Basic simulation studies on 60 GHz wireless technology employing QAM modulation

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Abstract. The 60 GHz technology engage between 57 GHz to 66 GHz occupying an unlicensed band consisting of four channels with 2 GHz bandwidth each. The wavelength of such technology approximates 5 mm enabling milli-meter wave communication. It benefits transmission security for crucial data. Indoor networking equipment with large bandwidth and high-capacity streams lag free High-Definition video from tablet to television. This paper intends to present the simulation studies on 60 GHz mm-wave band technology employing QAM modulation for wireless applications. The experimental results were obtained by simulating the designed architecture in Agilent ADS software tool and further presented to deduce the insight of future Wi-Fi for wireless applications.

Keywords: 60 GHz wireless technology, Transmitter front-end, Quadrature Amplitude Modulation, Power Spectrum, Error Vector Magnitude.

1. Introduction

The 60 GHz technology relies on set of wireless network protocols referred as 60 GHz Wi-Fi. It could also be referred as WiGig (Wireless Gigabit System). The wireless networking standard designated at operating frequency declared as IEEE 802.11ad. Low power and enormous performance devices could be modelled at gigabits per second rates. WiGig offers Phased array beamforming at transmitter antenna elements providing better communication at shorter distance of 10 meters. WiGig devices operate at data transmission rate of 7Gbps. Milli-meter-wave radio equipment for personal communications [6] are built with reduced size and weight, small-sized antennas and low radiated power. Reduced-interference micro-cellular mobile and personal communications services become possible because of 60 GHz oxygen absorption. 60 GHz technology were used in major communication systems such as Low probability intercept communication, inter-satellite communication, urban links and Personal communication networks.

64-QAM achieves better Error Vector Magnitude with high data rate and low power consumption [8]. Space diversity with very small antenna spacing combat multipath fading at 60 GHz [5]. Scattering and diffraction were the main propagation phenomenon giving rise to multipath in rural area. By picking the best combinations of Transmitter and Receiver pointing angles at any location, path loss and RMS delay spread can be reduced substantially in outdoor scenario [9].

60 GHz future home networks can be realized in either cell-based approach or ad-hoc based approach. Seamless connectivity [7] can be achieved if the antennas were connected to the existing optical fiber infrastructure (Radio over Fiber). 60GHz technology are resistant to Electromagnetic interference (EMI) in medical environment. so, image transfer technology in future medical imaging devices is made
possible by 60 GHz technology. Multi-gigabit network based on 60 GHz combining with future mm Wave 5G wireless mobile technology allow real-time high-speed transfer of the MRI scans which are of high quality to local and remote locations. DICOM (digital imaging and communications in medicine) [11] standard manage the transfer of those scans.

This paper enumerates the simulation studies on 60 GHz mm-wave band transmitter front end along with QAM modulation. The QAM modulation is designed in Digital signal processing network while the transmitter is simulated in Analog/RF network. The co-simulation of Digital signal processing network and Analog/RF network is performed for employing it appropriate towards wireless applications.

Figure 1. Generating 60 GHz using simulated transmitter architecture

2. Simulation study of 60 GHz Transmitter performance in Analog/Radio Frequency Network

The basic working of transmitter operating at 60GHz as shown in Fig. 1 is described as follows. The message signal is passed through Intermediate Frequency (IF) filter. The Butterworth band pass filter provides maximally flat frequency response over the desired band of frequencies. The IF Amplifier accepts the intermediate frequency signal, amplify it and pass it to Radio Frequency (RF) Mixer. Mixer performs frequency translation. Mixer could be referred as up converter as output frequency is higher than input frequency.

The Local Oscillator is multiplied with the intermediate frequency signal producing sum and difference frequencies. $f_1=57.6 \text{ GHz}$, $f_2=2.4 \text{ GHz}$, therefore $f_1+f_2=60 \text{ GHz}$ and $f_1-f_2 = 55.2 \text{ GHz}$. The difference frequency is outside the operating frequency range. The sum signal is the required RF signal. The lower power RF signal is converted to high power signal by using RF power amplifiers. It drives the antenna at transmitter.

The Chebyshev bandpass filter offers simplicity and better selectivity. The RF filter passes only the signal at sum frequencies. The 60 GHz signal is transmitted through free space via transmitting antenna. The frequency domain or harmonic balance analysis is done to plot the spectral components of voltage or current in non-linear circuit. The power of -50 dBm is applied at the input of the designed transmitter operating at 2.4 GHz. It is inferred from Fig. 3 about -12.781 dBm of output power is obtained at designed frequency of 60 GHz.
Figure 2. Spectral components of designed transmitter at Intermediate Frequency (2.4 GHz).

Figure 3. Spectral components of designed transmitter at Radio Frequency (60 GHz).

3. **Study on Constellation properties of QAM Modulation**

Figure 4. Generating In-phase and Quadrature components of a signal by performing Quadrature Amplitude Modulation
Fig. 4 depicts the working of QAM modulator. The 4-bit shift register brings out two groups of In-phase and Quadrature bits. The Digital to Analog converter converts into four levels. The In-phase and Quadrature signals are each applied to a mixer along with a local oscillator (LO) signal. LO signal is applied directly to one mixer, but it is shifted by 90 degrees and applied to the other mixer. The two mixer outputs are AM signals but at different phases. They are added together to generate 16-QAM (Quadrature Amplitude Modulated) Signal. 4 bits per symbol or time interval are transmitted. Data rate quadruples in the same bandwidth.

![Constellation property of QAM modulation](image)

**Figure 5.** Constellation property of QAM modulation

The constellation points as shown in Fig. 5 are ordered in a square grid with comparable horizontal and vertical spacing. More bits per symbol can be transmitted by choosing higher order of constellation. If the mean constellation energy is constant, then the points in higher order constellation are close together resulting in more noise and higher bit error rate. The signal energy needs to be increased to reduce the bit error rate for higher order modulation. Dense constellations achieve better spectral efficiency. Higher order QAM achieves high data rate but results in reduced separation between constellation points i.e., reduced noise resistant.

![Input bits fed to the designed modulator](image)

**Figure 6.** Input bits fed to the designed modulator
4. Co-simulation of designed modulator in Digital Signal Processing network and designed transmitter in Analog/RF network

Agilent ADS Ptolemy is a platform for performing signal processing simulations. Circuits simulated in schematic window can be instantiated as a subnetwork and are included in a signal processing schematic leading to Co-simulation. The circuit blocks can then be simulated along with signal processing components as shown in Fig. 9.

Pseudo Random bit source generates bits randomly. In mapper, the modulation type is chosen as QPSK. It maps the generated bits to symbols in QPSK format. The complex to Rectangular converter separates In-phase and Quadrature components. The constellation can be interactively plotted in dot or connected format. Raised cosine filters are used for spectrum shaping or band limiting. Up sample the bandlimited In-phase and Quadrature channels by a factor of 8. The In-phase and Quadrature signals are connected to QAM modulator with 50 Ω resistor in parallel.
**Figure 9.** Co-simulation of the designed transmitter with QAM modulation in Agilent ADS Ptolemy

**Table 1.** Specifications of simulation study on the designed transmitter

| Parameter          | Value                                      |
|--------------------|--------------------------------------------|
| IF Frequency       | 2.4 GHz                                    |
| RF Frequency       | 57.5 GHz                                   |
| Modulation         | QAM-16, QAM-32, QAM-64, QAM-128, QAM-256  |
| Data rate          | 1Gbit/sec                                  |
| Antenna            | Isotropic                                  |

The input power of -36.444 dBm is applied to the input of designed transmitter with QAM modulation operating at 2.4 GHz. The output power of -10.542 dBm at 60 GHz is obtained for 2-QAM modulated transmitter and -7.985 dBm at 60 GHz for 16-QAM modulated transmitter. It could be observed from Fig. 10, 11 and 12.

**Figure 10.** Power Spectrum of the input signal
Figure 11. Power Spectrum of 2-QAM Modulated Signal

Figure 12. Power Spectrum of 16-QAM modulated signal

5. Error Vector Magnitude (EVM) measurement

Error Vector Magnitude is a measure of modulation accuracy and error performance in complex transmitter system. The location of the actual signal on the I-Q diagram may be drifted from the ideal position. Error vector is the difference between the desired (ideal) signal vector and the actual signal vector as depicted in Fig. 13. The error vector magnitude is the length of the vector which connects the I/Q reference-signal vector to the I/Q measured-signal vector.

\[
%EVM = \frac{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1} I_{\text{err}}^2[n] + Q_{\text{err}}^2[n]}}{EVM \textit{ Normalization Reference}} \times 100\%
\]

Where \( n \) is the symbol index, \( N \) is the number of symbols, \( I_{\text{err}} = I_{\text{reference}} - I_{\text{measured}} \) and \( Q_{\text{err}} = Q_{\text{reference}} - Q_{\text{measured}} \).
Higher order QAM results in reduced separation between constellation points. Hence as the order of QAM increases, the constellation points become closer. There is only small drift in the location of actual signal from its ideal position. From Table II, it is observed that as order of QAM increases, the percentage difference between the actual and ideal positions are reduced. The EVM of 26.2% for 16-QAM, 12.9% for 32-QAM, 13.0% for 64-QAM, 6.7% for 128-QAM, and 4.8% for 256-QAM are measured.

The unlicensed band of 60GHz can support data rate of 1Gbps in a millimeter range.

6. Conclusion

Hence basic simulations on designing 60 GHz transmitter front end with QAM modulation is performed using Agilent ADS software tool. The QAM modulation is designed in Digital signal processing network while the transmitter is simulated in Analog/RF network. The Co-simulation of Digital signal processing network and Analog/RF network are done using Agilent ADS Ptolemy tool. The performance measure such as modulation power, constellation, transmitted spectrum and error vector magnitude are studied and analysed.

Hence the unlicensed 60 GHz ISM transmitter can be deployed in medical centres or homes to initiate fast connectivity at low cost. The 60 GHz radios can support multi-gigabit per second data communication. Video data transmission from one point to another can be done wirelessly. Antennas and transceiver circuits can be further built with high level of miniaturization leading to low interference effect on other wireless systems in the same environment thus securing sensitive information.
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