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IMPLEMENTATION OF OPTIMIZED TRANSMULTIPLEXER USING COMBINATIONAL WINDOW FUNCTIONS

Anuj Garg 1, Ankit Saxena2, Anupama Arora3, Narendra Singh4
Department Of Electronics and Communication,
Jaypee University of Engineering and Technology, Guna
E-mail: 1a.garg1008@gmail.com, 2ankit9002saxena@gmail.com, 3anupamaarora02@gmail.com, 4narendra.singh@juet.ac.in

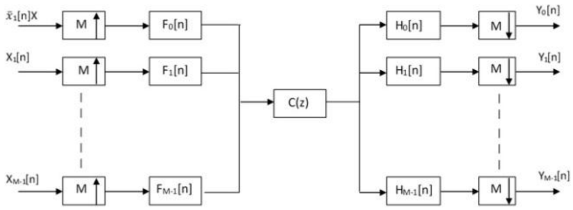
Abstract –

This paper proposes an efficient approach for the design of M-channel maximally decimated near-perfect reconstruction (NPR) type transmultiplexer. Cosine modulation is used to design the synthesis and analysis sections of the transmultiplexer. A bisection-type optimization algorithm has been applied to minimize the interference parameters like inter-channel interference (ICI) and inter-symbol interference (ISI). Results are included which indicates the comparision done by different windows for interference parameters . Very small values of ICI and ISI have been obtained by using combinational window functions.

Keywords-
ICI , ISI

I. INTRODUCTION

A transmultiplexer is FDM-TDM converter and vice-versa. It consists of synthesis block at transmitter end and precedes the analysis block at receiver end. At the transmitter end, M-input signals are first interpolated by the factor of M and synthesized into one composite signal using synthesis filter bank $F_k(z)\ for\ k = 0,1, \dots \dots \dots, M-1$. Finally added to form a single signal for transmission over a given transmission channel C(z). Conversely, at the receiver end, the composite signal is split out into M-output signals with the help of the analysis filter bank $H_k(z)$ and then decimated by a factor of M .[1][5]



The z-transform of the output at particular l^{th} sub-channel is given in terms of z-transform of the M input signals

$$X_1(z) = \sum_{k=0}^{M-1} \left[\frac{1}{M} \sum_{m=0}^{M-1} H_l\left(z^{\frac{1}{M}}.\omega^m\right).C\left(z^{\frac{1}{M}}.\omega^m\right).f_k\left(z^{\frac{1}{M}}.\omega^m\right) \right] X_k(z)$$

$$\omega = e^{-j2\pi/M} \qquad (1)$$

$C(z)$ Represents the transmission characteristics of the transmission channel.

The above equation can also be expressed in transfer function form as:

$$X_l(z) = \sum_{k=0}^{M-1} T_k(z) X_k(z) \qquad (2)$$

Where T_{lk} is the Transfer function b/w output of l^{th} sub-channel and input of k^{th} sub-channel and defined as

$$T_{kl}(z) = \sum_{m=0}^{M-1} F_l(zW^i) C(zW^i) H_k(zW^i) \qquad (3)$$

In case of PR-type Transmultiplexer with the ideal channel, $T_{lk}(z)$ should be zero for $l \neq k$ and one for $l = k$, i.e., the total error and interference are vanished.[2]

1.1 Performance measuring parameters :

- **InterChannel Interference (ICI)**

The ICI is the leakage of signal from the remaining $M-1$ subchannels to given particular sub-channel. This occurs due to interference of the filters in their stopband. The ICI in the k^{th} sub-channel can be conveniently measured as:

$$E_{ICI}(l) = \frac{1}{\pi} \int_0^{\pi} \sum_{K=0, k \neq l}^{M-1} \left| T_{lk}(e^{j\omega}) \right|^2 d\omega \qquad (4)$$

Where T_{lk} can be measured from the equation above [2]

- **InterSymbol Interference (ISI)**

The ISI is caused by the interference of other symbols in the same subchannel. This occurs due to the non-ideal nature of the filters within their passband and the fact that channel frequency response is not uniform for all sub-channels. The ISI in the k^{th} subchannel can be measured as:

$$E_{ISI}(l) = \frac{1}{\pi} \int_0^{\pi} \left(\left| T_{ll}(e^{j\omega}) - 1 \right|^2 \right) d\omega \qquad (5)$$

When including the transmission channel, the ICI and ISI cannot be evaluated without taking into consideration how the transmission channel is affecting the direct transfer function of that subchannel.[2]

II. Prototype filter designing :

This section shows how M-channel critically sampled FIR filter banks can be generated using proper **cosine modulation techniques** and a proper prototype filter.[3]

This technique has several advantages over many other techniques.

- Compared to the case where all the subfilters are designed and implemented separately, the implementation of both the analysis and synthesis banks is significantly more efficient since it requires only one prototype filter and a unit performing the desired modulation operation.[3]
- The actual filter designing becomes much more straight forward since only parameters to be optimized are coefficients of single protype filter.[3]
- Alternatively, the filter orders and the overall delay caused by the filter bank to the signal can be considerably reduced. This is very important in communication applications.[3]

In Cosine-Modulated filter banks, the entire analysis and synthesis filter are generated from single prototype filter with the aid of cosine modulation and MDFT technique. [3]

If $H(z)$ is a prototype filter, then the analysis and synthesis filters are related by [2]

$$h_i(z) = 2h(n)\cos\left(\frac{\pi}{M}\left(k+\frac{1}{2}\right)\left(n-\frac{M}{2}\right)+(-1)^k\frac{\pi}{2}\right) \quad (6)$$

$$g_i(z) = 2h(n)\cos\left(\frac{\pi}{M}\left(k+\frac{1}{2}\right)\left(n-\frac{M}{2}\right)-(-1)^k\frac{\pi}{2}\right) \quad (7)$$

In the proposed paper, window used is **Generalized Four Term Cosine Window (GCW) defined as:**

$$\omega[n] = \sum_{i=0}^{3}(-1)^i A_i cos\left(\frac{2\pi in}{N}\right) \quad (8)$$

For $n = 0,1,2 \ldots\ldots N$. The values are the weights of the terms for $i = 0,1,2,3$. Without loss of generality, this window function is normalized. The adjustable parameter x vector contains only four adjustable terms, independently of the subchannel filter order and the number of subchannels, that is,

$$x = [A_0, A_1, A_2, \omega_c]$$

After finding weights A_0, A_1 *and* A_2 , the remaining weight A_3 is determined according to the condition.[1]

$$\sum_{i=0}^{3} A_i = 1 \quad (9)$$

This window has been then compared with the windows listed below.

Table 1 Window Functions[4]

S. No.	Name	Window Equation	SLFOR
1	Kaiser	$\omega(n) = \dfrac{I_0\left(\beta\sqrt{1-\left(\frac{2n}{N}\right)^2}\right)}{I_0(\beta)}$ for $n \le N/2$ Where I_0 is the zero[th] order modified Bessel function. The window shape parameter (beta) depends on attenuation of the desired filter	-6dB/octave
2	PC6	$\omega_{PC6}(n) = \begin{cases}\gamma_6[l_6(n)] + (1-\gamma_6)[d_6(n)], & \lvert n\rvert \le N/2 \\ 0, & \lvert n\rvert > N/2\end{cases}$ $l_6(n) = \begin{cases}1-24\left\lvert\frac{n}{N}\right\rvert^2\left(1-2\left\lvert\frac{n}{N}\right\rvert\right), & \lvert n\rvert < N/4 \\ 2\left(1-2\left\lvert\frac{n}{N}\right\rvert\right)^3, & N/4 \le \lvert n\rvert \le N/2\end{cases}$ $d_6(n) = cos^6\left(\frac{n\pi}{N}\right), \quad \lvert n\rvert \le N/2$	-24 to -42 dB/octave
3	PC4	$\omega_{PC4}(n) = \begin{cases}\gamma_4[l_4(n)] + (1-\gamma_4)[d_4(n)], & \lvert n\rvert \le N/2 \\ 0, & \lvert n\rvert > N/2\end{cases}$ Where $0 \le \gamma_4 \le 8.235$ $l_4(n) = \frac{1}{\pi}\left\lvert\sin\left(\frac{2\pi n}{N}\right)\right\rvert + \left(1-2\left\lvert\frac{n}{N}\right\rvert\right)cos\left(\frac{2\pi n}{N}\right), \quad \lvert n\rvert \le N/2$ $d_4(n) = cos^4\left(\frac{n\pi}{N}\right), \quad \lvert n\rvert \le N/2$	-24 to -30 dB/octave

III. Optimization Technique :

Bisection Algorithm is used to minimize the interference parameters namely ICI and ISI .

This algorithm proved to better than the other earlier proposed algorithms. In this proposed work, a single-variable optimization technique is used with ICI given in as an objective function

$$E_{ICI}(l) = \frac{1}{\pi}\int_0^{\pi} \sum_{K=0,k\neq l}^{M-1} \left|T_{lk}(e^{j\omega})\right|^2 d\omega \qquad (10)$$

The cutoff frequency ω_c of the prototype filter is selected as a variable parameter. The proposed optimization technique is independent of the window function. Initially, the supplied input parameters, i.e., sampling rate, passband and stopband frequencies, number of bands, passband ripple and stopband attenuation are specified. Based on these inputs, the filter order and initial value of cutoff frequency will be calculated, then the window coefficients of the selected window function are determined and they remain fixed. The filter coefficients of the prototype lowpass filter and filters of synthesis and analysis section are determined using cosine modulation. The ICI in a particular subchannel for current value of cutoff frequency is calculated. The absolute value of ICI is selected as an objective function. In the optimization routine cutoff frequency of the prototype filter is continuously iterates as per the search direction and calculate the corresponding value of these parameters. The algorithm terminates the loop as it attains the optimum value of the objective function. [2]

- Objective Function : Modulus of ICI
- Variable parameter : Cutoff Frequency
- Nature : Iterative

  Advantage : Computationally fast

IV. Results and discussion

The implementation of the transmultiplexer has been done using matrix laboratory (MATLAB) R2009a version 7.8.

- For the case of 8 channel QMF with the following parameters:

$$A_s = 50, \omega_c = 0.0795, N = 47$$

S. No	**Window**	**ICI(dB)**	**ISI(dB)**
1	GCW	-92.7871	-77.6077
2	PC4	-93.5656	-77.088
3	PC6	-95.6677	-76.0512

Table-4.1 Comparison of different windows for 8 channel

With these parameters above ICI and ISI have been calculated and the windows below are compared . Best results are shown by PC6 window.

`	**Window**	**ICI(dB)**	**ISI(dB)**
1	GCW	-196.5606	-73.5677
2	Kaiser	-204.0476	-79.0981
3	PC4	-204.0548	-80.0095

- For the case of 32 channel QMF with the Following parameters:

$$A_s = 60, \omega_c = 0.225, N = 95, F = 10000, f_p = 1020, f_s = 1230$$

With these parameters above ICI and ISI have been calculated and the windows below are compared. Best results are shown by PC4 window.

Table-4.2 Comparison of different windows for 32 channel

- For 64-channel , following results have been obtained with the Following parameters

  $$A_s = 64, \omega_c = \frac{\pi}{32}, N = 225, F = 10000, f_p = 447.5, f_s = 533.25$$

  With these parameters above ICI and ISI have been calculated and the windows below are compared. Best results are shown but PC6 window.

S. No.	**Window**	**ICI(dB)**	**ISI(dB)**
1	GCW	-150	-89.076
2	PC4	-167.0120	-186.782
3	PC6	-167.2891	-203.0567

Table-4.3 Comparison of different windows for 64 channel

V. Conclusion

From the above results and discussions it can be easily concluded that in the case of 8-Channel and 64 channel qmf , PC6 window has found to be the best among all compared windows , since it has the better side-lobe fall off rate(SLFOR) and has provided us with the optimized ICI and ISI values.

On the very similar note , in case of 32 channel qmf , PC4 has given the best results since among all the compared windows it has the highest

SLFOR and has provided us with the optimized ICI and ISI values.

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