Design and Sensitivity Analysis of Direct Conversion RF Receiver for IEEE 802.11a WLAN System at 5.8 GHz Frequency

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Abstract—**This paper presents the design of a direct conversion RF receiver and its sensitivity performance analysis for WLAN point to point communication at 5.8 GHz band based on IEEE 802.11a standard. The direct conversion RF receiver has been designed with proper selection of RF sub-components such as low noise amplifier (LNA), RF amplifier, power divider and filter. The selected RF sub-components of the RF receiver have been further analyzed for sensitivity performance. It is shown that the system noise figure influences RF receiver's sensitivity. It is contributed by the first stage of RF subcomponent which is LNA in the RF front-end system. As results, the 1.31 dB system noise figure has been selected in order to get the best sensitivity for direct conversion RF receiver which is -74 dBm and dynamic range of 47 dB at 54 Mbps. Besides, this direct conversion RF receiver has met sensitivity specification for all data rates based on the IEEE 802.11a standard.**

Keywords-RF Receiver; RF front-end; Direct Conversion; WLAN; Receiver Sensitivity; IEEE 802.11a

I. INTRODUCTION

In wireless local area network (WLAN) system, the design of RF front-end system is very important in order to meet the performance specification of WLAN system such as IEEE 802.11, IEEE 802.16, Wireless Broadband (WiBRO) and HiperLAN. In references [1]-[3], the analysis of sensitivity has been discussed for RF receiver design based on IEEE 802.11a standard. A proper selection of RF sub-components and its performance analysis are very important in RF receiver design and development. This paper presents the design and sensitivity analysis of direct conversion RF receiver for WLAN point to point communication at 5.8 GHz band based on IEEE 802.11a standard. The sensitivity analysis is focused on the different ranges noise figures of LNA. The selections of RF subcomponent for direct conversion RF receiver are based on the requirement to meet performance specification in IEEE 802.11a standard. The selected RF sub-components of the RF receiver have been further analyzed in Advanced Design System (ADS) software for sensitivity performance as specified in the standard.

II. DESIGN REQUIREMENTS

The IEEE 802.11a standard has been approved in 1999 for WLAN system application. Using orthogonal frequency division multiplexing (OFDM) technology, it offers different communication data rates from 6 to 54 Mbps in 5 GHz Unlicensed National Information Infrastructure (UNII) band [4]. The 5 GHz UNII band has lower band (5.15 to 5.25 GHz), middle band (5.25 to 5.35 GHz) and upper band (5.725 to 5.825 GHz) with four 20 MHz channels bandwidth at different output power levels as shown in Figure 1. The upper 5 GHz UNII band is also known as 5.8 GHz band. Thus, with this allocation of power level, the 5.8 GHz band is suitable for outdoor point to point communication where with 29 dBm of output power, the WLAN signal can transmit and receive for longer distance between two points.

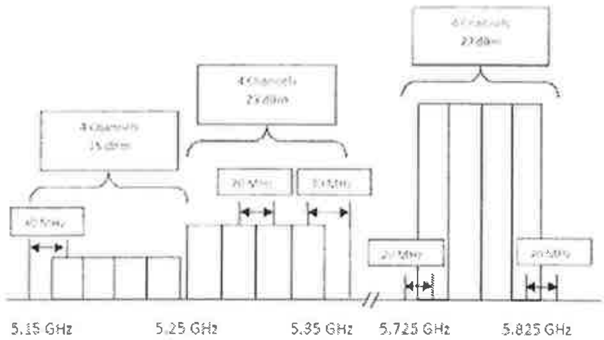

Figure 1. IEEE 802.11a standard for 5 GHz UNII band

The detailed specifications for this standard at physical layer are given in Table I. According to the table, sensitivity and noise figure are the key specification that must be complied in IEEE 802.11a WLAN receiver design especially at RF front-end system. These require proper selection of RF sub-components such as LNA, RF amplifier and filter with the analysis of RF receiver's sensitivity in order to meet sensitivity specification at 6, 9, 12, 18, 24, 36, 48 and 54 Mbps of data rate.

TABLE I. IEEE 802.11A FOR PHYSICAL LAYER SPECIFICATION

Parameters	Specifications
Frequency Bands	5.725-5.825 GHz (Upper Bands)
Channel Bandwidth	20 MHz
Number of Channel Per Bands	4
Sensitivity	-82 dBm for 6 Mbps -81 dBm for 9 Mbps -79 dBm for 12 Mbps -77 dBm for 18 Mbps -74 dBm for 24 Mbps -70 dBm for 36 Mbps -66 dBm for 48 Mbps -65 dBm for 54 Mbps
Noise Figure	<10 dB

III. RF RECEIVER DESIGN

The direct conversion RF receiver has been chosen where it converts directly a RF signal of desired channel to a baseband signal or vice versa without converting to intermediate frequency (IF). It is also known as zero IF architecture [5]. Direct conversion receiver architecture offers several attractive features, which is suitable to be implemented in IEEE 802.11a WLAN receiver. There are several advantages such as high integration, low power consumption, can be made simpler, no image frequency and low cost of implementation [6]-[9].

Figure 2 shows the configuration of direct conversion RF receiver architecture for WLAN point to point communication at 5.8 GHz band and Figure 3 shows a prototype of the RF receiver which consists of LNA, power amplifier, power divider and bandpass filters.

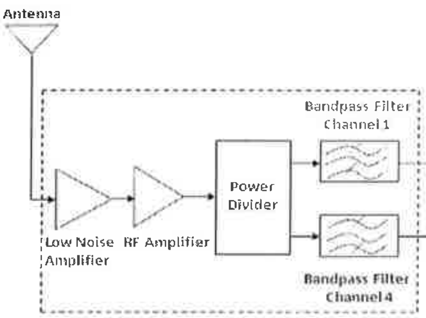

Figure 2. Direct conversion RF receiver configuration for WLAN point to point communication at 5.8 GHz band

The operation of RF receiver starts at the antenna. The antenna will capture modulated OFDM signal in the air. The signal then guided to LNA. LNA is an important part where it deals with noise; noise characteristics of the first stage of receiver exert a large influence on the entire system. Besides lowering noises, LNA also act as pre-amplifier before RF amplifier.

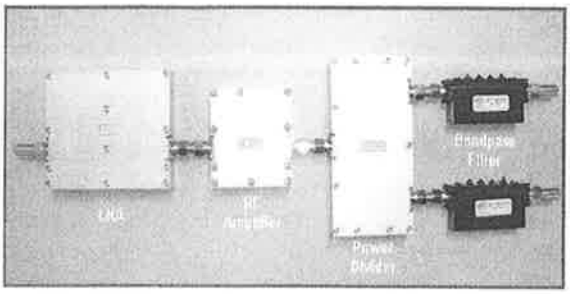

Figure 3. Prototype of direct conversion RF receiver

The signal will be filtered at center frequencies of channel 1 and channel 4 in the upper 5 GHz UNII band. The bandpass filter will allow only signal with both center frequencies as stated pass through it, other frequencies will be filtered. The frequencies of channel 1 and channel 4 of bandpass filter will be extracted from its modulation envelope by detector, leaving pure OFDM signal. Demodulator will convert this signal into data signal where the output will be obtained.

IV. SENSITIVITY ANALYSIS

For most RF receiver system design, there are several parameters that must be considered such as sensitivity, selectivity, spurious response rejection, intermodulation rejection, frequency stability and radiation emission [10]-[12]. In this paper, the effect of noise figure to the sensitivity performance is analyzed in the direct conversion RF receiver.

In RF receiver design, Harold Friis defined total system noise figure mathematically by using (1).

$$NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \ldots + \frac{NF_n - 1}{G_1 G_2 \ldots G_{n-1}} \quad (1)$$

where NF_{total} is equivalent input noise factor (linear), Fi is stage noise factor (linear) and Gi is stage gain (linear).

By using (1), the overall system noise figure computed is 1.31 dB.. This is 8.69 dB lower than specified noise figure in IEEE 802.11a standard for receiver system. Table II shows the individual noise figure and total noise figure of the system. The noise figure of passive components such as filter and power divider are equally loss [13]. It is shown that the system noise figure is mainly influenced by the early stage of .RF receiver subcomponent.

TABLE II. INDIVIDUAL AND SYSTEM NOISE FIGURE

Stage	Component	Gain (dB)	NF(dB)
1	LNA	29	1.3
2	RF Amp	16	4
3	PWD	-3	3
4	BPF	-3.61	3.61
Total Noise Figure (NF_{Total}) = 1.31 dB			

For IEEE 802.11a standard, sensitivity has been defined as a minimum signal received from antenna connector and must has a packet error rate (PER) less than 10% or 0.1 at a physical sublayer service data unit with length of 1000B [14]. Mathematically, sensitivity referenced to the input is defined as the sum of the minimum detectable signal (MDS) and the required output signal to noise ratio is given by (2).

$$Sensitivity_{dBm} = -174dBm + 10\log B + NF_{sys} + SNR \qquad (2)$$

where, B is channel bandwidth, NF_{sys} is system noise figure and SNR is signal to noise ratio.

To prove that the system noise figure will effect to the sensitivity performance, 1.3 dB, 2 dB, 10 dB and 15 dB system noise figure are chosen to simulate sensitivity performance at 54 Mbps data rate. The 1.3 dB and 2 dB system noise figure are based on the available RF subcomponent of LNAs. However, the 10 dB and 15 dB system noise figure are chosen to indicate that the overall system noise figure cannot be higher than 10 dB.

The sensitivity performance results in Figure 4 are simulated by using ADS software. The system noise figure in the simulation is added 5 dB implementation margins. The additional 5 dB implementation margin has to be taken consideration into as required in IEEE 802.11a standard. Figure 4 shows that at 1.3 dB, 2 dB, 10 dB and 15 dB system noise figure, while input signal level at the sensitivity respectively are -74.1 dBm, -73.5 dBm, -65.5 dBm and -60.5 dBm. Hence, for better sensitivity performance requires low system noise figure. Otherwise, the high system noise figure will limit the receiver's sensitivity performance.

Figure 4. Sensitivity at different system noise figure

For further analysis, the 1.3 dB of system noise figure has been chosen. Figure 5 show results of sensitivity performance where packet error rate (PER) versus input power level (received RF power) over eight different data rates are plotted in the same graph.

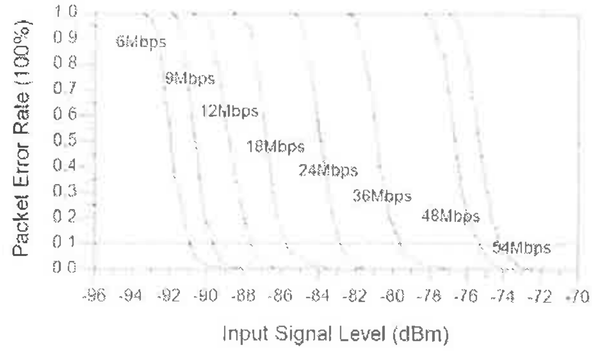

Figure 5. RF receiver's sensitivity performance

At higher data rate (54 Mbps), the minimum input level sensitivity at 10% or 0.1 of PER is approximately -74 dBm while at the lowest data rate (6 Mbps), the minimum input level sensitivity is -91 dBm.

According to this sensitivity simulation result, the SNR can be calculated by using (3).

$$SNR = 174dBm - 10\log B - NF_{sys} - Sensitivity_{dBm} \qquad (3)$$

where B is 20MHz channel bandwidth and NF_{sys} is 1.3 dB with additional 5 dB implementation margin. The calculated SNR are listed in Table III for eight different data rate. As shown in Table III, it can be concluded that the higher the data rate, the higher the value of SNR.

In determining the dynamic range of the receiver, equation (4) is used. Dynamic range is the useful signal level range for RF receiver that can process with a particular information quality. Dynamic range is defined as the differences in power level between the system 1 dB compression point (P1dB) and the minimum sensitivity power level. Dynamic range is calculated by subtracting the system sensitivity from the system input P1dB ($P_{in,1dB}$) of the direct conversion RF receiver as shown in (4).

$$DR = P_{in,1dB} - Sensitivity_{dBm} \qquad (4)$$

The calculated dynamic range is listed in Table III. The calculation of dynamic range is based on the simulated minimum sensitivity level and -27 dBm of system P1dB for all data rates.

TABLE III. IEEE 802.11A SPECIFICATION VERSUS SIMULATION RESULT

Data Rate (Mbps)	Sensitivity (dBm) (Specification)	Sensitivity (dBm) (Simuation)	SNR (dB)	Dynamic Range (dB)
6	-82	-91	6.49	64
9	-81	-90	7.49	63
12	-79	-88	9.49	61
18	-77	-86	11.49	59
24	-74	-83	14.49	56
36	-70	-82	15.49	55
48	-66	-80	17.49	53
54	-65	-74	23.49	47

V. CONCLUSION

A direct conversion RF receiver for WLAN point to point communication at frequency 5.8 GHz has been designed with proper selection of RF sub-components such as LNA, RF amplifier, power divider and filters. The selected RF sub-components for the RF receiver have been further analyzed in ADS software for sensitivity performance. It is shown that the system noise figure influences RF receiver's sensitivity. It is contributed by the first stage of RF subcomponent which is LNA in the RF front-end system. As results, the 1.31 dB system noise figures has been selected in order to get the best sensitivity for direct conversion RF receiver which is -74 dBm and dynamic range of 47 dB at 54 Mbps. Besides that, this direct conversion RF receiver has met sensitivity specification for all data rates based on the IEEE 802.11a standard.

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