Effective Normal Binary ordering in QAM compared with Gray Coded scheme for enhanced voice quality in Sofware Defined Radios

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***Abstract* - Quality means uniformity around a target value. The quality of transmitted voice is an important means of gauging performance of equipment and services related to voice communication. This paper shows how normal binary ordering in Quadrature Amplitude Modulation (QAM) can be used in an effective manner for voice transmission purposes in a soft radio to give better quality results. This would be compared to the M-ary Gray Coded Mapping Scheme which has proved so far a vital tool in error correction. These comparisons apply under some shortcomings like the use of same number of quantization levels i.e. M number of quantization levels for a signal being fed to an M-ary modulator, e.g. using 16 level quantization alongwith 16-QAM. The paper will review the comparison of the two coding schemes used in modulation techniques for voice signals. The relative and accuracy of the two techniques would also be discussed. It will be shown that for the above mentioned scenario (M quantization levels and M-ary QAM), the normal binary coded QAM performs better than Gray-coded QAM. This being done, a second scheme is proposed which performs much better than the previous.**

***Keywords*—SDR, QAM, Gray Code, Constellation Mapping**

I. INTRODUCTION

Quality of voice is a major concern in equipment and services relating to speech transmission. The term **quality** can be defined as “the degree to which a set of inherent characteristic fulfills requirements” or simply the “conformance to requirements” [1].

Wireless coverage doesn't mean a thing if people can't comprehend what's being said. Modulation schemes are being exploited greatly for this purpose in order to improve voice signal’s quality. Many voice enhancement systems on the market today adapt to the specific voice characteristics by adjusting the speech to appropriate listening levels, and readjusting dynamically throughout the signal transmission regardless of background noise. Perhaps service providers have focused on only one side of the voice quality equation.

Numerous sources of unwanted noise and distortion in voice signals has always put the researchers on the quest to find ways to curtail the noise levels in voice signals. The modulation block of a digital communication system presents a high target in this respect. Various techniques have been employed to use the coding schemes like the gray code [2] in the most effective way so as to withstand the noise effects and enhance the quality of voice signals in Soft Radios.

A **Software Defined Radio** (SDR) system is a radio communication system where the digitization is at (or very near to) the antenna and all of the processing required for the radio is performed by software residing in high-speed digital signal processing elements [3]. Thus an SDR provides flexible and interoperable communications [4].

The normal binary ordering is the general numeral system that represents numeric values using two symbols, i.e. 0 and 1 whereas the reflected binary code, also known as Gray code after Frank Gray, is a binary numeral system where two successive values differ in only one digit [5].

Modulation is the process of conveying the information over the medium. Digital modulation represents the transfer of the digital bit stream from the transmitter to the receiver(s) via the analogue informational channel (the medium). During the modulation process the informational signal modifies one or more carrier parameters like amplitude, frequency and phase. In QAM, the signal employs two quadrature carriers, cos $2\pi f_c t$ and sin $2\pi f_c t$, each of which is modulated by an independent sequence of information bits. The transmitted signal waveforms have the form [6]

$$u_m(t) = A_{mc}\, g_T(t)\, \cos 2\pi f_c t + A_{ms}\, g_T(t)\, \sin 2\pi f_c t$$

where A_{mc} and A_{ms} are the sets of amplitude levels that are obtained by mapping k-bit sequences into signal amplitude.

Reconfigurability is an important aspect in digital communication system i.e. to be able to test the various modulation coding schemes. When the radio is software based i.e. SDR, the task of changing the mapping schemes becomes very simple.

In section II the proposed idea of coding scheme for a better voice quality signal in software radios will be discussed and it will throw some light on the comparison of the proposed method with the currently used method on the basis of a self formulated error calculation scheme.

In section III another useful proposed variation of the coding scheme will be highlighted and finally the last part is devoted to conclusions.

II. Proposed Idea

First a voice signal for example a sine wave is passed through an AWGN channel with Gray-Coded 16-QAM signal constellation. The original sine and the recovered sine is shown in Fig.1.

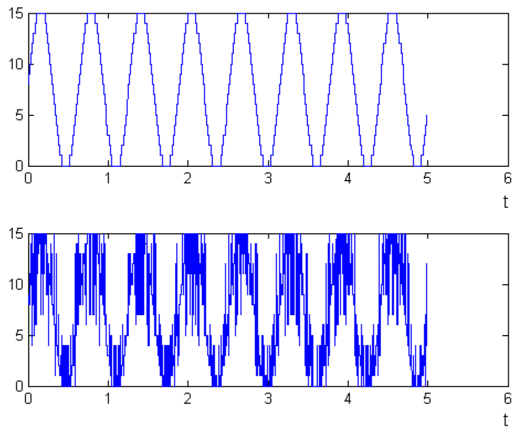

Fig. 1. Effect on a sinosoid when using Gray-Coded 16-QAM signal constellation

Then the same sine wave is passed through the same AWGN channel with Binary-Coded 16-QAM Signal Constellation. The resulting waveform is shown in Fig.2.

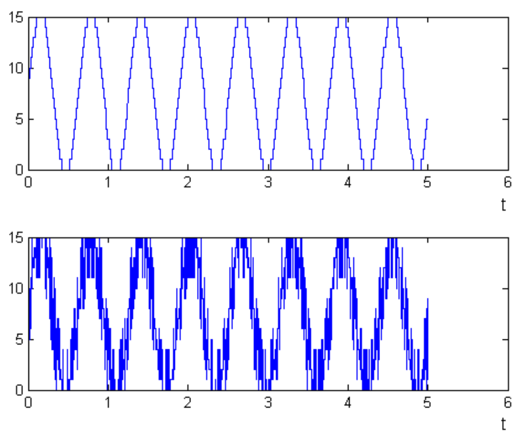

Fig. 2. Effect on a sinosoid when using Binary-Coded 16-QAM signal constellation

We can see that the voice quality achieved by normal binary mapping scheme is better than that by Gray Coded Scheme.

Keep in mind that this is only achieved when the number of quantization levels are equal to constellation points e.g. for 8 bit quantization i-e 256 levels, we must use 256-QAM. For simplicity, the example of 16-QAM is explained for 16 quantization levels i-e 4 bit quantization.

The voice signal after sampling is not converted to bits and then into symbols because the number of quantization levels is equal to the number of symbols possible for 16-QAM and thus a 16-QAM modulator can be realised as directly taking the integers (obtained after quantization) as input symbols ranging from 0-15. So, we will not go into the bit level. Sampled voice signal is treated as input to the modulator and integers are recovered at the output of the demulator. This is our recovered voice signal.

A. *Error Calculation*

As we are not dealing at bit level, we will not calculate Bit Error Rate (BER). Symbol Error Rate (SER) is also not useful as a symbol mapped at an incorrect location in one scheme will also be incorrectly mapped in the other scheme and SER will be the same. The criteria should be as such that it shows how much the level in each symbol is disturbed.

So, the criteria proposed to compare the received voice signals for both the schemes is expained below

1) Subtract the output voice signal from the original one. In case for the received sinosoids in Fig.1 and 2. the subtracted waveforms are shown in Fig.3 and 4.

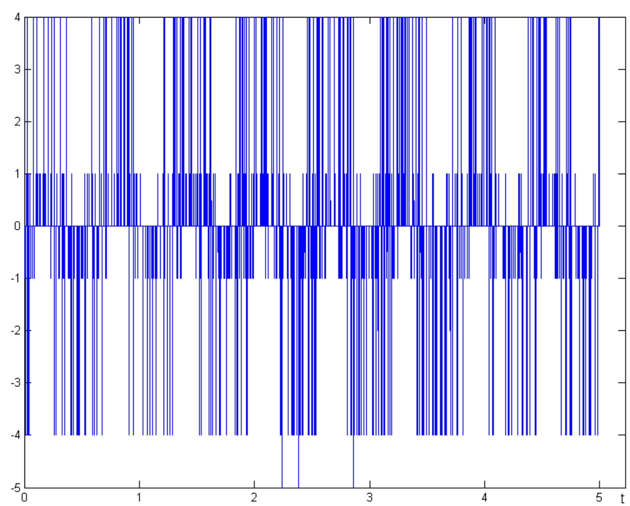

Fig. 3. The resulting wavefrom after subtracting received sinosoid from the original sinosoid when using Gray-Coded 16-QAM signal constellation

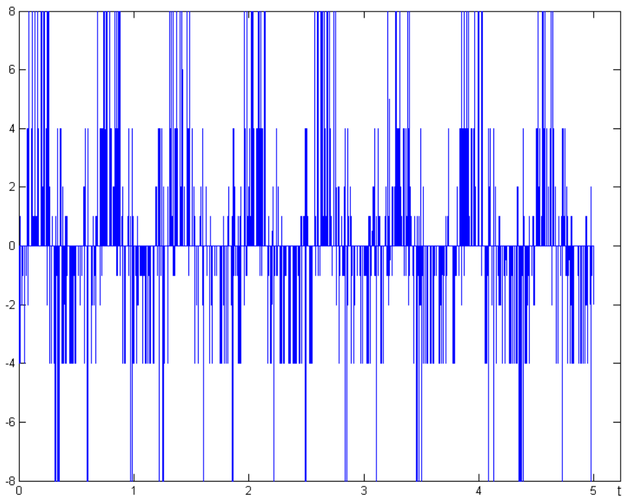

Fig. 4. The resulting waveform after subtracting received sinosoid from the original sinosoid when using Binary-Coded 16-QAM signal constellation

2) Then the absolute of every value in these waveforms is taken. The resulting waveforms are shown in Fig.5 and 6.

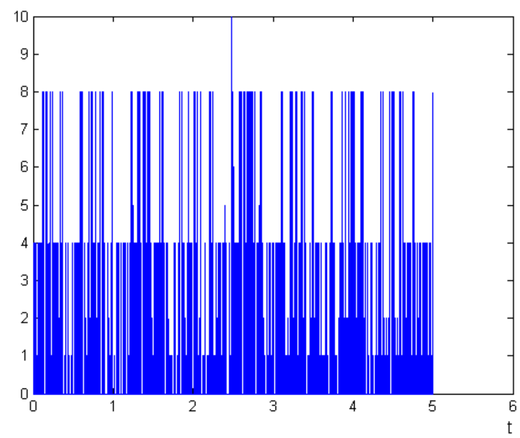

Fig. 5. Resulting plot after taking the absolute of every value in the waveform of Fig.3.

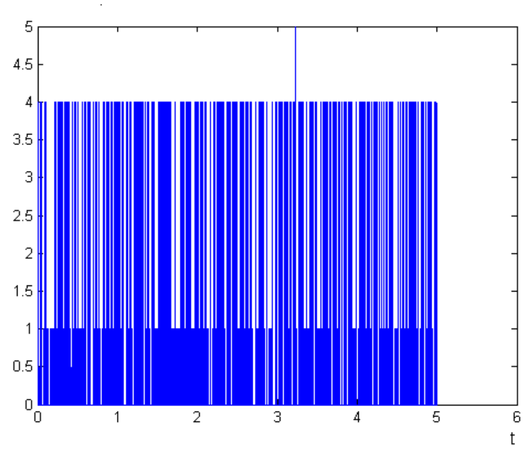

Fig. 6. Resulting plot after taking the absolute of every value in the waveform of Fig.4.

3) Then the values at each time index are summed up for the waveforms in Fig.5 and 6. We find that the resulting error values for this example are:

3002 for Gray-Coded 16-QAM Signal Constellation and 1865 for Binary-Coded 16-QAM Signal Constellation.

B. *Result*

The smaller this value, the better is the received voice quality. It is seen that Binary Ordering gives the smaller value as compared to Gray coded scheme. So, it is proven that Binary Ordering gives better voice quality.

What is the reason? Why we get better voice quality in case of binary ordering? If we look at the ordering in both schemes, we notice that in gray coded scheme only one bit is changed if a symbol is mapped incorrectly but how much the level of that symbol is disturbed? We have to use the ordering in which the level is not disturbed much. Let us take an example

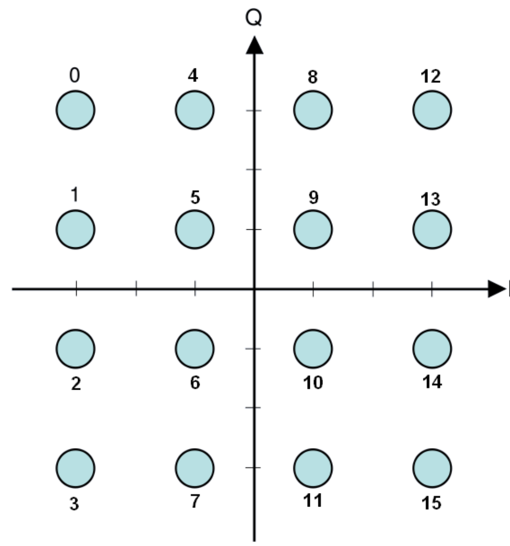

Fig. 7. Constellation diagram for a Binary-Coded 16-QAM

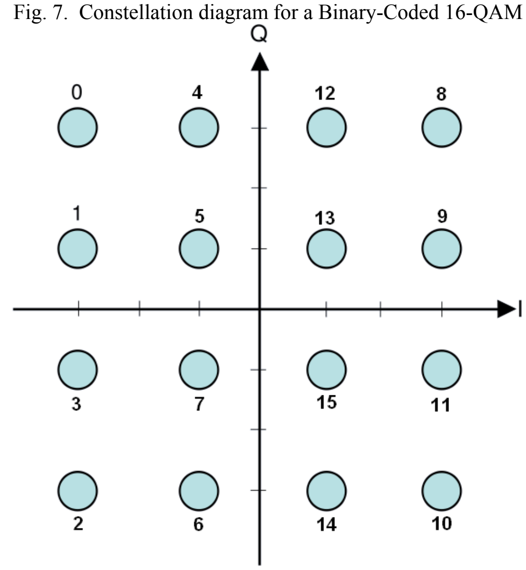

Fig. 8. Constellation diagram for a Gray-Coded 16-QAM

If 4 is mapped as 8 in Binary Scheme of Fig.7 (level raised by 4), the same 4 maps at 12 in the gray coded scheme of Fig.8 (level raised by 8). Similarly if we observe each symbol we notice that binary ordering is better in this aspect i.e. the level is not disturbed much.

III. Another Proposed Scheme

Our basic aim is to prevent a symbol to be mapped at a place where its level changes too much. This second proposed scheme is also for the same scenario when the number of quantization levels is equal to the number of constellation points in QAM. By carefully looking both mapping schemes in Fig.7 and 8, we notice that we don't want a symbol to be mapped incorrectly towards right or left but if it maps downward or upward the level doesn't change much.

So, if we increase the distances of constellation points horizontally and decrease vertically while keeping the overall power constant, we can greatly improve our results. The modified constellation diagram is shown in Fig.9.

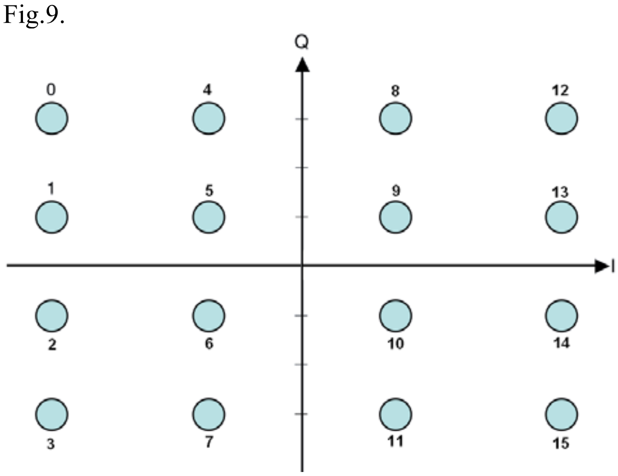

Fig.9. Constellation diagram for a Binary-Coded 16-QAM with increased horizontal spacing and decreased vertical spacing between constellation points.

The same sine wave is now passed through the same channel and the communication system with this second proposed scheme. The recovered wave is shown in Fig.10.

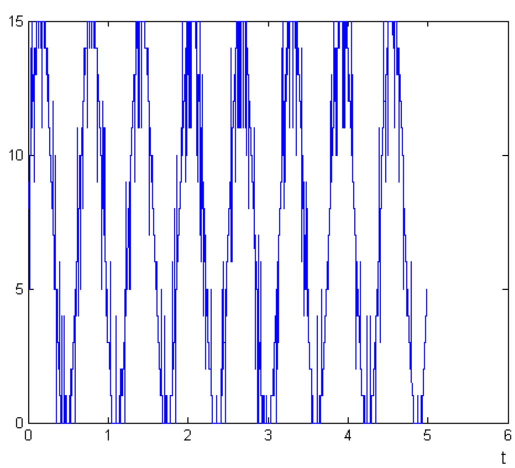

Fig. 10. Recovered wave after applying the second proposed scheme.

The subtracted waveform is shown in Fig.11.

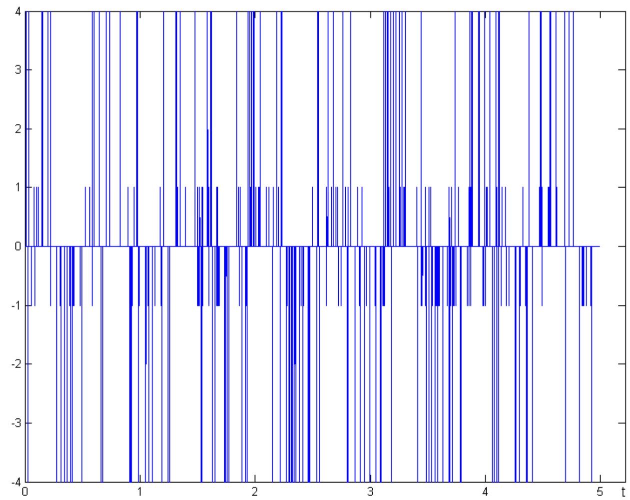

Fig. 11. The resulting waveform after subtracting the sinosoid of Fig.10 from the original sinosoid.

The resulting waveform after taking the absolute of every value in the waveform of Fig.11 is shown in Fig.12.

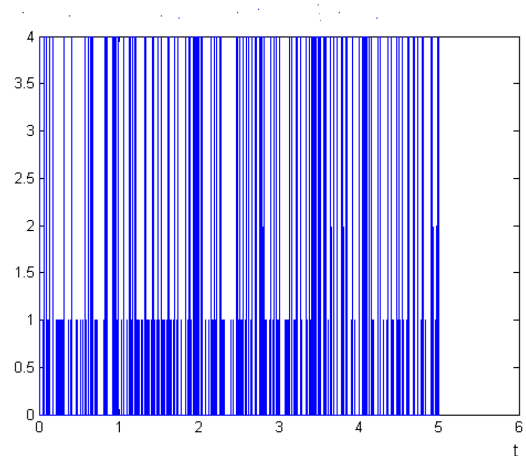

Fig. 12. Resulting plot after taking the absolute of every value in the waveform of Fig.11.

The summation of this waveform gives us the error value. We have noticed that this error value is reduced much more and we will get better voice quality with the same transmitted power. Fig.13 shows the comparison of error values for the 3 schemes.

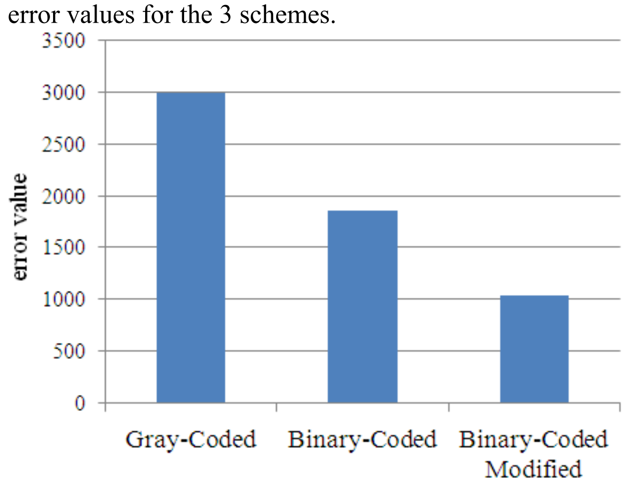

Fig. 13. The comparison of error values for the 3 schemes

IV. CONCLUSION

This paper presented a scenario for voice signals in which the number of quantization levels is equal to the number of constellation points in M-ary QAM. It was shown that in this specific scenario the quality of voice signals is much better when using the binary coded QAM instead of using the Gray coded arrangement. Moreover, it was shown for the same scenario that by increasing the spacing between the constellation points horizontally and decreasing the spacing vertically (such that the overall power remains the same) we get a much better received voice signal.

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