



Cairo University

# FPGA IMPLEMENTATION OF TIMING RECOVERY IN DVB-T2

By

Eng. / Sherif Maher Saad Elewa

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
in Partial Fulfillment of the  
Requirements for the Degree of  
MASTER OF SCIENCE  
in  
Electronics and Communications Engineering

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Under the Supervision of  
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**Title of Thesis:**

FPGA Implementation Of Timing Recovery In DVB-T2

**Key Words:**

Digital Video Broadcasting; Synchronization; FPGA; Correlation; Sampling Frequency Offset

**Summary:**

DVB-T2 received signal, being an OFDM signal, suffers from timing errors. The broad objective of this study is to illustrate how to recover the time for the DVB-T2 received signal. This is done using robust algorithms divided on two main stages. Firstly, the accurate start of the frame detection. Secondly, the sampling frequency offset detection and correction. The hardware implementation for the proposed system is presented using some methods to reduce the hardware complexity keeping the performance. The RTL implementation is simulated on Modelsim and tested on Altera Stratix III device.

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# Nomenclature

$L_{data}$	number of data symbols
$N_{P2}$	number of P2 symbol
$N_{T2}$	number of T2-frames
$T_F$	duration of one T2-frame
$T_{P1}$	duration of the P1 symbol
$T_{SF}$	duration of one super-frame
$T_S$	duration of one OFDM symbol
ADC	analog to digital converter
AWGN	additive white Gaussian noise
BCH	Bose-Chaudhuri-Hocquenghem
CBS	correlation based synchronization
CFO	carrier frequency offset
CM	complex multipliers
COFDM	Coded orthogonal frequency division multiplexing
DBPSK	differential binary phase shift keying
DFT	discrete Fourier transform
DVB-T	terrestrial digital video broadcasting first generation
DVB-T2	terrestrial digital video broadcasting second generation
FDF	fractional delay filter
FEC	Forward error correction
FEF	Future Extension Frame
FFT	fast Fourier transform
FIR	finite impulse response
HBF	half band filter
ICI	inter carrier interference
ISI	inter symbol interference

LDPC	low density parity check
LLF	log-likelihood function
LSB	least significant bit
MISO	multiple input single output
ML	maximum likelihood
MSB	most significant bits
NCO	numerical controlled oscillator
OFDM	orthogonal frequency division multiplexing
PDF	probability density function
PLL	phase locked loop
PLPs	pipelined physical layers
PML	pseudo maximum likelihood
PP	pilot patterns
PPM	part per million
QAM	quadrature amplitude modulation
QPSK	quadrature phase-shift keying
RAF	running average filter
RNE	Rounding to nearest even
RTL	register transfer level
SBS	slope based synchronization
SFO	sampling frequency offset
SISO	single input single output
SNR	signal to noise ratio
STO	symbol time offset

# Abstract

OFDM signals are sensitive to sample timing errors, causing both phase errors and sample duration offset. Sample duration errors causes loss of orthogonality between sub-carriers. As a result, inter-carrier interference is introduced, which causes destruction to the received signal. On the other hand, phase errors lead to wrong interpretation of the received symbols. Both types of errors degrade the system performance by increasing the bit error rate.

The second generation terrestrial digital video broadcasting (DVB-T2), being a wireless OFDM system, suffers from these time errors. A sampling frequency offset is introduced in the received signal due to the difference between the transmitter and receiver oscillators. This offset will be accumulated and finally turns into an integer and fraction offset in the received symbols. In addition, there is a time shift at the start of the received frame due to the delay of the channel itself. The DVB-T2 standard provides a specific symbol, called P1 symbol located at the start of the frame, in order to facilitate the time estimation process by identifying the correct start of the frame. Also, it is used in the coarse frequency estimation by detecting the fractional part of the carrier frequency offset. In addition, several pilots are presented inside the DVB-T2 frame to be used in the detection and synchronization purposes.

In this work, the P1 symbol will be exploited to estimate the correct start of the frame. This will be achieved via correlation using the maximum likelihood estimation mechanism to reach the highest accuracy. However, the complexity of this scheme is prohibited, thus, a smart mathematical deduction is followed to reduce the hardware implementation complexity.

In addition, asynchronous time tracking is achieved using two types of pilots (scattered pilots, and continual pilots) to track the sampling frequency offset. The tracking is done via fixed sampling rate at the beginning of the receiver. Then, a correlation with the previous mentioned pilots in time domain is performed to estimate the variance in the sampling offset. Finally, the correction is achieved by interpolation and decimation via multi-rate Farrow structure. The hardware implementation complexity is reduced by reordering and eliminating some unused blocks.

At the end of this work, we will be able to recover the time of the received DVB-T2 frame. The proposed architecture is a fast tracking loop with reduced hardware complexity and robust against noise under bad channel conditions.

Finally, the proposed system is tested for the effect of the carrier frequency offset errors to be sure that the system is not affected by such error. Finally the system is implemented with Verilog 2001 and simulated under Modelsim and gave the same performance as that of MATLAB model. We verify the functionality and the design of the RTL implementation by generating test vectors based on the MATLAB fixed point model and cross check it with the RTL data. The implementation is targeting the Altera Stratix III EP3SL150F1152C2N FPGA device.

# Chapter 1: Introduction

The terrestrial digital video broadcasting second generation (DVB-T2) is one of the most important and modern applications of the orthogonal frequency division multiplexing (OFDM) systems. However, being an OFDM system makes it vulnerable to time and frequency offsets and synchronisation errors. Thus, a timing recovery is needed to recover the received data and maintain the time synchronization. Hence, the DVB-T2 standard provides some pilots and preambles to facilitate the estimation of these offsets. In order to appreciate the challenges and introduce the solution, a discussion of the DVB-T2 system characteristics is needed. Then, in view of these characteristics, different problems are introduced in order to show the difficulties facing the DVB-T2 signal. The rest of this chapter discussed the thesis objectives and organization.

## 1.1 DVB-T2 System Overview

The terrestrial digital video broadcasting first generation (DVB-T) standard presented a very powerful digital television transmission system. This digital communication chain is developed based on quadrature amplitude modulation (QAM), robust forward error correction, and fast Fourier transform (FFT). Exploiting these communication techniques makes DVB-T very powerful digital communication system which immune to transmission errors and bad channel conditions. Recently, the second generation of the DVB standard has been emerged. The DVB-T2 standard providing a renovation of the terrestrial video transmission. DVB-T2 achieves a capacity increase of 50% over the old digital television DVB-T system [36]. Moreover, DVB-T2 is more suitable for mobile reception compared to the DVB-T which is originally developed for static and portable devices. DVB-T2 incorporates flexible physical layer structure. DVB-T2 employ new higher order modulation ranging from quadrature phase-shift keying (QPSK) to the newly introduced 256 QAM. The DVB-T2 also introduces larger range of options in FFT sizes starting with 1 K up to 32 K subcarriers. Each FFT size has a flexible set of guard intervals, bandwidth and pilot patterns to enable better spectral efficiency and adaptation to different terrestrial link conditions. Innovative error correction schemes have been introduced in the form of concatenated Bose-Chaudhuri-Hocquenghem (BCH) code and low density parity check (LDPC) code. In addition, flexible time interleaving and the introduction of the concept of piped physical layers (PLPs) improve the mobile performance of the DVB-T2 all add up to enhance the deployment of DVB-T2 in mobile devices.

All the above features add to the value of DVB-T2 physical layer. However, it becomes a challenge to incorporate those sets of features in a high performance decoder while preserving the compact size and low power mandated by mobile applications [7].

DVB-T2 characteristics are:

- Coded orthogonal frequency division multiplexing (COFDM) modulation with QPSK, 16-QAM, 64-QAM, or 256-QAM constellations.
- OFDM modes are 1k, 2k, 4k, 8k, 16k, and 32k. The symbol length for 32k mode is about 4 ms.

- Guard intervals are  $1/128$ ,  $1/32$ ,  $1/16$ ,  $19/256$ ,  $1/8$ ,  $19/128$ , and  $1/4$ . (For 32k mode, the maximum is  $1/8$ .)
- Forward error correction (FEC) is concatenated LDPC and BCH codes, with rates  $1/2$ ,  $3/5$ ,  $2/3$ ,  $3/4$ ,  $4/5$ , and  $5/6$ .
- There are scattered pilots with 8 different pilot patterns (PP). Also, there are continual, edge, P2, and frame-closing pilots.
- In case of 32k OFDM mode, a larger part of the standard 8 MHz channel can be used, adding about 2% extra capacity.
- The available channel bandwidths for the DVB-T2 signal are 1.7, 5, 6, 7, 8, and 10 MHz.
- The available transmission modes are single input single output (SISO) and multiple input single output (MISO) [6]. Recently, DVB-T2 system adopted MISO in order to provide high definition television [1, 2].
- Multiple PLP to enable service specific robustness.

### 1.1.1 DVB-T2 Frame Structure

The DVB-T2 frame structure consists of super-frames which split into number of T2-frames ( $N_{T2}$ ), and may sometimes contain Future Extension Frame (FEF) parts. These T2-frames are divided into some OFDM symbols. Each T2-frame begins with one OFDM symbol called P1 symbol. Then, there are number of P2 symbol ( $N_{P2}$ ) right after the P1 symbol. The rest of the T2-frame are number of data symbols ( $L_{data}$ ) as shown in Figure 1.1. These data symbols consist of normal symbols and one frame closing symbol located at the end of each frame to mark the end of the T2 frame. The duration of one super-frame ( $T_{SF}$ ), and the duration of one T2-frame ( $T_F$ ). The duration of one OFDM symbol ( $T_S$ ), and the duration of the P1 symbol ( $T_{P1}$ ).

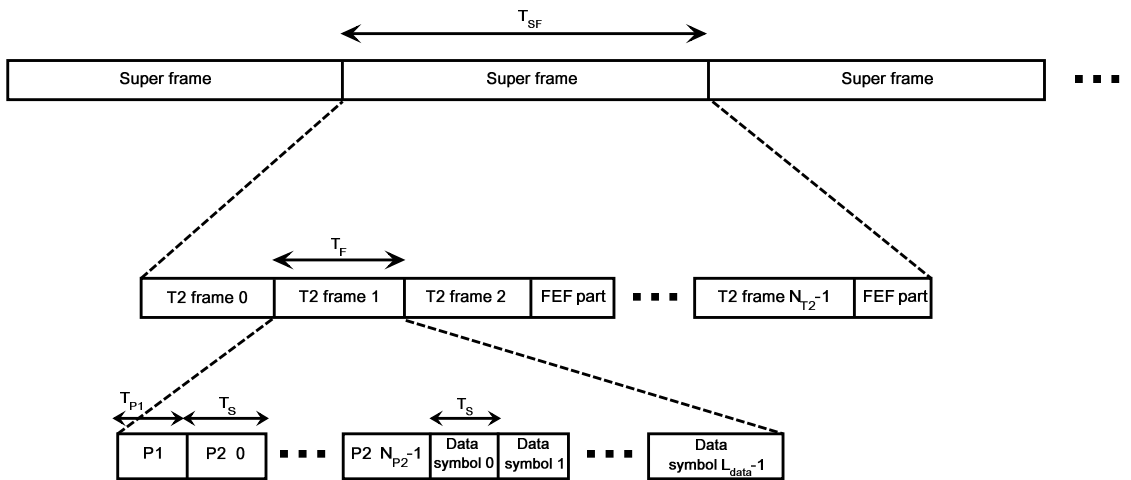


Figure 1.1: DVB-T2 Frame Structure