The Implementation of a Dynamic High-performance Notch Filter for Power Line Communications using a WDF Scheme

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Abstract: - PLC (Power Line Communication) technology provides broadband internet access through ordinary power lines. This technology has attracted the attention of operators because the cost required for network configuration is almost zero. The PLC is communication technique transmits voice and data signals through the power lines using high frequencies lying between a dozen kHz and hundreds of MHz. However, the PLC protocol can cause interference with existing wireless communication systems because it uses the same frequency range. Notch filters are a common way to eliminate this interference. In this paper, a dynamic high-performance notch filter incorporating WDF (Ed Note: This acronym should be spelled out at least once.) performance, verified through MatLAB, is presented.

Key-Words: - PLC, WDF, Elliptic Filter, Wavelet-OFDM, M-band transmultiplxer, IDWT / DWT

1. Introduction

The PLC (Power Line Communication) protocol transmits data signals, using the power line to communicate. However, the leakage of PLC signals is likely to affect other wireless systems.

If one propagates high-frequency signals on 60Hz power lines, wireless communication systems will be affected due to skin effect radiation. Therefore, the PLC frequency band currently used below 80MHz (ITU-R in the international allocation) along with aviation and broadcasting, amateur radio, radio astronomy, maritime safety / distress communications, etc cause concerns regarding power-line interference. Therefore, signal interference needs to be eliminated from power lines [1].

OFDM, which is often used in high-speed PLC systems, is one type of digital modulation technique in which the baseband signals are modulated using QAM (quadrature amplitude modulation) and signals called “sub carriers” converted by FFT (Fast Fourier Transform). In this paper, we refer to FFT-based OFDM as “FFT-OFDM”. Another method, OFDM based on wavelet transforms, Wavelet-OFDM, which uses DWT (Discrete Wavelet Transform), is a type of wavelet transform technique that has been developed recently[2]-[4]. Wavelet-OFDM does not need a guard interval (GI) to maintain the orthogonal characteristics between each subcarrier, and so the efficiency utilizing the frequency is better than that found for FFT-OFDM that uses a GI. The notches used in Wavelet-OFDM are deeper than those found in the conventional FFT-OFDM. The notch depth of the FFT-OFDM is about –13 dB, whereas that for the Wavelet OFDM is about –35 dB. Therefore, it is desirable that the immunity characteristics of a PLC modem using Wavelet-OFDM would be better than one using conventional FFT-OFDM [5].

We used WDF(Ed Note: Again it would be good to spell out the acronym.), which is based on wavelet OFDM since the depth of the notch is deeper than the existing OFDM wavelets. This paper is organized as follows: Section 2 presents the Wavelet-OFDM based on WDF. In Section 3, the WDF is applied to a dynamic high-performance notch filter and its performance is verified through

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MatLAB. In Section IV provides our conclusions and a summarization of this paper.

2. The Wavelet-OFDM based on WDF

2.1. The Wavelet-OFDM based on WDF System

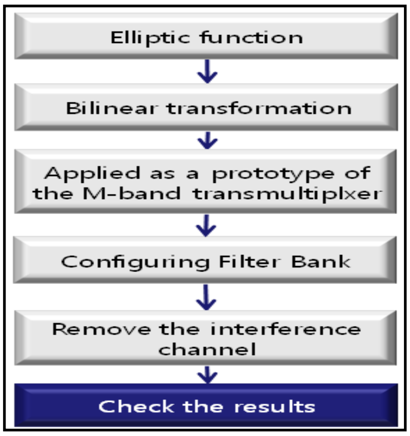


Fig. 1 The Wavelet-OFDM based on WDF system flow chart

The overall system flow chart is shown in Fig. 1. In order to design the WDF, we applied an elliptic function to a bilinear transform.

The WDF is applied as a Prototype of the M-band transmultiplxer structure. The filterbank based on the WDF is then completed. After setting the filterbank, the channel is set for what is desired for deletion. When one enters the number of the channel that particular channel is removed.

2.2. The WDF based on Elliptic Filtering

Elliptic filters have been widely used to achieve restrictive frequency domain requirements. They can simultaneously provide a small ripple pass band, a large stop band attenuation, and small transition bandwidths, with equal ripple characteristics in both the pass band and the stop band.

$$H(s) = \frac{H_0}{D_0(S)}\prod_{i=1}^{r} H_i(S)\ ,\ D_0 = \begin{cases} s+\sigma_0 (N = odd) \\ 1 (N = even)\end{cases}$$

$$r = \begin{cases} \frac{N-1}{2} (N = odd) \\ \frac{N}{2} (N = even)\end{cases} \quad (N = 1,2,3,\cdots,\infty) \qquad (1)$$

$$H_i(S) = \frac{s^2+\omega_z{}^2}{s^2+\frac{\omega_p}{Q_p}s+\omega_p{}^2} \quad \begin{cases} \omega_z = \text{zero frequency} \\ \omega_p = \text{pole frequency} \\ Q_p = \text{pole Q}\end{cases}$$

$$= \frac{s^2+A_{0i}}{s^2+B_{1i}s+B_{0i}} \qquad (2)$$

In the bilinear transformation method, H(z) can be obtained from the equivalent analog transfer function H(s) by the following substitution:

$$H(z) = H(s)_{|s=\frac{2}{T}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)=C\left(\frac{1-z^{-1}}{1+z^{-1}}\right)}$$

$$= \frac{H_0(1+z^{-1})}{(C+\sigma_0)-(C+\sigma_0)z^{-1}}$$

$$\prod_{i=1}^{r}\frac{(C+A_{0i})-2(C^2+A_{0i})z^{-1}+(C^2+A_{0i})z^{-2}}{(C^2+B_{0i}+B_{1i}C)-2(C^2-B_{0i})z^{-1}+(C^2+B_{0i}-B_{1i}C)z^{-2}}$$

$$= \frac{\beta_2+\beta_2 z^{-1}}{1-\beta_1 z^{-1}}\prod_{i=0}^{r}\frac{\alpha_{3i}-\alpha_{4i}z^{-1}+\alpha_{3i}z^{-2}}{1-\alpha_{1i}z^{-1}+\alpha_{2i}z^{-2}} \qquad (3)$$

$$\alpha_1 = \frac{2(C^2-B_{0i})}{C^2+B_{0i}+B_{1i}C}, \alpha_2 = \frac{2(C^2+B_{0i}-B_{1i}C)}{C^2+B_{0i}+B_{1i}C}$$

$$\alpha_3 = \frac{C^2+A_{0i}}{C^2+B_{0i}+B_{1i}C}, \alpha_4 = \frac{2(C^2+A_{0i})}{C^2+B_{0i}+B_{1i}C}$$

$$\beta_1 = \frac{C-\sigma_0}{C+\sigma_0}, \beta_2 = \frac{H_0}{C+\sigma_0}$$

where T = sampling period C =2/T.

$$H(e^{j\omega}) = \frac{H_0(1+e^{-j\omega})}{(C+\sigma_0)-(C-\sigma_0)e^{-j\omega}}$$

$$\prod_{i=1}^{r}\frac{[(C^2+A_{0i})\cos\omega-2(C^2-A_{0i})]^2}{[(C^2+B_0)\cos\omega-(C^2-B_0)]^2+(B_1C)^2\sin^2\omega} \qquad (4)$$

2.3. The Wavelet-OFDM System based on WDF

In general, the wavelet OFDM system is divided into IDWT / DWT. The WDF is applied as a Prototype of the M-band transmultiplxer structure. Fig. 2 shows the general M-band transmultiplexer. The transmultiplexer is composed of an analysis filter bank and a synthesis filter bank.

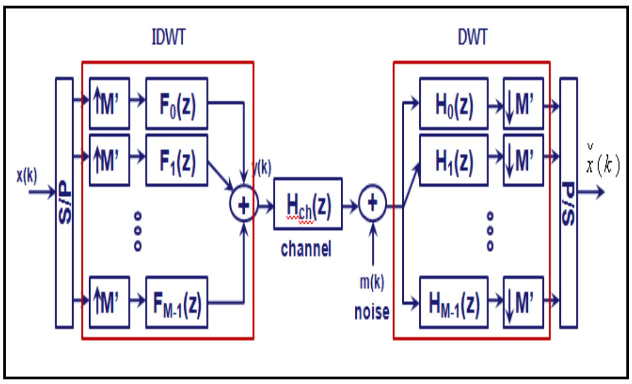


Fig. 2 The M-band transmultiplexer

The synthesis bank is expressed as:

$$F_m(z) = \sum_{k=0}^{N-1} f_m(k)z^{-k}, 0 \le m < M \quad (5)$$

The analysis bank is expressed as:

$$H_m(z) = \sum_{k=0}^{N-1} h_m(k)z^{-k}, 0 \le m < M \quad (6)$$

In the above equations, M indicates the number of subchannels and N represents the length of each filter. In general, N ≤ M < M' ; if M = M', then we have a maximally decimated M-channel transmultiplexer [5].

Perfect Reconstruction means that the output is equal to the input apart from the gain and a delay, and so the relationship between the analysis filter bank and the synthesis filter bank is:

$$f_m(k) = h_m(N-1-k), k = 0, 1, \cdots, N-1 \quad (7)$$

The above equation is expressed in the Z- domain as:

$$F_m = z^{-(N-1)}H_m(z) \quad (8)$$

All of the filters are obtained from a cosine modulated prototype filter P0(z) as:

$$P_0(z) = \sum_{k=0}^{2M-1} p_0(k)z^{-k} \quad (9)$$

Each of the filters utilizes:

$$f_m(k) = 2p_0(k)\cos\left[\frac{\pi}{M}\left(m+\frac{1}{2}\right)\left(k-\frac{N-1}{2}\right)-(-1)^m\frac{\pi}{4}\right] \quad (10)$$

$$h_m(k) = 2p_0(k)\cos\left[\frac{\pi}{M}\left(m+\frac{1}{2}\right)\left(k-\frac{N-1}{2}\right)+(-1)^m\frac{\pi}{4}\right] \quad (11)$$

The WDF is then applied as a Prototype of the M-band transmultiplxer structure:

$$f_m(k) = 2\left(\frac{H_0(1+e^{-j\omega})}{(C+\sigma_0)-(C-\sigma_0)e^{-j\omega}}\prod_{i=1}^{r}\frac{[(C^2+A_{0i})\cos\omega-2(C^2-A_{0i})]^2}{[(C^2+B_0)\cos\omega-(C^2-B_0)]^2+(B_1C)^2\sin^2\omega}\right) \cos\left[\frac{\pi}{M}\left(m+\frac{1}{2}\right)\left(k-\frac{N-1}{2}\right)-(-1)^m\frac{\pi}{4}\right] \quad (12)$$

$$h_m(k) = 2\left(\frac{H_0(1+e^{-j\omega})}{(C+\sigma_0)-(C-\sigma_0)e^{-j\omega}}\prod_{i=1}^{r}\frac{[(C^2+A_{0i})\cos\omega-2(C^2-A_{0i})]^2}{[(C^2+B_0)\cos\omega-(C^2-B_0)]^2+(B_1C)^2\sin^2\omega}\right) \cos\left[\frac{\pi}{M}\left(m+\frac{1}{2}\right)\left(k-\frac{N-1}{2}\right)+(-1)^m\frac{\pi}{4}\right] \quad (13)$$

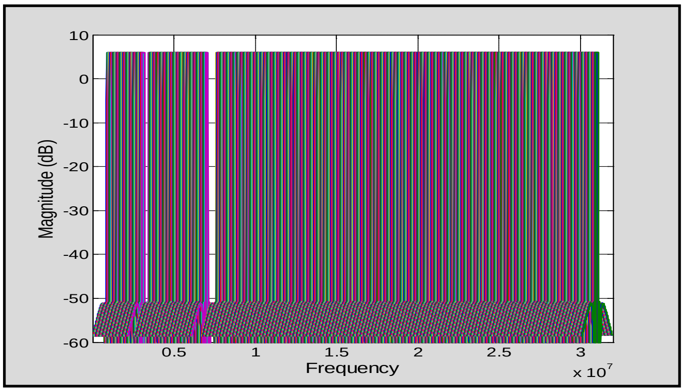
3 The Simulation Results and Analysis

The dynamic high-performance notch filter utilizing the WDF performance was verified through MatLAB.

Table 1 The ETSI HF Broadcasting Band

Ch.No	From (kHz)	To (kHz)	Bandwidth (kHz)
1	2300	2498	198
2	3200	3400	200
3	3900	4000	100
4	4550	4650	100
5	4750	5110	360
6	5750	6200	450
7	7100	7700	600
8	9300	9950	650
9	11550	12100	550
10	13550	13900	350
11	15050	15850	800
12	17400	17950	550
13	18900	19020	120
14	21450	21850	400
15	25670	26100	430

Table 1 presents the channel bandwidth from 2.3MHz to 30MHz for a total of 15 individual frequencies. The deleted bandwidth is distributed from 800kHz to 100kHz up to a certain minimum.



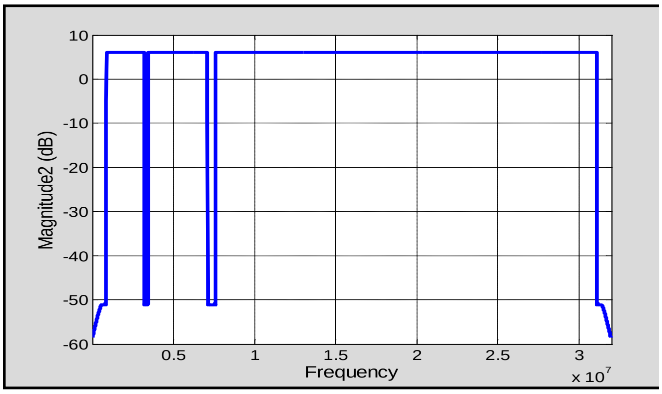


Fig. 3 The channel 2 and 7 removal results

Fig.3 shows the results of removing channels 2 and 7 from Table 1. It can be seen that 600kHz and 200kHz were deleted. The notch depth of channel 7 and channel 2 are both about-52dB.

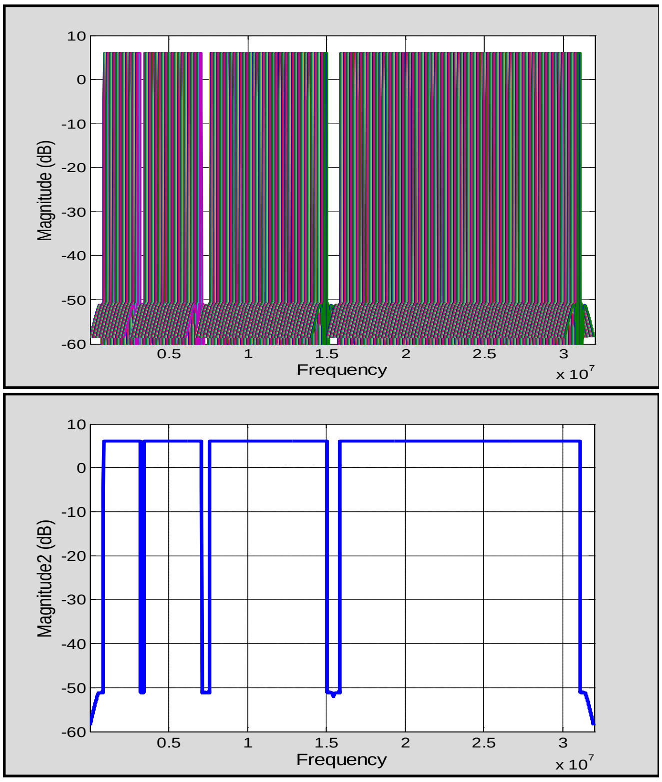


Fig. 4 The channel 2, 6, and 11 removal results

Fig.4 shows the results of removing channels 2, 6, and 11. It can be seen that 200kHz, 450kHz and 800kHz were deleted. In addition, as with the other simulation results, a notch depth of -52dB can be observed.

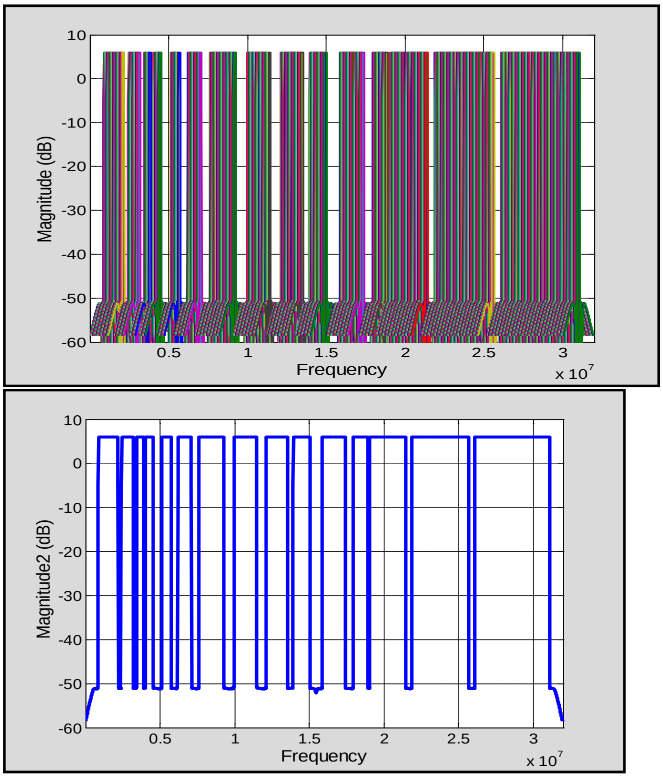


Fig. 5 The results of removing all 15 channels

Figure 5 shows the results when all 15 channelsw are removed. It shows that every corresponding frequency has been removed by -52dB.

4 Conclusion

PLC technology provides broadband internet access through ordinary power lines. PLC technology has recently developed an ultra-fast 200Mbps communication protocol. However, the power lines are designed to transfer power at 60Hz. Notch filters are a common way to eliminate the high frequency interference.

In this paper, we used WDF, which is based on wavelet OFDM, to achieve a deeper notch than existing wavelet OFDM methods. The design can remove any number of channels a user may desire, up to the 15 channels proposed in the ETSI.

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