Implementation and simulation of 16 Regular Triangle QAM (16-RTQAM) using GNU-RADIO*

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Abstract*–, Research in the emerging space industry is becoming attractive. One compelling area of current space research is the design of miniaturized satellites, known as CubeSats. Miniaturized satellites are enticing because of their numerous applications and low design-and-deployment cost. One of its challenges are the limited power resources. In this paper regular triangular quadrature amplitude modulatin (TQAM) is considered for this purpose for enhancing power resources with enhancing bit error performance. TQAM and SQAM are examined and simulated using GNUradio. The performance of 16 TQAM over satellite channel is compared with that of 16 QAM using GNUradio. Satellite links are currently being developed to provide higher data rates and improved power efficiency, i.e. lower average transmit power for a given error rate. Higher data rate is employed using higher order modulation scheme with good channels. A triangular lattice provides the most compact QAM constellations, i.e. constellation points closest to the origin .

***Keywords*-- Triangular constellation, QAM, bit error rate, AWGN channel, GNU Radio.**

I. INTRODUCTION

Satellite links are currently being developed to provide higher data rates and improved power efficiency, i.e. lower average transmit power for a given error rate. Higher data rate is employed using higher order modulation scheme with good channels. Quadrature amplitude modulation is widely used for this purpose.

At the receiver, maximum likelihood detection is achieved by choosing the constellation point closest to the received signal which depends on the Euclidean distances between these points. However, it can be a complex process especially for high modulation order **M**. A practical solution is to divide the constellation into vertical regions then find the closest point in this region to the received signal. There is a trade-off between the detection complexity and power efficiency in constructing a signal constellation [1]. The regular structure of SQAM results in a low detection complexity, which is one of the reasons it is widely used in communication systems. However, it is not optimum in terms of BER or power efficiency [2]. The optimum signal constellations in terms of BER performance were obtained by Foschini et al. [3], but the detection complexity for these can be high. They determined that the optimum constellation envelope for large M is circular. Further, it was shown that for large M, choosing constellation points from a triangular lattice is close to optimum.

A triangular lattice provides the most compact QAM constellations, i.e. constellation points closest to the origin [4]. For a given minimum Euclidean distance between signal points, the more compact the constellation the better the power efficiency, so a triangular lattice provides the best power efficiency. Regular TQAM (R-TQAM) was introduced which has a lower detection complexity than the optimum constellations in [3]. Irregular TQAM (I-TQAM) was introduced in [1], and shown to have an envelope which is close to optimum for large M. The ML detection of R-TQAM is more complex than SQAM [4], but simpler than I-TQAM. In this paper.The symbol mapping is a key factor in the error rate with QAM. The best possible mapping is a Grey code [5] which is used with SQAM. However, this mapping is not possible with TQAM, so a quasi-Grey mapping was employed for R-TQAM in [6].

The contributions of this paper are as follows. Clarify the concept of both SQAM and TQAM. Implementation of 16-RTQAM and 16-SQAM modulation and demodulation using GNURADIO. Comparing the performance of each modulation.

The remainder of this paper is organized as follows. First SQAM then TQAM are introduced. Second the implementation of 16-R-TQAM using GNUradio is discussed.

II. SQUARE QAM

A. Constellation Diagrams for SQAM

M-ary SQAM (where M is the signal level) have its signal constellation points ordered in square lattice. Different formats of SQAM constellation diagram is shown in Fig.1.

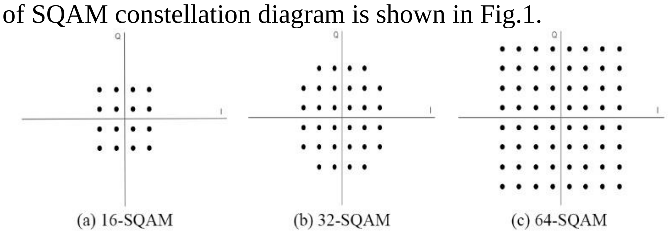

Fig. 1 Constellation Diagram (a)16-QAM (b)32-QAM (c)64-QAM.

As seen as modulation order increases, the distance between the points decreases so small amount of noise can corrupt the data. As the noise level increases the area covered by a point on the constellation increases. If it becomes too

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large the receiver would be unable to determine the correct position of the constellation, and this results in errors. Also as the modulation order increases the amplitude variation increases as well, so the level of efficiency falls.
For some systems the order of the modulation format is fixed, but in others where there is a two-way link, it is possible to adapt the order of the modulation to obtain the best throughput for the given link conditions. The level of error correction used is also altered. In this way, changing the modulation order, and the error correction, the data speed can be optimised whilst maintaining the required error rate.

B. SQAM noise margin

Higher modulation order achieves higher data rates and higher spectral efficiency but at the expense of less resilient to noise and interference. As signal to noise ratios (SNR) decreases errors will increase along with re-sends of the data, thereby slowing throughput. By reverting to a lower order modulation scheme the link can be made more reliable with fewer data errors and re-sends.

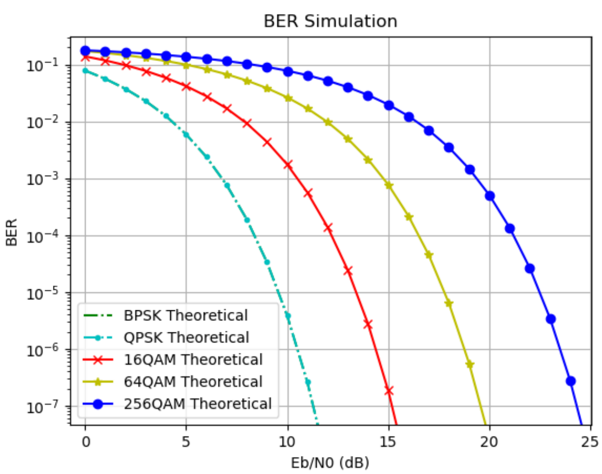

Fig. 2. BER performance of different modulation techniques.

Selecting the right order of QAM modulation for any given situation, and having the ability to dynamically adapt it can enable the optimum throughput to be obtained for the link conditions for that moment. Reducing the order of the QAM modulation enables lower bit error rates to be achieved and this reduces the amount of error correction required. In this way the throughput can be maximised for the prevailing link quality.
As data rates have risen and the demands on spectrum efficiency have increased, so too has the complexity of the link adaptation technology. Data channels are carried on the cellular radio signal to enable fast adaptation of the link to meet the prevailing link quality and ensure the optimum data throughput, balancing transmitter power, QAM order, and forward error correction, etc.

III. TRIANGLE QAM

For a given minimum Euclidean distance between signal points, the more compact the constellation the better the power efficiency, it can provide advantages up to 0.46 dB in case of 16-ary signal set while keeping low complexity for detection.

A. Constellation Diagrams for TQAM

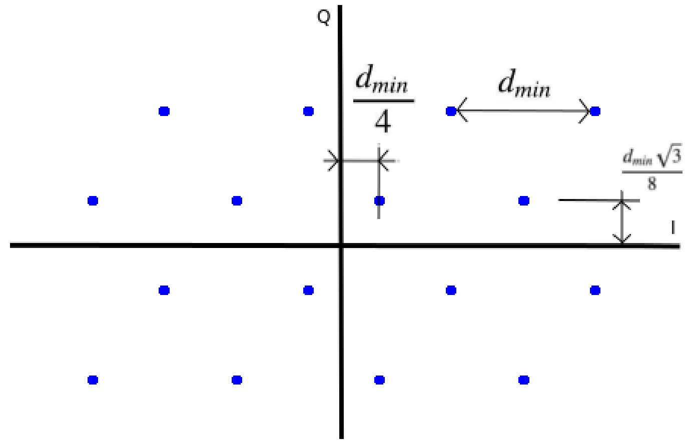

Fig. 3. Constellation Diagram of 16-RTQAM.

We consider 16-ary signal set depicted in Fig. 2 (a). Assume circle radius d, the average energy per symbol E_{s16} for the 16-SQAM and E_{t16} for the 16-TQAM can be calculated as follows

$$E_{s16} = 10d^2, \quad (1)$$

$$E_{t16} = 9d^2. \quad (2)$$

From (1) and (2) we can find the power gain PG_{16} of the 16-TQAM against the 16-SQAM becomes

$$PG_{16} = 10log_{10}\left(\frac{E_{s16}}{E_{t16}}\right) = 0.46dB \quad (3)$$

B. Detection method

An ideal detection method is maximum likelihood (ML) detection in which distance between each constellation point and received symbol is calculated and the closest constellation point regarded as the estimate of the transmitted symbol. This approach is optimum in performance but not a good choice for implementation.

A more practical solution is to divide the constellation into regions.

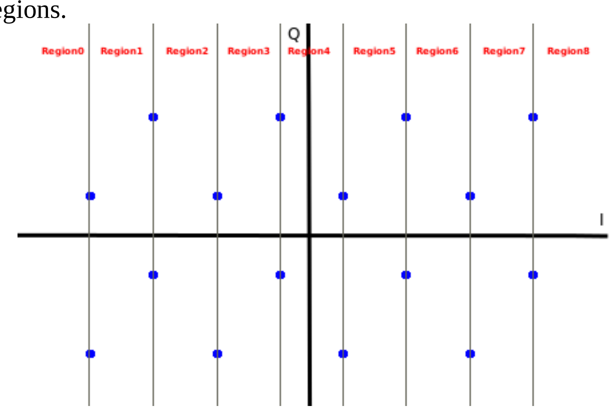

Fig. 4. Constellation Diagram Detection Reigons.

The received demodulated symbol $Z = x + jy$ where $j = \sqrt{-1}$, x and y are arbitrary real constants. Region selection is done by considering the value of x. In order that the demodulated symbol Z is to be detected as one of the costellation points in that reigon. The final decision is based on the imaginarry value y and the calculated boundary values.

C. Bit stream Mapping

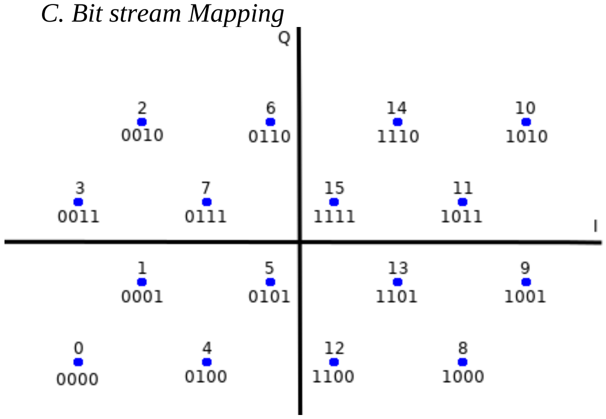

Fig. 5. Constellation Diagram bit mapping.

To minimize the number of bit errors Gray code is used in which only one bit differs between adjacent signal points. It has been used for the bit mapping method of the SQAM. But because in TQAM constellation there are six adjacent neighbors around every signal point, not four as in the SQAM perfect Gray coding is not possible. Quasi Gray code is used for bit mapping as in Fig.

The Gray coding penalty, the average number of bits which differs between adjacent symbols, can be calculated as follows

$$G_{t16} = 1.2375$$
$$G_{s16} = 1$$

where G_{t16} and G_{s16} denote the Gray coding penalties of the 16-TQAM and the 16-SQAM. As the Gray code penalty of 16-TQAM is larger than 1 that will cause degradation in bit error rate (BER) performance.

*D.*BER Performance

The BER performance comparison between 16-SQAM and 16-RTQAM is shown in Fig. 6. The comparison consider that binary data is transmitted over additive white gaussian noise (AWGN) channel for both modulation techniques.

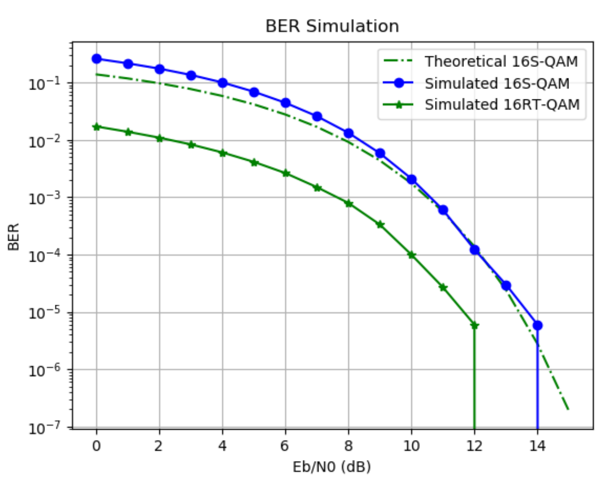

Fig. 6. BER performance of 16-SQAM and 16-RTQAM.

It is shown from the figure that the BER performance of the RTQAM is way better than SQAM with the same signal power.

For our field of interest the RTQAM has better power performance than SQAM at the same BER.

III. GNU-RADIO BLOCKS

GNU-RADIO blocks where developed using python programming language implementing 16-RTQAM modulator and demodulator as shown in Fig. 7 and Fig. 8.

The modulator block accepts a stream of bits which is mapped to the corresponding complex symbols according to quasi-gray mapping discussed above. It also normalizes symbol amplitude to enable power scaling at the transmitter side.

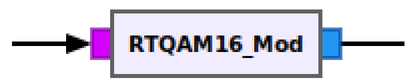

Fig. 7. 16-RTQAM modulator block.

The demodulator input is a complex symbol which is mapped to the corresponding bits according to the constellation region based detection technique discussed above.

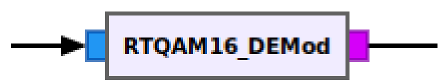

Fig. 8. 16-RTQAM demodulator block.

Both blocks are tested for functionality using GNU-RADIO and they function properly as programmed as shown in Fig. 9..

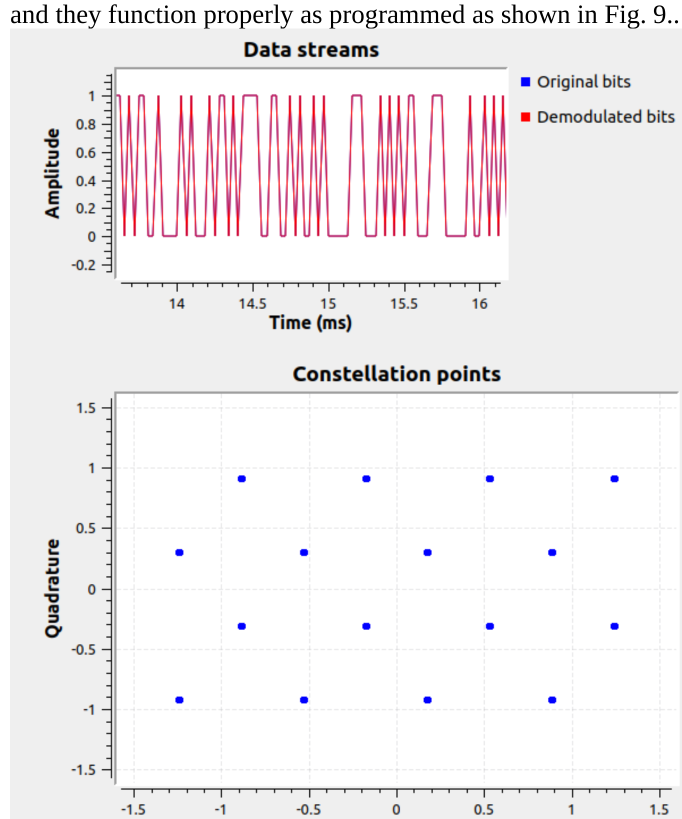

Fig. 9. Simulation results.

From Fig. 9. the simulation assumes random bit stream. we see that the original stream of bits at the input of the modulator is the same as the bit stream out of the demodulator as well as the constellation points at the correct position indicates the correct operation of the blocks.

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