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An implementation on GNURadio of a new model to ISDB-Tb using FBMC

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Abstract — **The modulation technique Filter Bank Multi Carrier (FBMC) is an alternative widely studied in order to replace Orthogonal Frequency Division Multiplexing (OFDM) in wireless telecommunications systems. The fact that FBMC does not use Cyclic Prefix and uses Polyphase Filters allows improvements in bit rate, bandwidth efficiency and robustness against multipath channel impairments. This implementation can bring advantages to Digital TV case in comparison to the traditional OFDM based systems because of the need to transmit higher resolution videos such as 4K and 8K. This article presents a study on the use of FBMC in Integrated System Digital Broadcasting Transmission B (ISDB-Tb), developing an application on GNURadio environment, analysing Bit Error Rate (BER) and power spectrum curves in a multipath channel.**

Keywords: FBMC, OFDM, ISDB-Tb, GNURadio, polyphase filters.

I. INTRODUCTION

The OFDM is one of the most used modulation techniques in telecommunication systems. However, the FBMC has become an alternative in order to improve the bit rate and bandwidth efficiency of wireless systems [1]. When OFDM is replaced by FBMC, the improvement in bandwidth utilization (bits/sec/Hz) may be up to 25% [2] as there is no need for Cyclic Prefix. At the same time, there is a 20% increase in robustness to interferences resulting in better bit error curve [3].

The FBMC innovation is the fact that the modulation is accomplished using a filter bank that splits the spectrum in narrow bands. However, the channel equalization becomes hard and it is necessary to implement a little more complex equalization methods. For those reasons, this article presents a modified model of ISDB-Tb using FBMC, which was implemented on GNURadio software defined radio environment with different channel estimators. The BER curves and frequency domain are presented to evaluate the obtained improvements with different channel estimators.

This article consists of seven sections. The first introduces the theme of the research. The second details the FBMC modulation method. The section three presents ISDB-T characteristics. In the fourth, it is showed the pilot based estimation method. The number five describes a developed model of ISDB-Tb using FBMC on GNURadio. In the sixth, the comparison results between estimation methods are presented, obtained through the simulations and finally the relevant conclusions to the initial objectives.

II. FILTER BANK MULTI CARRIER

FBMC can be understood if Figure 1 is considered. The data to be transmitted is split into M different paths in a filter bank arrangement. The resulting signal *s(k)* is expressed in (1) in which $a_{m,n}$ is the symbol, g_m the filter response shifted, and n the time position.

$$s(k) = \sum_{m=0}^{M-1} \sum_{n \in Z} a_{m,n}\, g_m\left(k - \frac{nM}{2}\right) \tag{1}$$

Mathematically, each filter can be expressed by (2).

$$B_k(f) = H\left(f - \frac{k}{M}\right) = \sum_{i=0}^{L-1} h_i e^{-j2\pi i\left(f - \frac{k}{M}\right)} \tag{2}$$

where f is the shifted frequency, L is the number of filter coefficients, and M is the number of sub channels.

Applying the Z transform, polyphase decomposition, and if $W_M = e^{-\frac{2j\pi}{M}}$, then we can find (3).

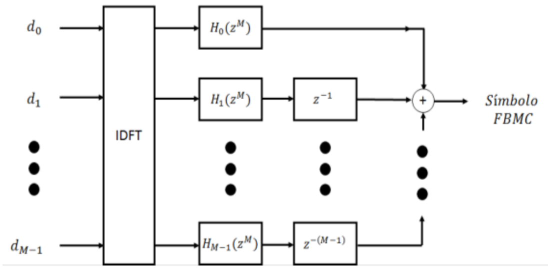

Fig. 1 FBMC modulator

$$B_k(z) = \sum_{p=0}^{M-1} W_M^{-kp} z^{-p} H_p(z^M) \tag{3}$$

It is possible to show (3) in a matrix version, such can be seen in (4), that represents the same system showed in Figure 1.

$$\begin{bmatrix} B_0(z) \\ \vdots \\ B_{M-1}(z) \end{bmatrix} = \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \cdots & W_M^{-(M+1)^2} \end{bmatrix} \begin{bmatrix} H_0(z^M) \\ \vdots \\ z^{-(M-1)} H_{M-1}(z^M) \end{bmatrix} \tag{4}$$

As non-orthogonal filters usually compose the filter bank, Offset Quadrature Amplitude Modulation (OQAM) is used. Hence, the symbols are transmitted in a staggered way in order to keep the orthogonality among adjacent carriers.

The complete system, transmitter and receiver, can be implemented through a combination of a polyphase filter bank and FFT blocks as explained in [4].

III. INTEGRATED SERVICES DIGITAL BROADCASTING TERRESTRIAL VERSION B

ISDB-Tb is the terrestrial digital TV standard adopted by 15 countries in Latin America and Africa. ISDB-Tb can be transmitted on 6, 7, or 8 MHz channels with 13 segments that are multiplexed in OFDM blocks and 1 segment as guard band as can be seen in Figure 2.

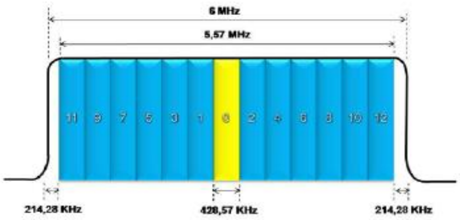

Fig. 2 Segmentation of ISDB-Tb channel

The 13 segments can be arranged for operation with One Segment, Standard Definition, or High Definition modes. The standard allows the use of QPSK, 16QAM, and 64QAM modulations in each particular OFDM layer. It uses 4992 data carriers, 625 pilot tones and an 8K IFFT with zeros insertion to complete the frame. The Cyclic Prefix values can be 1/4, 1/8, 1/16, or 1/32 of the useful OFDM symbol time. We can use three different modes showed in Table I [5].

TABLE I. ISDB-TB TRANSMISSION PARAMETERS

Mode	Parameters				
	Carriers	*Useful Carriers*	*Pilots*	*Useful Time*	*IFFT Length*
1	1405	1248	157	0.252ms	2048
2	2809	2496	313	0.504ms	4096
3	5617	4992	625	1.008ms	8192

IV. PILOT BASED CHANNEL ESTIMATION

In order to estimate the transfer function of the channel, pilot tones are sent in the ISDB-Tb. The scattered pilots have an amplitude of either +4/3 or -4/3. These values depend on a Pseudorandom Binary Sequence (PRBS) with polynomial $x^{11} + x^9 + 1$, positioned in every 12th sub channel. The starting subcarrier is either the 0th, 3rd, 6th, or 9th according to the OFDM or FBMC symbol order [5].

After finding the transfer function of the pilots (*Hp*) by (5), where *Y(k)* and *X(k)* (always different from zero) are the amplitudes of received and transmitted pilot respectively, an interpolation method, such as linear or cubic, is applied with the purpose of estimating the other subcarrier responses. This operation can be done not only in the frequency domain but also in the time domain.

$$Hp(k) = \frac{Yp(k)}{Xp(k)} \qquad (5)$$

In the linear case, it is used (6).

$$H(k) = (1-a)H_p(k) + aH_p(k+1) \qquad (6)$$

where a is a constant determined by the relation between the distance of the carrier until the pilot and the distance until the next pilot.

On the other hand, applying the cubic interpolation, (7) is used.

$$H(k) = A(a)H_p(k) + B(a)H_p(k+1) + C(a)z(k) + D(a)z(k+1) \qquad (7)$$

where *A(a)*, *B(a)*, *C(a)*, and *D(a)* are constants related to *a*, and *z(m)* is the second order derivation obtained by the pilot information [6].

V. ISDB-TB USING FBMC IMPLEMENTATION

The complete ISDB-Tb proposed system employing FBMC is depicted in Figure 3. As it can be seen, the source generates data which are modulated, added zeros, staggered (pre OQAM) and multiplied by beta. Then, an IFFT and synthesis filters are applied.

The resulting signal is sent through the channel. At the receiver, the signal passes through the analysis filters and FFT. Then, the opposite steps performed at the transmitter are accomplished.

For this implementation, a system model was created on GNURadio utilizing the C++ programming language, in order to form a Flow Graph. This model was constructed in a way that both the traditional OFDM and FBMC-based ISDB-Tb can be simulated in real time. The configuration used was the full segment, Mode 3, 64QAM, 4992 useful subcarriers, and 1/16 CP in the OFDM system.

Four channel estimators were implemented: two of them only in the frequency domain with linear or cubic interpolation, one in the frequency and time domain with cubic method [7] and the last one specifically to FBMC in the frequency domain with cubic using 3-tap equalization [4].

VI. RESULTS

In order to obtain these results it was used a 64-QAM random source. Then, by analyzing the spectrum representation in Figure 4, it is possible to observe that the spectrum of FBMC has a decay of about 70dB more than OFDM.

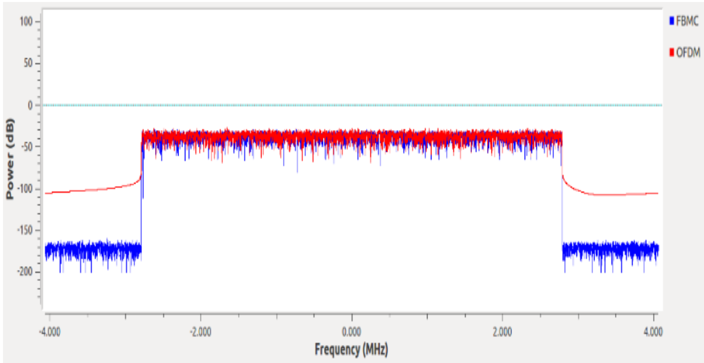

Fig. 4 FBMC and OFDM spectra

Figures 5, 6, and 7 present the BER curves found for the introduction of Gaussian noise in a Brazil A digital TV channel model [8], which encompasses 6 paths with 0, 0.15, 2.2, 3.05, 5.86, and 5.93 microseconds of delay and 0, 13.8, 16.2, 14.9, 13.6, and 16.4dB of attenuation respectively, using different estimator for FBMC and OFDM systems. The

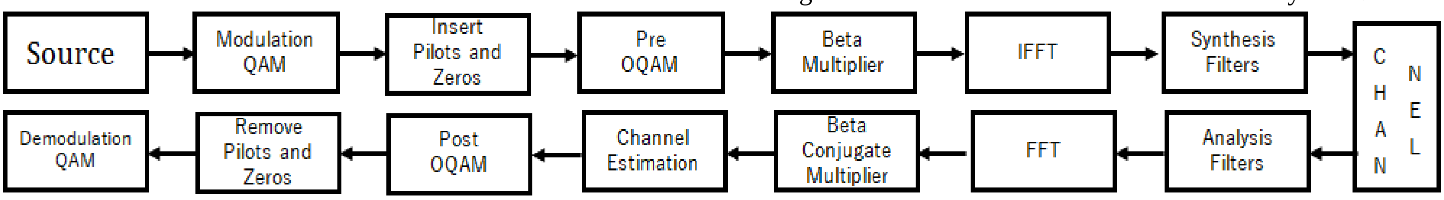

Fig.3 Schematic of ISDB-TB FBMC

estimators used were chosen according to most common applied on OFDM and FBMC systems.

From Figure 5, 6 and 7, the FBMC based system presents a better robustness to Gaussian Noise in a multipath channel even in the absence of a Cyclic Prefix, using the same estimators. Other important aspect is the fact that the equalization using 3-taps designed in order to avoid the adjacent channel interference in the case of FBMC allows a great improvement in the robustness to impairments, resulting in a bit rate increase of 6% for CP equal to 1/16.

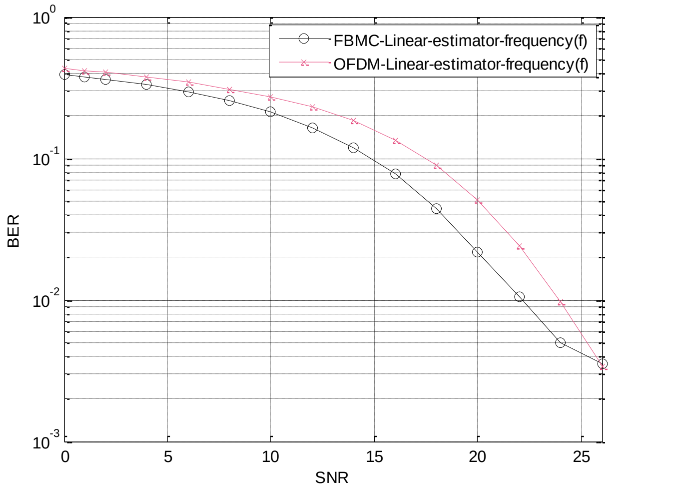

Fig. 5 BER curves using linear interpolation for estimation on frequency

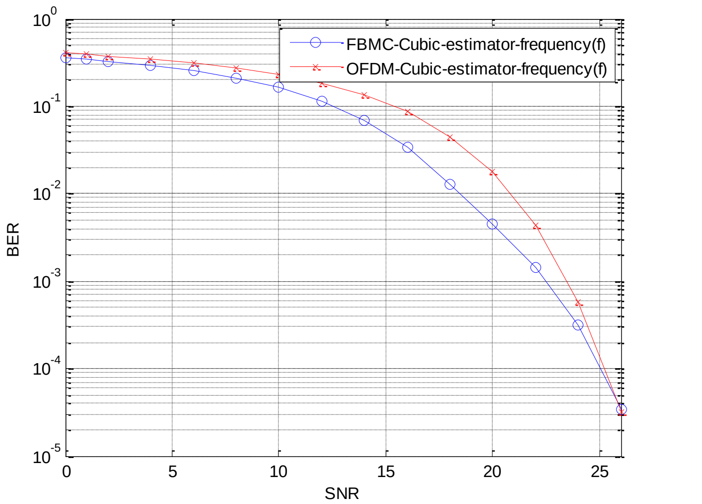

Fig. 6 BER curves using cubic interpolation for estimation on frequency

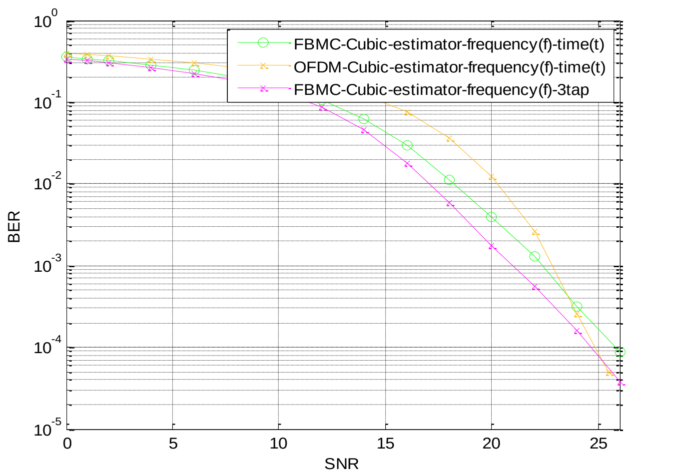

Fig. 7 BER curves using cubic different estimators

The Table II contains a summary with the obtained results.

TABLE II. SUMMARY OF BER RESULTS

Sistema	***Linear Estimator (f) (10^{-2})***	***Cubic Estimator (f) (10^{-3})***	***Cubic Estimator (f/t) (10^{-3})***	***3-tap Estimator (10^{-3})***
FBMC	22dB	23dB	22dB	21dB
OFDM	24dB	23,5dB	22,5dB	-

VII. CONCLUSION

This study has proved that the implementation of ISDB-Tb digital TV system employing FBMC instead of OFDM is viable and brings some advantages. Among them the increase of bit rate and bandwidth efficience in terms of bits/sec/Hz around to 25% if the CP is 1/4. In addition, due to the decay of spectrum, reducing the interferences among adjacent sub channels, there is an improvement in terms of BER in multipath channels.

When the estimators are analyzed, it is possible to verify that 3 tap equalization it is necessary to cancel the interference among adjacent subchannels, which increases the robustness to interferences with a little more computational complexity.

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