VLSI architectures of filterbanks for subband coding of HDTV signals

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Abstract

VLSI architectures of filterbanks necessary for an HDTV subband codec have been investigated. Different techniques have been combined in order to achieve a compact realization. The application of special QMF structures results in a further reduction of hardware expense. High clocking rates are handled using two dimensional polyphase filterbanks in combination with pipelining and parallel processing. An architecture suitable for one-chip implementation of a 10 × 14 tap QM filterbank has been developed.

Key words: High definition television, Image coding, Subband decomposition, Codec, VLSI circuit, Quadrature mirror filter, Polyphase circuit.

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I. INTRODUCTION

I.1 HDTV transmission

High definition TV (HDTV) systems with an aspect ratio of 16:9 and improved picture quality are under development at several research institutes. Compared to today's digital studio standard, the requirements for the realization of digital HDTV systems are considerably increased. Very high data rates and extremely high clocking rates are causing problems for the realization of transmission systems.

For transmission via analog channels, analog multiplexing combined with adaptive subsampling (HD-MAC) is proposed for a reduction of bandwidth to about 12 MHz. Due to the substitution of analog broadband transmission lines by the digital broadband net B-ISDN, the development of digital codecs for HDTV signals is necessary. In particular for studio-to-studio transmission (contribution), digital transmission with better picture quality than HD-MAC is required. Additionally B-ISDN is supposed to substitute analog transmission lines step by step within the next years. The transmission of HDTV signals from studios up to home TV receivers (distribution) is expected to be completely digital in the far future.
### 1.2 Digital coding algorithms

For digital transmission of HDTV signals, it is necessary to reduce the high source bit rates by application of source coding algorithms, because even interlace scanning results in a sampling frequency of 72 MHz and a PCM source bit rate of 1.15 Gbit/s [5]. Digital coding algorithms [10] offer an enormous reduction of transmission bit rate without effecting visual picture quality. The hardware expense for digital HDTV codecs depends on the data reduction factor required and the picture quality wanted (Table I).

**TABLE I.** Overview of digital HDTV coding algorithm for 1250 lines/50Hz/2:1.

<table>
<thead>
<tr>
<th>coding algorithm</th>
<th>DPCM</th>
<th>DCT</th>
<th>subband coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>block oriented</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>motion comp.</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>data reduction</td>
<td>2:1</td>
<td>4:1</td>
<td>8:1</td>
</tr>
<tr>
<td>bit rate/Mbit/s</td>
<td>565</td>
<td>280</td>
<td>140</td>
</tr>
<tr>
<td>hardware expense</td>
<td>middle</td>
<td>high</td>
<td>very high</td>
</tr>
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<td></td>
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</table>

Simple coding algorithms such as DPCM allow transmission bit rates of 565 Mbit/s without reduction of picture quality. Two-dimensional DPCM algorithms utilizes both the spatial statistical properties of TV pictures and masking effects of the human visual system. The application of recursive DPCM algorithms for HDTV is difficult due to the high sampling rates [7].

For larger data reduction factors, transform coding algorithms provide a better relation between picture quality and transmission bit rate. Subband coding and adaptive block transform coding, e.g. discrete cosine transform (DCT), are under discussion for transmission with 140 Mbit/s [6]. For both algorithm classes, the decorrelation necessary for data reduction is achieved in frequency domain by band splitting. For the application of two-dimensional block transform algorithms the picture is divided into rectangular blocks of equal size. Typically, square blocks with a size of 8 x 8 or 16 x 16 pels are used. Separately for each single block, a set of frequency coefficients is computed. The number of the coefficients corresponds to the number of pels per block. The coding gain is achieved by coding and transmitting these coefficients instead of the original samples. For this purpose they are sorted, quantized and coded. For the reconstruction of a block, an inverse transform is used. Due to the error propagation of the inverse transform, the accuracy must be much higher than for the original pels. The visibilities of quantizing errors varies from coefficient to coefficient depending on the corresponding frequency band. In particular the coefficient for DC and low frequency bands must be coded very accurately. If the quantization is too coarse, the block structure becomes visible in reconstructed images. Such patterns are called blocking effects.

For two-dimensional subband coding, the images are filtered without arbitrary block limits. After a separation of subbands with limited band width by an analysis filtering, a subsampling is possible without a loss of information. The original image can be reconstructed from the subbands by synthesis filtering. The combination of filters in horizontal, vertical or even diagonal direction has been proposed [2] [6] [16]. Due to the decorrelation achieved by filtering and the properties of the human visual system, the subbands differ in both the statistical properties and the visibility of quantizing errors. The reduction of transmission bit rate is achieved by the application of specialized coding algorithms to the subbands. For the coding of the separated subbands, various combinations of DPCM, DCT, cascaded subband coding, deadzone quantizing and statistical coding algorithms have been proposed [2] [6]. Besides the coding gain and the absence of blocking effects, subband coding algorithms offer an easy reduction of processing clock rates by subsampling. Subband coding algorithms are supposed to be suitable for transmission bit rates of 140 Mbit/s and lower. For the transmission of HDTV signals with 140 Mbit/s, an intrafield coding without motion compensation can fulfill the needs [13]. This allows the realization of a codec with considerable hardware expense. For better quality or lower bit rates, a form of motion compensated prediction has to be provided.

Horizontal and vertical band splitting can be performed using a 2D analysis filterbank (Fig. 1) with symmetrical band limits (Fig. 2). Both vertical and horizontal subsampling is applied. In order to reduce the hardware expense, separable 2D-filters are used. A similar filterbank is required at the decoder for the synthesis of the HDTV signal from the four subbands. For such a band-splitting, the low pass filtered band I can be transmitted e.g. using a DCT coder (Fig. 3). For the high pass filtered bands II to IV, adaptive quantizing with a combination of run length coding and variable word length coding is sufficient. By filtering and subsampling a reduction of sample frequencies by the factor 1/4 for each signal is achieved. That means for an HDTV codec, that only analysis and synthesis filterbanks need to handle the high clock rates of HDTV signals directly. Therefore, application specific circuits (ASIC's) developed for digital broadcast TV can be used for the coding of the HDTV subbands, too.