VNU Journal of Natural Sciences and Technology, Vol. 29, No. 1 (2013) 57-64

# Design of a Simple OFDM _IF Transceiver on FPGA

Trần Thị Thúy Quỳnh[1], Trịnh Anh Vũ[1,*], Hoàng Hưng Hải[2]

[1] *VNU University of Engineering and Technology, 144 Xuân Thủy Str., Cầu Giấy Dist., Hanoi, Vietnam*

[2] *R&D Institute, Viettel Corporation*

Received 19 July 2012

Revised 31 July 2012; accepted 06 March 2013

**Abstract.** The paper presents a design methodology for OFDM signal transmission in intermediate carrier frequency (IF) and its implementation on FPGA chip. Compared to IEEE 802.11a standard, this diagram is simpler and obviously does not stand for complex transmission channel. But this diagram is a good candidate for simple case and can be easily modified to suit specific applications. Although the diagram looks simplified, but it still contains all key features of OFDM signal that among them, the synchronization is the biggest challenge. Design was conducted at Department of wireless Communication (UET, VNU Hanoi) and the implementation result was a good success.

*Keywords*: OFDM, Synchronization, FPGA.

## 1. Introduction

Today, the OFDM technique emerges as a technique for Long Term Evaluation (LTE) in Communications. This technique has many great advantages such as spectrum efficiency and the ability resisting to channel fading…

Many papers concerning to this technique as [1,2]…, not only due to the key features of OFDM signal but also the method of designing the transmitter and the receiver was presented. However, the details of these designs are limited and may not be necessary to be implemented on all frame structure by 802.11a standard in different applications [3].

This paper proposes a simple diagram for OFDM transmitter and receiver in immediate carrier frequency. All diagrams are digitally designed for FPGA chip. Although this diagram is kept in simplicity, but it still contains whole key features of OFDM signal and can be easily modified to specific applications. Design was implemented at Department of wireless Communication (UET, VNU Hanoi) and result was successful.

## 2. OFDM signal Structure by IEEE.802.11a standard

### *2.1. Description:*

OFDM (Orthogonal Frequency Division Multiplexing) is a frequency domain technique.

* Corresponding author. Tel: 84-915509358.
E-mail: vuta@vnu.edu.vn

The data is modulated via a IFFT (Invert Fast Fourier Transform) block. A OFDM symbol contains many sub-carriers carrying parallel and independent data flow. So data rate in each flow can be decrease substantially. Because sub-carrier orthogonal each other, which is why bandwidth of those sub-channel can be overlapped partially. This in return creates high spectrum efficiency. At receiver, the OFDM symbol is then transformed by FFT block to recovery data.

*2.2. The frame structure of OFDM signal by 802.11a standard*

Figure 1 shows the structure of OFDM signal by 802.11a standard [1]

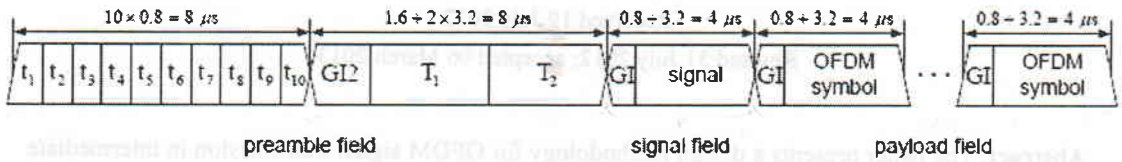



Figure 1: Packet format of the IEEE 802.11a PHY.

OFDM symbol by this standard is made by IFFT 64-point but contain only 52 of sub-carrier (for shaping spectrum). In order to ensure that the receiver cans synchronous detection, it is necessary to add some assistant bits in OFDM symbol as Header, CP, Pilot

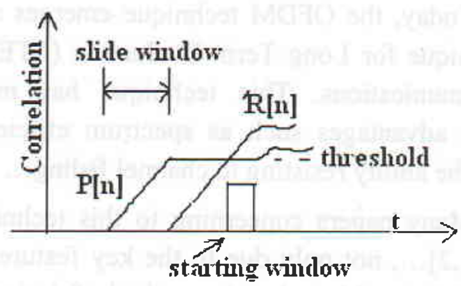
- The Header is used for detecting the appearance of packet and gives the synchronization information. There are ten identical short PN sequences ($t_1$, $t_2$,..$t_{10}$) and two long PN ($T_1$,$T_2$) in header. Those PN sequences will be use to get carrier frequency offset information. Short PN combines with long PN can also help to correctly determine the starting point of OFDM symbol.

- CP (or GI in figure) is used for resisting the multi-path channel. The partial copy of OFDM symbol is added to the front of symbol. Based on CP, the multi-path signals always have complete period for Fourier transform. Result in the orthogonal between sub-carrier will remain.

- There are 4 Pilots in four sub-carriers in an OFDM symbol. The Pilot is used for channel estimation so that receiver can correct signal if having distortion caused by channel.

*2.3. Detection of packet*

Using the auto correlation (P[n]) and cross correlation (R[n]) of PN in header, we can detect correctly the appearance of packet. It is explained in [1](figure 2)




$$P[n] = \sum_{m=0}^{N_s-1} |r[n+m]|^2 \quad (1)$$

$$R[n] = \sum_{m=0}^{N_s-1} \bar{r}[n+m] \cdot r[n+m+N_s] \quad (2)$$

$$M[n] = \frac{|R[n]|^2}{(P[n])^2} \quad (3)$$

Figure 2. Threshold between autocorrelation and cross correlation.

Here $N_s$ =16 is length of short PN which also equal the wide of slide window in correlation. r[n] is sample at time moment t=n

The packet can be detected when ratio M[n] crosses a predetermined threshold (typical = 0.5 or 0.7). A window is made in this moment called the starting window (or Region of Interest, ROI). The stability of this window is very importance because we can get in this widow some key information as bellow.

*2.4. Carrier frequency offset* [4]

Consider the argument of R[n] (2). If carrier offset = 0, the argument also is equal to zero, because the samples r[n] exactly equal samples r[n+$N_s$] so r[n].r*[n+$N_s$] is a real number. If carrier offset does not equal zero, r[n] and r[n+$N_s$] will different the factor exp(-j2π.Δf.$N_s$) so argument of R[n] will equal Δφ = Δf.$N_s$.(4)

$$R[n] = \sum_{m=0}^{N_s-1} \bar{r}[n+m] \cdot r[n+m] = e^{-j\Delta\phi} \cdot \sum_{m=0}^{N_s-1} |r[n+m]|^2. \quad (4)$$

From here we can get information of Δf and realize the compensation of frequency offset

*2.5. Sampling time*

For OFDM-IF signal, the receiver needs sampling correctly in middle of data duration. On this task we use the Gardner filter [5]. The sampling rate here equal two time data rate.

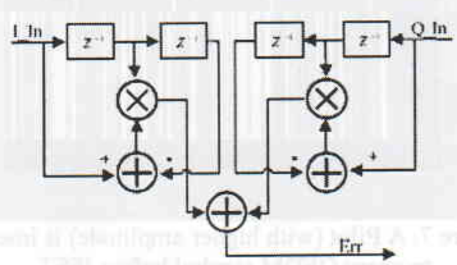



Figure 3. Construction of Gardner filter.

To combine the starting window and the Gardner filter we can determine sample time and symbol time [6].

*2.6. Error phase correction by pilot*

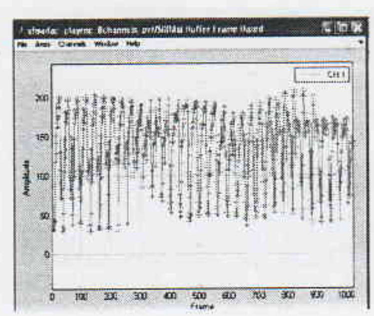
Although the compensation of the carrier frequency offset is realized, few differences remain between transmitter and receiver in both time domain and frequency domain. Moreover there are other influences of channel on the synchronization. All of these facts affect the pilot. Using the known pilot, we can correct all of these errors [7].

## 3. Proposed diagram

For simplicity and easy evaluation of system, we build a scenario and signal structure as follows:

*3.1. Using a image as source file*

a)



b)

Figure 4. a) The image as source file.
b) Format file.mat of image.

The matrix of image (a) is converted to file.mat (b). This file is recorded in SDRAM for transmitting to receiver. The data flow then is divided into two branch I and Q and mapping to subcarrier by QPSK constellations. Design uses the System Generator Tool of Xilinx Company. After compiling, a file.bit is made and embedded to FPGA chip (Virtex 4 ) on VHS-DAC and VHS ADC of Lyrtech company. The system for transmission is setup. Full diagram as figure 5

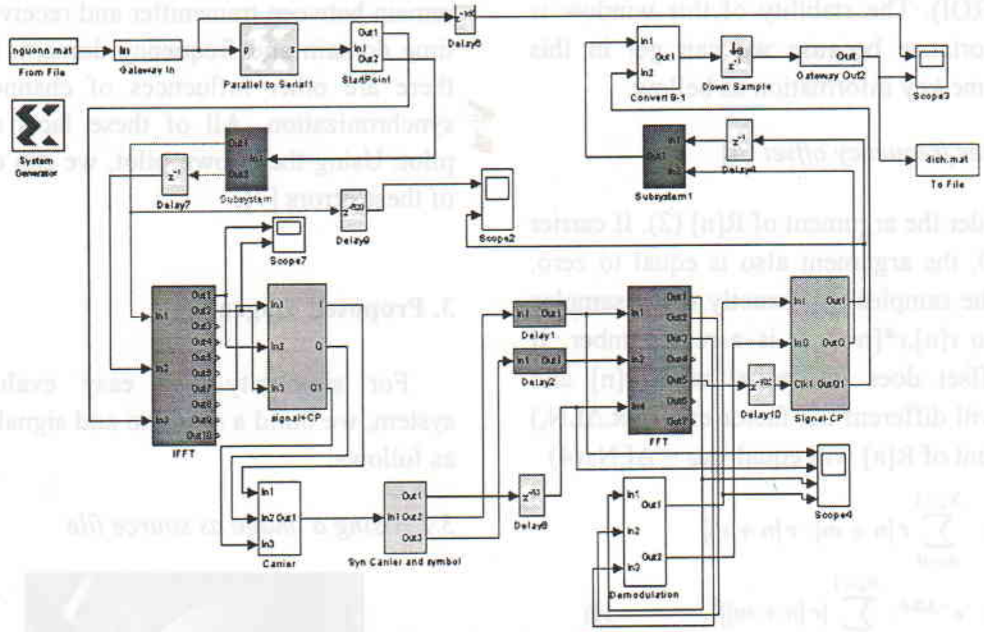



Figure 5. Full design diagram.

## 3.2. Two of short PN sequences

We use only two short PN [-1 -1 1 1 -1 1 1 1 1 -1 1 -1 -1 1 -1 -1] in time domain
In simulation signal of R[n] and P[n] received as figure 6

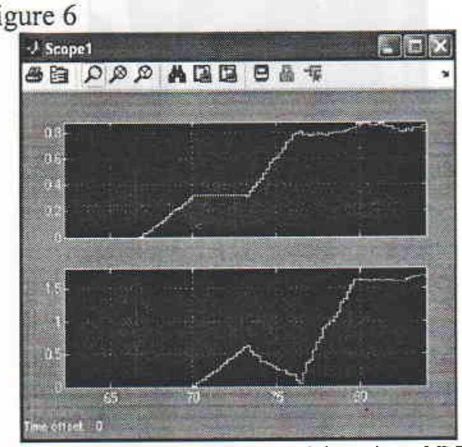



Figure 6. The curves of P[n] (above) and R[n] (below).

## 3.3. Using 1 bit Pilot

There is 1 bit-Pilot insert to every OFDM symbol. Its position is index by 64-FFT. See figure7

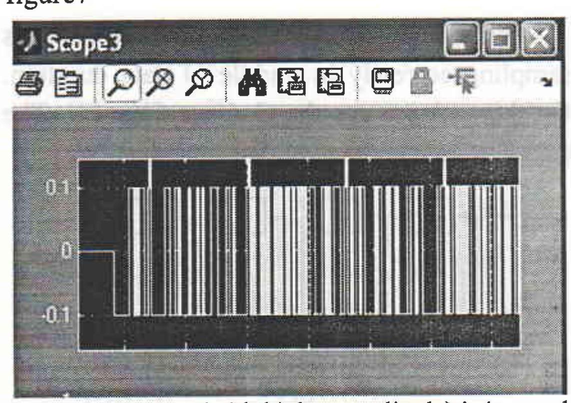



Figure 7. A Pilot (with higher amplitude) is inserted to every OFDM symbol before IFFT.

### *3.4. Create CP*

In order to receive 16-sample CP, the changing sampling rate is used. Using a FIFO with ratio of writing in and reading is equal to 4/5. So duration of OFDM symbol is shrunken, it gives a free place for CP insert.

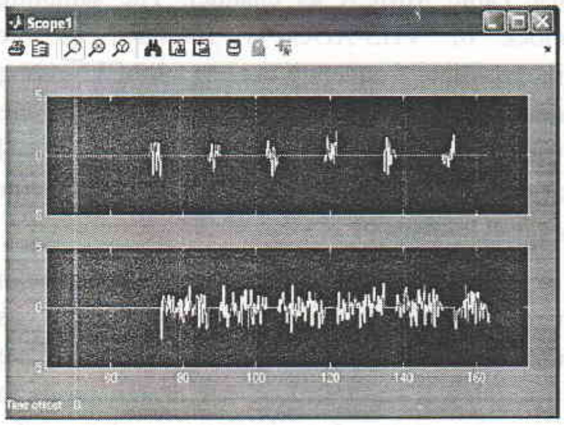



Figure 8. CP copy (above) and shrunken OFDM symbol (below).

### *3.5. Up-convert to intermediate frequency*

Two branch I,Q is multiplied separately with sine and cosine generator then sum up them. As IFFT transform magnitude of signal may be small, so we have to use AM modulation on intermediate frequency.

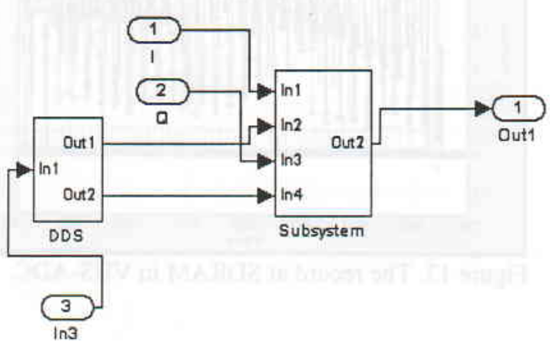



Figure 9. Up convert to intermediate frequency.

### *3.6. The compensation of the frequency offset*

The argument of R[n] from the starting window will compensate the local oscillation. In simulation, we make initially the frequency offset between transmitter and receiver for checking the operation of this block. If this block works correctly, the recreated offset frequency will be the same as initial offset frequency (Fig.10)

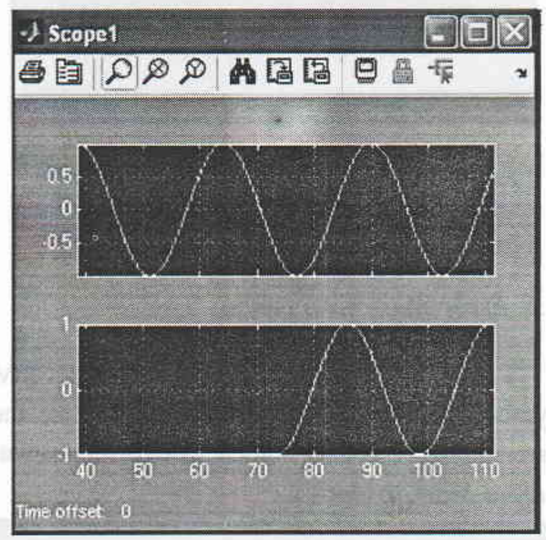



Figure 10. Offset frequency (above) and recreated frequency (below).

### *3.7. Implementing sample and symbol synchronization*

The most importance in synchronization is detection of the sample time and symbol time. In our design, we use the Gardner filter for this task. After getting a correct position in start window we can generate sample clock easily. Note that this method is different from QAM technique. Because OFDM is technique in frequency domain, the difference of clock in transmitter and receiver will be converted to the difference of phase.

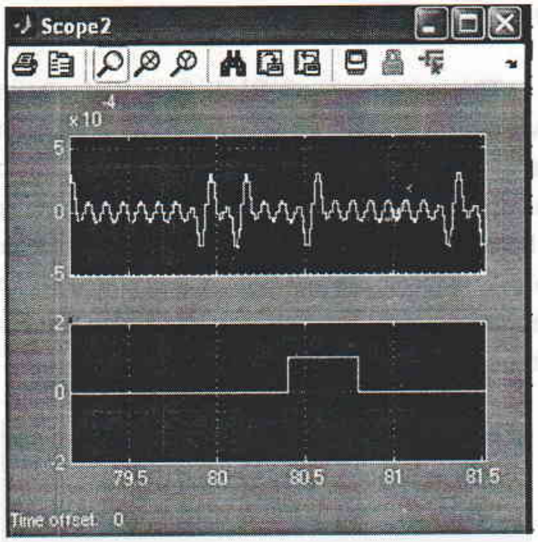



Figure 11. Starting window select the sample moment.

### 3.8. Error phase correction

Figure 12 shows the role of Pilot in OFDM symbol. Based on the variation of pilot, the error phase correction block has correct signal before decision block.

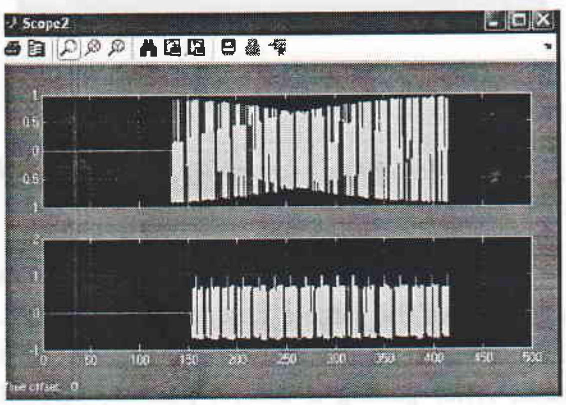



Figure 12. signal before (above) and after (below) phase correction base on pilot.

## 4. Application for transmission of a image file

The image was a successful transmission to receiver. Below is the record in SDRAM at VHS-ADC (Fig.13). It is exactly similar to record at SDRAM in VHS-DAC (Fig. 4). We use cable MMCX as channel. The sampling clock of VHS-ADC is 100Ms/s, so the intermediate frequency here is 12 MHz giving data rate of 2Ms/s (by QPSK = 4Mb/s). Here we focus on synchronization technique in real system on FPGA so we do not count error caused by noise.

There are some limitations in this design with data rate. Compare to work in [4], its design reach higher data rate (with intermediate frequency is 45 MHz) so our design needs to improve more for increasing data rate. Otherwise our design also is basic platform to build diagram compatible to specific channel. It means that depending on channel the number of PN sequence and the number Pilot can be chosen suitably for decreasing the complexity

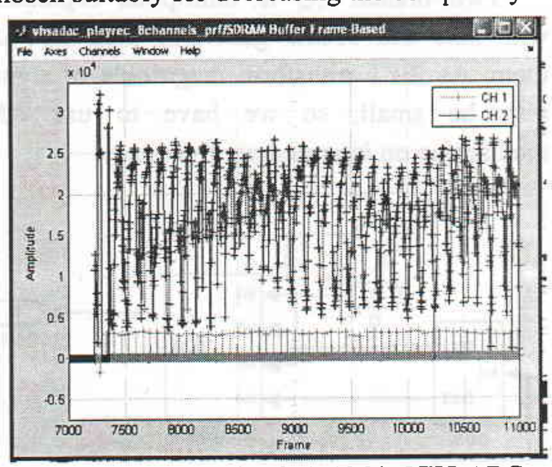



Figure 13. The record at SDRAM in VHS-ADC.

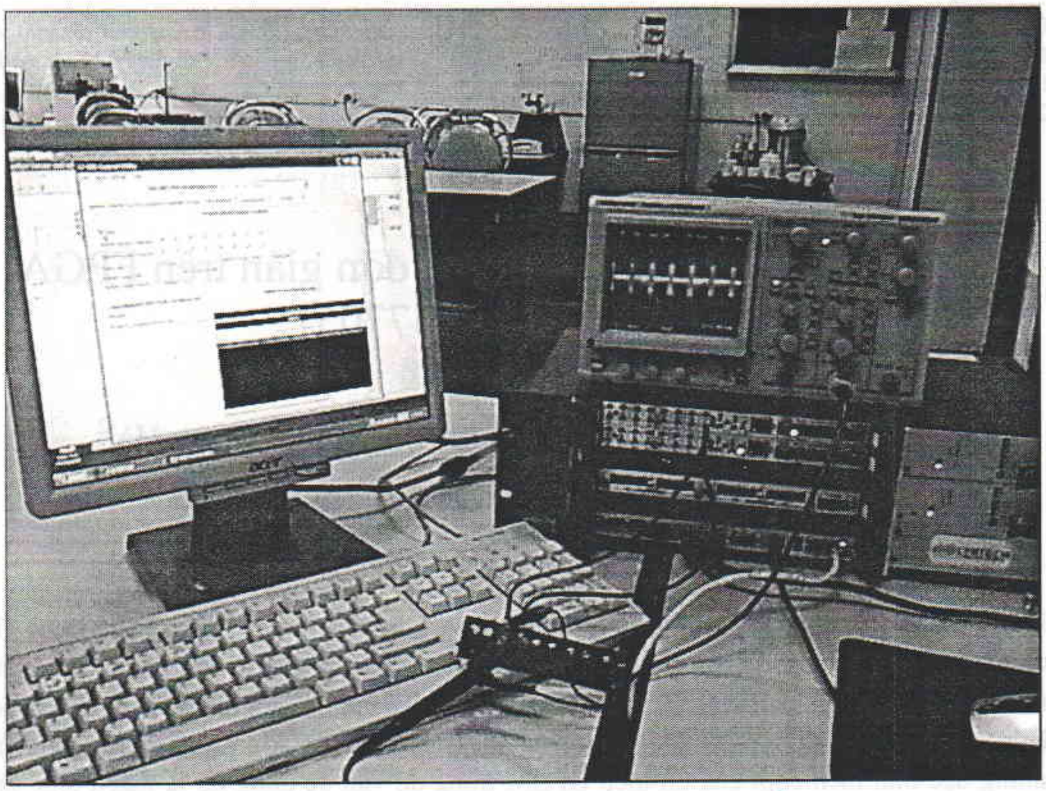


Figure 14. System for design and test.

## 5. Conclusion

A design diagram for OFDM_IF transmission is implemented successfully on FPGA chip. Although simple, it includes all of key features of OFDM technique. Otherwise in some specific applications when the channel is not complex, we can chose suitable number of PN and number of Pilot for decreasing the complexity in design. In future work we will improve design for more data rate as standard 802.11a.

## Acknowledgment

This work is sponsored by the Asia Research Center and the Korea for Advanced Studies

## References

[1] Ludwig Schwoerer, "VLSI suitable synchronization algorithms and architecture for IEEE 802.11a physical layer", Nokia research Center, 2002IEEE.

[2] Jamil Ahmad, "A novel fine frequency Synchronization Technique for OFDM Wireless Systems", 17th European Signal Processing Conference (EUSIPCO 2009).

[3] Hlang Minn, Vijay K.Brargava, Khaled Ben Letaief, "A robust Timing and Frequency Synchronization for OFDM System", IEEE Transaction on wireless communications, Vol.2,No.4,July 2003.

[4] M.Jose Canet, Felip Vicedo, Vicenc Almenar, Javier Valls, "FPGA Implementation of an IF transceiver for OFDM based wlan", 2004 IEEE

[5] Francisco Cardells Tomo, Asun Perez Pascual, Vicente Torres Carror, Javier Valls Coquillar, Vicenc Almenar Terre, "Design of a DVB-S receiver in FPGA", 2003 IEEE.

[6] Danienl Cardenas, German Arevalo, "All Digital Timing Recovery and FPGA Implementation", Co. Politecnico, Ecuador, 2005.

[7] Lars Erup, Floyd M.Gardner, Robert A.Harris, Interpolation in digital Modems-Part II: Implementation and Performance, IEEE Transaction on Communications, Vol.41, No. 6, June 1993.

# Thiết kế bộ thu phát OFDM-IF đơn giản trên FPGA (Quỳnh: 0983 057705)

Trần Thị Thúy Quỳnh[1], Trịnh Anh Vũ[1], Hoàng Hưng Hải[2]

[1]*Trường Đại học Công nghệ, ĐHQGHN, 144 Xuân Thủy, Cầu Giấy, Hà Nội, Việt Nam*
*Viện nghiên cứu và phát triển Tập đoàn Viễn thông Viettel*

Bài báo trình bày phương pháp thiết kế hệ thống truyền tín hiệu OFDM trên tần số trung gian (IF) và thực hiện trên chip FPGA. So với chuẩn IEEE 802.11a, sơ đồ thiết kế là đơn giản hơn và không áp dụng được cho kênh truyền phức tạp. Tuy nhiên sơ đồ này đáp ứng tốt với những trường hợp đơn giản và dễ dàng sửa đổi để thích hợp với một ứng dụng xác định. Mặc dù đơn giản song sơ đồ chứa đựng tất cả những đặc tính then chốt của tín hiệu OFDM trong đó vấn đề đồng bộ là thách thức lớn nhất. Thiết kế được tiến hành tại Bộ môn thông tin vô tuyến, khoa Điện tử Viễn thông trường ĐHCN, ĐHQG Hà Nội và cho kết quả thực hiện trên FPGA tốt.