DESIGN OF A 1Gbps WIRELESS TRANSCEIVER

EEL 6374 Course Project

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Abstract

In this project, we have designed a multiple-access 1Gbps MIMO wireless RF transceiver that supports data rates of at least 1Gbps in the 57-64 GHz unlicensed spectrum. OFDMA was the choice of the multiple access scheme and a 4X4 antenna configuration with Space-Time Block Coding (STBC) was used at the transmitting and receiving ends to improve the bit-error rate (BER) performance and the coverage range of each access point. The transceiver design is based on heterodyne architecture as is highly influenced by the availability of commercial components in the 60 GHz spectrum. The transceiver employs OQPSK modulation and is capable of sustaining data rates of 1Gbps within a transmission range of 275m. In this report we discuss several issues pertaining to the design of the transceiver and its performance. A combination of design tools like MATLAB, Syscalc and ADS were used in the design and the performance evaluation of our system.
1. Introduction

The FCC has allocated a unprecedented 7 GHz of bandwidth in the 57-64 GHz range. With the availability of cheap and reliable commercial components in the 60 GHz band (henceforth, we shall refer to the 57-64 GHz band loosely as the 60 GHz band), there has been increased interest in the design and deployment of commercial wireless systems like point-point communications, wireless data communications etc. We suggest the interested reader refer to [1] [3] and references there in.

The reasons behind our choice of the 60 GHz band for the design of the 1Gbps WLAN is two-fold. First, the availability of cheap commercial components have greatly assisted and influenced us in the design and performance evaluation of the WLAN transceiver design. Flexible design was possible due to the availability of about 7 GHz of bandwidth in this 60 GHz spectrum band. Also the availability of literature dealing with the issues involving the 60 GHz band has prompted us to choose this particular band.

Secondly, we expect the system designed in the 60 GHz to experience minimal interference from the existing systems as there are very few or almost no systems operating in this spectrum. Also, there is considerable attenuation due to oxygen absorption in the 60 GHz band. This additional attenuation due to oxygen leads to minimal interference from other WLAN access points and hence we believe that large scale deployment of our system is possible.

The rest of the report is organized as follows. In Section 2, we discuss the propagation model for the wireless LAN channel. Section 3 discusses the choice of RF spectrum, FCC regulations and the maximum range of our WLAN system under the MIMO antenna configuration. The notion of Space-Time Block Codes (STBC) in multiple antenna systems is introduced in Section 4. Section 5 gives a detailed description of single user transceiver architecture and its performance is evaluated in Section 6. Section briefly discusses the incorporation of multiple-access in the present transceiver architecture. Section 7 concludes the report.

2. Propagation model

The model for the Base Station (BS) (also called Access point) and the Mobile Station (MS) is shown in Figure 1. The BS and MS have heights $h_i = 3m$ and $h_r = 1m$, respectively. The horizontal distance between BS and MS is $d$.

![Figure 1: BS/MS system model.](image1)

![Figure 2: Ground reflection propagation model.](image2)

We will consider ground reflection in our model, and assume the ground to be a perfect conductor. The dipole antennas are vertically placed, so that the reflection coefficient is $\Gamma = -1$. Vertical dipoles would avoid the problem of total E field fluctuation which would happen in the horizontal placed dipoles.

Figure 2 shows the ground reflection model. The line-of-sight distance is $d'$ and the distance of the reflection path is $d''$. The total $E$ field due to line-of-sight and reflected path is
\[ E_{\text{total}} = E_0 d_0 \frac{e^{j\omega_0 (r-d')/c}}{d'} + \Gamma \frac{E_0 d_0}{d^*} e^{j\omega_0 (r-d')/c}, \]

where the constant \( E_0 d_0 = \sqrt{\frac{\eta P G_i}{2\pi}} \), with \( \eta \) denoting the wave impedance in the free space, \( P_r \) and \( G_r \) denoting the transmitted power and gain for the transmitting antenna. In the following subsection, we shall obtain the expression for strength of \( E_{\text{total}} \) by making two different approximations.

### 2.1 Far-location approximation

When \( d \gg h \), we call the region to be ‘far-field region’. In the far-location region, we can assume that \( d \approx d' \approx d'' \), and then the total E field becomes

\[ E_{\text{total}} = E_0 d_0 e^{j\omega_0 (r-d')/c} \left[ 1 + \Gamma e^{j\omega_0 (d'/c - d'')} \right] \]

Denote the difference between these two paths as \( \Delta = d'' - d' \), then the phase difference due to path length difference is

\[ \theta_\Delta = \frac{2\pi \Delta}{\lambda} = \frac{\omega \Delta}{c} \approx \frac{4\pi h_r h_i}{\lambda d}. \]

We have

\[ |E_{\text{total}}| = \frac{E_0 d_0}{d} \left[ (1 + \Gamma \cos \theta_\Delta)^2 + (\Gamma \cos \theta_\Delta)^2 \right]^{1/2}. \]

It can be shown that the power density is (using the fact that \( \Gamma = -1 \))

\[ W_i = \frac{PG_i}{\pi d^2} \cos^2 \left( \frac{\theta_\Delta}{2} \right) \approx \frac{PG_i}{\pi d^2}, \]

where \( d \gg h \) has been used in making the approximation.

The received power by the receiving antenna is

\[ P_r = W_i A_{em} = PG_i G_r \left( \frac{\lambda}{2\pi d} \right)^2, \]

where \( A_{em} = \frac{\lambda^2}{4\pi} G_r \) is the effective aperture of the receiving antenna.

### 2.2 Near location approximation

When \( d \gg h \) is not true, we call the region to be a near-location region. In this region we cannot make the approximation \( d \approx d' \approx d'' \). Therefore, the exact expression for the total E field is

\[ E_{\text{total}} = E_0 d_0 e^{j\omega_0 (r-d')/c} \left[ \frac{1}{d'} + \Gamma \frac{e^{j\omega_0 (d'/c - d'')}}{d^*} \right], \]

and

\[ |E_{\text{total}}| = E_0 d_0 \left[ \left( \frac{1}{d'} - \frac{1}{d''} \cos \theta_\Delta \right)^2 + \left( \frac{1}{d^*} \sin \theta_\Delta \right)^2 \right]^{1/2}. \]

It can be shown that
\[ P_r = W_i A_{em} = P G_i G_r \left( \frac{\lambda}{4\pi} \right)^2 \left[ \left( \frac{1}{d'} - \frac{1}{d^n} \cos \theta_A \right)^2 \right. \left. + \left( \frac{1}{d^n} \sin \theta_A \right)^2 \right], \]

where \( d' = \sqrt{(h_i+h_r)^2 + d^2} \) and \( d^n = \sqrt{(h_i-h_r)^2 + d^2} \).

### 3. Power Constraints and Coverage Range

#### 3.1 Power Constraint and Antenna

According to FCC rule 15.255, within the band 57-64 GHz, the average power density of any transmitted power cannot exceed \( 9 \mu W/cm^2 \), as measured 3 meters from the transmitting antenna. Therefore, the average power we can transmit is

\[ P_t G_i = 9 \mu W/cm^2 \times 4\pi(300cm)^2 = 1.0179 \times 10^7 \mu W = 40dBm. \]

The choice of antenna is an important aspect in our problem. At 60 GHz, the wavelength is only 5 mm, which means that the path loss will be more severe than lower RF frequencies like the 2.4 GHz band used for 802.11g. Therefore, in most literature, high gain antennas have been considered. In our project, we will only consider the dipole antenna. One reason is that the power efficiency is not a concern, and another is that we would like to have a moderate performance when the MS is close to BS, in which case an antenna with less directivity is preferred. The half wavelength dipole has a good tradeoff between the radiation resistance and the antenna directivity. Therefore, in our design we will use same number of half-wave length dipole antennas for both BS and MS.

The field strength for half-wavelength dipole is

\[ |E_\theta| = \frac{\eta_0 I_\theta}{2\pi r} \frac{\cos \left( \frac{\pi}{2} \cos \theta \right)}{\sin \theta}, \]

where the coordinate system is defined in Figure 3. According to the definition, the directivity gain is

\[ D(\theta, \phi) = \frac{\int \int U(\theta, \phi) d\theta d\phi}{\int_0^{2\pi} \int_0^{\pi} U(\theta, \phi) \cos \left( \frac{\pi}{2} \cos \theta \right) \sin^2 \theta d\theta d\phi}. \]

where \( U(\theta, \phi) = \frac{r^2 E^2}{2\eta} \).

![Figure 3: Coordinate system for half-wavelength dipole.](image)

![Figure 4: Antenna radiation pattern.](image)
The gain of half-wavelength dipole is \( D = D(\theta, \phi)_{\text{max}} = 1.64 = 2.15\, \text{dB} \), which means that
\[
\frac{2}{\int_{0}^{\pi} \frac{\cos^2\left(\frac{\pi}{2} \cos \theta\right)}{\sin^2 \theta} d\theta} = 1.64.
\]
Therefore we have
\[
D(\theta, \phi) = \frac{1.64 \cos^2\left(\frac{\pi}{2} \cos \theta\right)}{\sin^2 \theta}.
\]

If we assume the antenna efficiency to be \( e = 1 \), then we have \( G(\theta, \phi) = eD(\theta, \phi) \). The antenna gain pattern is shown in Figure 4.

As will be shown later, we will use four antennas on both the base station and the mobile station, in order to use space time coding. In our simplified scheme, we will not use the sector model. Antenna sector and antenna array can be added into our scheme to improve the performance in multi-user environment and to increase the power efficiency.

We will propose an adaptive scheme for the number of antennas used later. The full four-antenna will be used for space-time coding in the worse case, such as on the edge or close to the BS, only two antennas are needed in average case to lower the occupied bandwidth, and only one antenna is needed in the best case.

### 3.2 Coverage Range

The coverage range is determined by the receiver sensitivity and the transmitted power. At 60 GHz, in clear weather and the normal conditions, the radio frequency attenuation due to oxygen has a peak value, which is 15dB/km in the normal conditions. This provides a good spatial separation to achieve space reuse for wireless network systems.

The power received by the MS antenna can be calculated using the derived conclusions for far-field region and near-field region, respectively. In the far-field region, the received power is
\[
P_r = P_t + G_i + G_r + 20 \log_{10} \left( \frac{\lambda}{2\pi d} \right) (\text{dBm}).
\]
In the near-field region, the received power is
\[
P_r = P_t + G_i + G_r + 20 \log_{10} \left( \frac{\lambda}{4\pi} \right) + 10 \log_{10} \left( \frac{1}{d^4} - \frac{1}{d^2} \cos \theta \Delta \right)^2 + \left( \frac{1}{d_\Delta} \sin \theta \Delta \right)^2 (\text{dBm}).
\]

The calculated received power is shown in Figure 5. Based on Figure 5(a), the transmitting antenna gain as a function of \( d \), we classify the far-field and near-field region. We assume it to be a far-field region when the antenna gain is close to the maximum value 1.64, and a near-field region when then antenna gain is very small. For power densities we have derived for these two regions should have better precision (i.e. the region where \( d < 1\, \text{m} \) and \( d > 10\, \text{m} \)), and the interim part may not be so accurate.

From Figure 4 (a) and (b), we know that the transmitting antenna pattern has a null when \( \theta = 0 \) or \( \theta = 90^\circ \), which means that the received power show be 0 when MS is directly under the BS. However, in practice MS will seldom be so close to the BS, so we can calculate how close MS can be to BS and still receive sufficient power to achieve the target BER.

The receiver sensitivity can be obtained from the equation
As will be shown in our later sections, the maximum bandwidth needed for our 1Gbps system is 1.33GHz, and SNR required to achieve $10^{-6}$ Bit-Error-Rate (BER) is 6.4 dB for 4-by-4 antenna case, and the noise figure NF is 5 dB. We can calculate
\[
P_r = (KT)_{dB} + 10\log_{10}B + SNR_{req} + NF.
\]

From Figure 5, we can calculate the coverage range to be approximately 225m.

Since the entire 7 GHz bandwidth is available for data transmission, by employing more complex modulation schemes like 64-QAM and forward error control coding, multiple users can be supported by the access point without any degradation in the performance or in the coverage range.

**4. MIMO System and Space-Time Block Codes**

In our project, we use Multiple-Input Multiple-Output (MIMO) system with four antennas at the BS and at the MS.

Many established communication systems today use multiple antennas at the base station. For instance, a typical base station in the Global System for Mobile communications (GSM) has two receiving antennas. Obviously, a BS that employs receiver diversity can improve the quality of the uplink (from the terminal to the base station) without adding cost, size or power consumption to the terminal. In recent years, it has been proven that a substantial amount of the performance gain can be achieved by using multiple antennas at the transmitter and the receiver. Also, at the operating frequency 60GHz, the half-wavelength dipole is only 5mm long, which provides a possibility to use multiple antennas both on MS and BS.
There are many types of Space-Time Codes (STC) [4] to achieve transmitter diversity, such as Space-Time Block Code (STBC), Space-Time Trellis Code (STTC) and Layered Space-Time code. Herein we only use linear Orthogonal Space-Time Block Code (OSTBC). Linear OSTBC have a relatively simple structure: the transmitted code matrix is linear in the real and imaginary parts of the data symbols, or equivalently, in the symbols and their complex conjugates. The most important characteristic of linear OSTBC is that the decoding metric can be decoupled for each transmit symbol, which leads to much less decoding complexity than STTC.

In this project, we provide three different transmitting schemes, all using STBC: four-by-four antennas, where a coding gain is needed, and two-by-two antennas, when the conditions are good (i.e. the receiving power is not so low therefore the coding gain is not necessary), to save some bandwidth.

4.1 Four-transmitting antenna scheme

For complex constellation such as QPSK, when the number of transmit antennas $N_t > 2$, the rate is always less than 1. Here we choose $3/4$ rate linear OSTBC. The code matrix is:

$$X = \begin{bmatrix} s_1 & 0 & s_2 & -s_3 \\ 0 & s_1 & s_2^* & s_3^* \\ -s_2^* & -s_3 & s_1^* & 0 \\ s_3^* & -s_2 & 0 & s_1^* \end{bmatrix}$$

where $s_1, s_2, s_3$ are three QPSK symbols, $^*$ means conjugate, each row of $X$ represents each transmit antenna, and each column of $X$ represents each transmit time slot. The QPSK constellation is represented as $\pm \frac{\sqrt{2}}{2} \pm \frac{\sqrt{2}}{2}i$ with normalized power. We notice that this code matrix uses 4 time slots to transmit 3 QPSK symbols, so the rate is $3/4$, which means we need a total 1.33GHz null to null band width to achieve 1 G bits/sec data rate using QPSK modulation. We notice that in this scheme at any time slot, there are only 3 transmitting antennas. Supposing the total transmit power to be $P$, we distribute $P/3$ power for each transmit antenna not $P/4$. So $s_1, s_2, s_3$ are to $\frac{\pm \frac{\sqrt{2}}{2} \pm \frac{\sqrt{2}}{2}i}{\sqrt{3}}$ in this case.

4.2 Two-transmitting antenna scheme

This two transmit antenna scheme is a special case for linear OSTBC, which can achieve the transmit rate as 1. The code matrix is:

$$X = \begin{bmatrix} s_1 & s_2^* \\ s_2 & -s_1^* \end{bmatrix}$$

In this scheme, we use 2 time slots to transmit 2 QPSK symbols, so 1Gbits/sec data rate needs 1 GHz band width. Each transmit antenna has a power of $P/2$.

5. Transceiver Architecture

In this section we discuss the architecture of our 4X4 multiple antenna transceiver. Since the architecture of the 4 data paths along the 4 antennas is identical we discuss only the design of single antenna transmitter path and single antenna receiver path. Since we use a TDD switch with high isolation and the transmission and reception are separated in time (note that this transceiver is actually only half duplex), it is possible to consider the design of transmitter and receiver separately.
5.1 Transmitter Architecture

For our wireless transceiver design, we consider the heterodyne architecture. The design was primarily motivated by the availability of commercial components. The transmitter architecture is shown in figure 6. The input data, consisting of I & Q channels is first encoded using a Space-Time Block Code (STBC). Since the rate of the STBC is 4/3, the output bit rate (symbol rate) is 1.33 Gbps (667 Mbps). The digital data is then converted into an analog signal using a high speed DAC and pulsed shaped using a root raised-cosine-filter (RCF) to minimize the effects of inter-symbol-interference (ISI) and also the transmission bandwidth of the system. The I & Q signals are up-converted to an IF frequency of 2.4 GHz and combined to form the complex IF signal. The choice of 2.4 GHz as the IF frequency was motivated by the availability of components in that frequency range. Even though one might argue that such a low IF frequency might lead to degradation in the performance of the transceiver, we believe that it is offset by the fact that there is minimal interference in the 60 GHz band and also strong attenuation due to oxygen absorption. OQPSK modulation is used to reduce the non-linearities in the system. The RF bandwidth for this system is 1.33 GHz. A voltage controlled oscillator (VCO) is used to convert the IF signal into the 57-64 GHz band. A variable gain amplifier followed by a medium range power amplifier (PA) is used to amplify the signal to the desired power level. The band-pass filter (BPF) is used to filter out the spurious emissions from the PA. A variable-gain amplifier is used in our design to achieve power control, so as to minimize the interference to adjacent cells and also to save the power at the transmitter.

Fig. 7 shows the schematic of the single antenna transmitter in Agilent ADS environment. Note that the band-pass filter after the IF stage is replaced by a combination of low-pass and high-pass filters. Since there were no commercial BPFs available with such a wide bandwidth, we implemented the BPF as a combination of LPF and HPF. The commercial components utilized in the design of the transmitter are tabulated in Table 1.

5.2 Receiver Architecture

Considering the challenges on the hardware system by the high operation radio frequency 60 GHz, we choose to use indirect conversion for our receiver. Figure 8 shows the architecture for the receiver. The components we choose for each part are given in Table 2.

However, it is possible to realize direct conversion. We have found a high speed ADC to convert the RF signal direct to high data rate digital signal. But in order to demonstrate the constellation, we will show the indirect conversion result in the follow.

We choose to use TDD switch for multiplexing, considering that at such high frequency it may be hard to build a high isolation switch. We found an updated high frequency SPDT switch with low insertion loss in [2].

Since noise figure is dominated by the first stage, we put an LNA on the first stage of receiver, which is followed by a band select filter.

We choose a VGA to be IF amplifier, for two reasons: first, it has high IP3, which is seldom seen in the 2.4 GHz LNA which is usually used for WLAN transmitter. Since we will not consider IP3 after the channel select filter, and the IP3 is dominated by the last stage, therefore IP3 of the IF amplifier is the bottleneck for the receiver IP3. Also, by using a VGA, we can tune the gain therefore not to saturate the IF Amp and the following components.

The channel selection, if directly using a band pass filter, would require a band pass filter with percentage bandwidth \(1.33GHz / 2.4GHz = 55\%\), which is hard to manufacture. Therefore, we use a low pass filter (LPF) together with a high pass filter (HPF) which is equivalent to a band pass filter. The LPF and HPF can be found more easily.
Figure 6: Architecture of the single antenna transmitter.

Table 1: Components parameters for transmitter

<table>
<thead>
<tr>
<th></th>
<th>Model</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>IIP3/OIP3 (dBm)</th>
<th>P1dB (dBm)</th>
<th>Image Rejection Gain or Isolation (dB)</th>
<th>Others</th>
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<tbody>
<tr>
<td>TDD Switch</td>
<td>[1]</td>
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<td>-1.8</td>
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<td></td>
<td></td>
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<td>N/A</td>
<td>N/A</td>
<td>Fe=60.5 GHz</td>
<td>Bandwidth=7GHz</td>
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<td>Power Amplifier</td>
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<td>3.8</td>
<td>25 (I)</td>
<td>16 (I)</td>
<td></td>
<td></td>
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<td>Driver Amplifier</td>
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<td>10</td>
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<tr>
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<td>IQ-1545</td>
<td>-5.5</td>
<td>5.5</td>
<td>16</td>
<td>6</td>
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</tr>
<tr>
<td>LO1</td>
<td>MAX2751</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>P_out=10dBm</td>
<td>Freq range=1-3GHz</td>
</tr>
<tr>
<td>IF Amp</td>
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<td>2</td>
<td>32 (O)</td>
<td>23 (O)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPF</td>
<td></td>
<td>-0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td>F3dB = 3.0GHz</td>
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</tr>
<tr>
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<td>0.2</td>
<td></td>
<td></td>
<td>F3dB = 1.8GHz</td>
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<td>LO2</td>
<td>Norden Millimeter VCO</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>P_out=10dBm</td>
<td>Freq range=1-3GHz</td>
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<td>7</td>
<td>16(I)</td>
<td>7</td>
<td>30</td>
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<td>RCF</td>
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<td></td>
<td></td>
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<td>MAX108</td>
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<td>N/A</td>
<td>N/A</td>
<td>Sample rate=1.5Gbps</td>
<td>Resolution=8bits</td>
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5.3 System parameters

We use SyScalc software to calculate the system gain, noise figure, as well as IP3. Figure 10 shows the SyScalc environment for the single antenna transmitter system. Note that although we use a 4X4 transmit antenna structure, the system parameters like Gain, Noise Figure and OIP3 will be same as the single antenna transmitter if the total transmit power is scaled by a factor of 3 (refer to Section 4). From simulation results it has been found that the designed transmitter has a gain of 32.47 dB, noise figure of 18.81 dB and an OIP3 of 35.37. The noise figure is on higher side due to the selection of components. Note that Gain and OIP3 play a more important role that the NF at the transmitter side.
Figure 11 shows the Syscalc implementation of the single antenna receiver architecture. As shown in Figure, the total noise figure for receiver is 5.75 dB, and the OIP3 is 3.86 dBm (or IIP3 -17.79 dBm). This IIP3 is enough for our transmitter, since we have shown in Section 3 that the maximum possible receiving power level is -24 dBm.

![Diagram of single antenna receiver architecture](image)

**Figure 8:** Single antenna receiver architecture.

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**6. Simulation Results**

We have simulated the transmitted spectrum at the transmitter side, the demodulated constellation at the receiver side using ADS, as well as the BER performance using MATLAB.

In our transmitter simulation, OQPSK modulation was used to simulate the power spectral density (PSD). The plots in Fig7 show the PSD of the signal at

- Data input
- Raised cosine filtering
- Up conversion to IF frequency
- IF Amplification
- Up conversion to RF frequency
- Amplified and filtered output fed to the antenna

Table 2: The components parameters for receiver

<table>
<thead>
<tr>
<th>Model</th>
<th>Gain (dB)</th>
<th>NF (dB)</th>
<th>IIP3/OIP3 (dBm)</th>
<th>P1dB (dBm)</th>
<th>Image Rejection Gain or Isolation (dB)</th>
<th>Others</th>
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<tr>
<td>TDD Switch</td>
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<td>1.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>40</td>
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<tr>
<td>LNA</td>
<td>ALH382-0</td>
<td>21</td>
<td>3.8</td>
<td>23 (I)</td>
<td>13 (I)</td>
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<td>Band Select Filter</td>
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<td>0.15</td>
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<td>-</td>
<td>Fc = 3GHz, bandwidth = 3GHz</td>
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<td>MDB207 Image rejection Mixer</td>
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<td>7</td>
<td>16 (I)</td>
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<td>IF Amp</td>
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<td>16</td>
<td>2</td>
<td>32 (O)</td>
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<tr>
<td>LPF</td>
<td>TTE Chebyshev LP</td>
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<td>F3dB = 3.0GHz</td>
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<td>TTE Chebyshev HP</td>
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<td>LO2</td>
<td>MAMIM 2.4GHz Monolithic VCO</td>
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<td>Mixer2</td>
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<td>11.7</td>
<td>3.2 (I)</td>
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<td>ADC</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Sampling rate 2Gsps</td>
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</table>
The eye diagram of the transmitted signal is also shown in Fig.12. Note that the eye diagram for the I and Q channels are the same.

In our receiver simulation, we using an OQPSK modulator module to generate signals, with power levels specified to be those at the edge of our coverage range (-71.01 dBm) and close to the BS (-84.00 dBm). Figure 13 shows the constellation, trajectory plot, as well as spectrum of the demodulated I/Q signals. Figures 13 (a), (b) and (c) are for the case when MS is on the edge of the coverage range with receiving power -70.01. Figures 13 (d), (e) and (f) are when MS is very close to BS, with receiving power level -80 dBm. Clearly, on the edge, the constellation is neat with four states, and the demodulated I/Q signals have identical spectrum.
The BER performance is simulated using MATLAB. We simulate the BER vs. SNR curve for one-by-one, two-by-two and four-by-four transmit antennas with Addictive White Gaussian Noise (AWGN) channels, as shown in Figure 14. AWGN channels do not provide diversity, but both linear OSTBC schemes still have larger coding gain than one transmit antenna scheme. In our simulation we find for one antenna scheme to achieve a BER of $10^{-6}$ requires about 8.6 dB SNR. But for two transmit antennas scheme, to achieve a BER of $10^{-6}$ requires about 7.2 dB SNR and for 4 transmit antennas scheme only about 6 dB is enough. Comparing to single transmit antenna, 2 transmit antennas scheme provides 1.4 dB coding gain without any extra bandwidth cost. Four antennas scheme yields 1.2 dB coding gain comparing to two transmit antennas schemes with extra 1/3 bandwidth cost.

Although this project only requires AWGN channel, in real case, fading channels are more common. In this case, multiple transmit antennas schemes outperform single transmit antenna scheme much more because linear OSTBC achieves full transmit diversity gain when fading channels provide diversity.

Since we are using 4X4 transceiver architecture with OSTBC coding, MATLAB was used as the platform for BER performance simulation. The system parameters derived through simulation from ADS and Syscalc were used in the simulation. In fact, a comparison of various MIMO systems was done so as to evaluate the performance gains achieved through employing multiple antennas at the transmitter and receiver. The simulation was done both for AWGN channel model and also Raleigh fading channel.
7. Multi-user communications

Until now, we have considered only the design of Wireless transceiver design in a single user environment. In this section, we discuss issues related to the design of the transceiver in a multi-user environment. OFDMA is a very popular choice for multi-user communications due to several reasons. It is robust against multi-path interference, tolerant to delay spread, bandwidth-efficient and eliminates the need for equalization at the receiver end. It has already been incorporated in 802.11g standard, in which the available bandwidth is divided amongst 52 orthogonal carries out of which 4 are used as pilot carriers. Users are supported on the 48 orthogonal channels. Each of these channels can employ a variety of modulation/coding schemes.
depending on the channel conditions of that particular user. We envision a similar multi-user communication scenario for our 1Gbps wireless LAN system. Below is a block diagram of a transceiver supporting multi-user communications based on MIMO-OFDMA. Note that the block-diagram is a simplified model of more complex practical system.

![Block diagram of a transceiver supporting multi-user communications based on MIMO-OFDMA.](image)

**Figure 14:** BER performance in AWGN channel.

### 8. Conclusions

In this project we have designed and evaluated the performance of a 1 Gbps transceiver in the 60-GHz unlicensed band. A 4X4 antenna system was used to boost the BER performance and also the coverage range of the access point. OQPSK modulation was used to reduce the system non-linearities. Through simulations and analysis it has been shown that a data rate of 1 Gbps can be sustained with a BER of 1e-6 with a coverage range of about 275m. Our entire transceiver architecture was built from commercially available components. Although system level integration might be a tough challenge presently, we believe that advances in IC design would make this 1 Gbps transceiver a possibility.

### References