 the receiver structure and implementation improvement will be presented, exploiting the properties of digital FIR quadrature filters (Ref. 11).

QUADRATURE DETECTION MULTIFREQUENCY RECEIVER

Quadrature detection multifrequency receiver is a convenient practical implementation of an envelope detection receiver. This solution has the advantage of avoiding any demodulation process with respect to the more conventional technique of multiplying the receiver signal with in-quadrature sinusoids and subsequent low-pass filtering (Ref. 7).

Let us consider the detection of one of M possible frequencies f_i, i=1,2,...,M. The general structure of an envelope detector receiver is shown in Fig. 1, where s(t) represents the input signal and M envelope detectors are used.

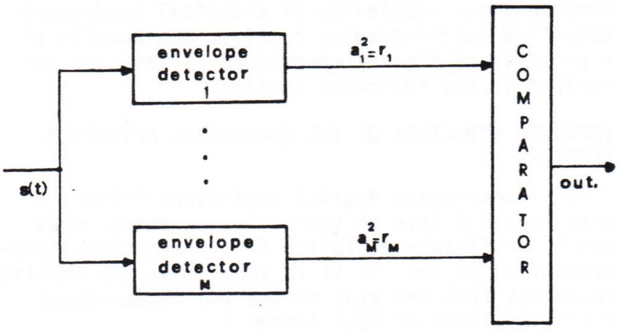

Fig. 1 - General structure of an envelope detector receiver.

A quadrature detection multifrequency receiver determines the envelope of each possible transmission frequency by means of M couples of quadrature filters $H_i(f)$ and $\hat{H}_i(f)$, i=1,2,...,M. The filters $H_i(f)$ are non-overlapping band-pass filters of sufficiently narrow bandwidth W. The center frequency of each of them coincides with the nominal frequency f_i of a different transmission waveform. The filters $\hat{H}_i(f)$ are defined as

$$\hat{H}_i(f) = -j(\mathrm{sgn} f)H_i(f) \tag{1}$$

D8.6.1

If the two filters $H_i(f)$ and $\hat{H}_i(f)$ are driven by the received waveform, their respective outputs $x_i(t)$ and $\hat{x}_i(t)$ form a Hilbert transform pair.

Hence the envelope of the i-th transmission frequency can be estimated as

$$a_i(t) = \left[x_i^2(t) + \hat{x}_i^2(t)\right]^{1/2} \qquad (2)$$

which in ideal conditions (i.e. absence of interferences and noise with ideal filter frequency masks) should be a constant value. It can be observed that an equivalent detection strategy can be used for the evaluation of the envelope squares of the possible transmission frequencies, as shown in Fig. 1,

$$r_i(t) = a_i^2(t) \qquad (3)$$

that avoids any square root operation in the receiver implementation. The performance of a receiver of this type has been analysed in Refs. 12-13 and in Ref. 9 a receiver prototype using CCD-based FIR quadrature filters was described.

Because the envelope is a low-pass signal of bandwidth W/2, the filtering operations involved in the envelope - or envelope square - evaluation have to be performed only once every 1/W seconds. This is particularly advantageous if we use FIR digital (or discrete) filters for $H_i(f)$ and $\hat{H}_i(f)$, because the samples of the outputs $x_i(t)$ and $\hat{x}_i(t)$ may be supplied at the reduced rate W. This condition permits time-multiplexing a single filtering hardware unit among all the filters to be implemented as described in Ref. 9.

Furthermore, if the transmission frequencies satisfy certain conditions, the structure and the computational complexity of a digital quadrature detection multifrequency receiver can benefit of a property of digital quadrature filters, as described in the following Section.

IMPROVED STRUCTURE OF THE QUADRATURE DETECTION RECEIVER

FIR linear-phase digital quadrature filters of even length N have an attractive property, that can be profitably exploited in the receiver implementation. In Ref. 11 it is shown that the impulse responses f(n) and g(n) of the two linear-phase digital filters of even length N

$$F(f) = A(f)e^{-j\pi f(N-1)T} \quad , \ |f| \leq 1/T \qquad (4)$$

$$G(f) = -j(\mathrm{sgn} f)A(f-\tfrac{1}{2T})e^{-j\pi f(N-1)T} \quad , \ |f| \leq 1/T \quad (5)$$

1/T being their associated sampling rate, are simply related by

$$g(n) = \pm(-1)^n h(n) \qquad , \quad 0 \leq n \leq N-1 \qquad (6)$$

where + is for $N=2(2k+1)$ and - is for $N=2(2k)$, with k any integer. The filter G(f) is the quadrature filter associated to the linear-phase filter whose magnitude response is the symmetric one of that of F(f) with respect to 1/(4T). The two filters F(f) and G(f) have their impulse responses simply related by an alternate sign inversion operation.

Suppose now that the M possible transmission frequencies f_i, $i=1,2,\ldots,M$ (M even), are chosen in such a way that satisfy the relation

$$f_{M-i+1} = 1/2T - f_i \quad , \ i=1,2,\ldots,M \qquad (7)$$

1/T being the sampling rate of the signal digital filtering inside the multifrequency receiver.

The couples of quadrature filters $H_i(f)$, $\hat{H}_i(f)$ and $H_{M-i+1}(f)$, $\hat{H}_{M-i+1}(f)$ are symmetric with respect to 1/4T and, if they are realized by FIR linear-phase digital filters of even length N, according to Eqs. 4-6, their impulse responses are in couples related by

$$\hat{h}_{M-i+1}(n) = \pm(-1)^n h_i(n) \qquad (8)$$

$$h_{M-i+1}(n) = \pm(-1)^n h_i(n) \qquad (9)$$

with $i=1,2,\ldots,M$.

According to the Eqs. 8-9, the filtering structure of Fig. 2 supplies two different signals (out 1 and out 2) to the quadrature envelope detector essentially through the computational complexity of only one filtering operation. It only needs an additional adder to the classical FIR filter structure realized in the direct form.

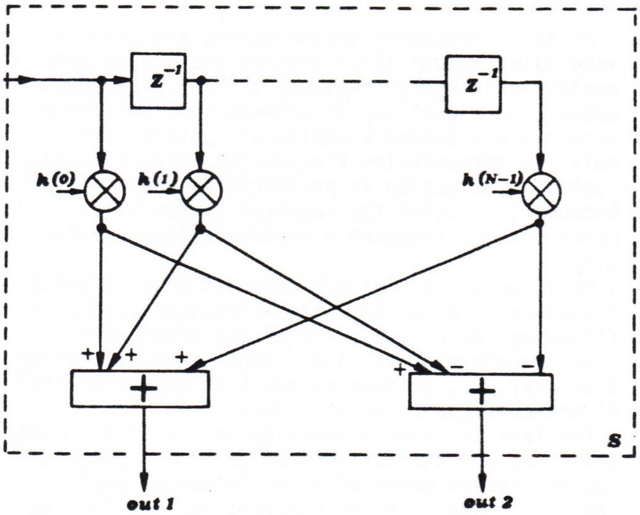

Fig. 2 - Proposed filtering structure.

When in Fig. 2

$$h(n) = h_i(n) \qquad , \quad i=1,2,\ldots,M \qquad (10)$$

out 1 supplies $x_i(kT)$ and out 2 supplies $\pm x_{M-i+1}(kT)$, k integer, whilst when

$$h(n) = \hat{h}_i(n) \qquad , \quad i=1,2,\ldots,M \qquad (11)$$

out 1 supplies x(kT) and out 2 supplies $\pm x_{M-i+1}(kT)$. The sign uncertainty can, of course, be removed, but is inessential in the present application due to the square operations in Eq. 2.

A single hardware filtering unit, as that shown in Fig. 2, can be time-multiplexed among the filters to be implemented. In the time interval T between two consecutive input signal samples, only the switching of the two sets of filter coefficients $h_i(n)$ and $\hat{h}_i(n)$, $0 \le n \le N-1$, for a specific i, is required. This operation gives the four output quantities $x_i(kT)$, $\hat{x}_i(kT)$, $x_{M-i+1}(kT)$ and $\hat{x}_{M-i+1}(kT)$ necessary for the envelope evaluations at the frequencies f_i and f_{M-i+1} at the time instant $t=kT$ according to Eq. 2 or Eq. 3.

Of course the single hardware filtering unit of Fig. 2 can be time-multiplexed among more than two couples of quadrature filters in the time interval T, if the switching and filtering operations are sufficiently fast. As a limiting situation, all the 2M filterings can be performed in the time interval T through the switching of the corresponding M sets of filter coefficients. Intermediate hardware implementations are possible by using few hardware filtering units to perform all the 2M required filterings.

The above property of digital quadrature filters and the use of the hardware structure of Fig. 2 allow the quadrature detection receiver to perform the required 2M filterings essentially through the computational load of M filterings (thus increasing the receiver speed by a nominal factor of 2), requiring only the adder shown in Fig. 2 as additional adder.

CONCLUSIONS

An improved structure of a quadrature detection multifrequency receiver has been proposed, that, exploiting in particular a property of digital quadrature filters, greatly reduces the computational load of the overall receiver. Consequently more efficient hardware implementations with a reduced complexity can be realized through the time-multiplexing of a single filtering unit, like that shown in Fig. 2, among the different envelope detectors of Fig. 1. These characteristics suggest the proposed structure as a possible alternative and attractive solution with respect to the more conventional structure of an envelope detector using demodulation stages and low-pass filterings for a non-coherent FSK receiver in data communications and for a tone detector in telephone networks.

Presently the performance of a quadrature detection receiver, as well as of filter banks and spectral analysers, based on the structure presented in this paper is under evaluation (in comparison with more conventional techniques) for a practical hardware implementation.

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