Journal of Asian Scientific Research
ISSN(e): 2223-1331
ISSN(p): 2226-5724
DOI: 10.18488/journal.2.2018.83.144.151
Vol. 8, No. 3, 144-151

URL: www.aessweb.com

A COSTAS LOOP VARIANT FOR LARGE NOISE

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Article History
Received: 26 March 2018
Revised: 7 May 2018
Accepted: 11 May 2018
Published: 15 May 2018

Keywords
Digital communications
Costas loop
Noise
Constellation diagram
Decision direction
Carrier recovery.

ABSTRACT

The Costas loop with decision direction can be used for 4QAM demodulation. In this paper we make the decision directed Costas loop more resistant against noise by application of the folding method, that is, carrier recovery after transforming the constellation diagram so that the constellation points coincide. Excellence of our Costas variant is that it can operate under heavy noise conditions.

1. INTRODUCTION

Costas loop is a sort of the well-known phase locked loops, intended primarily for SSB demodulation [1]. Costas loop has been modified for 4QAM demodulation (decision directed version, Best, et al. [2]. These versions solve both the carrier recovery and the signal extraction. For carrier recovery only, the simplest solution is the 4th power approach [3] but that is noise sensitive as we show it in Section 3.

In this paper a method called as folding method has been detailed for carrier recovery in Section 4. In Section 5 we demonstrate the superiority of the folding method over the 4th power method when the goal is better SER vs. SNR performance. In the analyses we use MATLAB/Simulink and the system analysis feature of AWR. Special feature of our new solution is capability for operation even in bad SNR condition. This is necessary in our further experiments [4].

A detailed literature can be found in Best, et al. [2].

2. 4QAM DEMODULATION WITH DECISION DIRECTED COSTAS LOOP

A decision directed Costas loop is shown in Fig. 1. Carrier recovery is shown left from the dashed line, and signal reconstruction part (decision direction) can be found right. Basis of the operation is that VCO driver signal is formulated using both I and Q arms (upper and lower), and the error signal is integrated in the middle arm. The problem with this version is that for high noise levels, the Costas loop does not find the carrier and thus the error is high as you can see in Fig. 2. As a conclusion, carrier recovery in noise should be improved.

The decision directed demodulator system is detailed in Fig. 1. The Figure shows the three parts of the system investigated: the 4QAM generator, the evaluation block and the Costas loop itself. The Costas loop consists of three branches: In the upper and the lower branch the channel signal is processed, while in the middle branch the error signal is formulated for the VCO. The upper and the lower branch has the same topology. The mixer is followed by four blocks that integrates the mixer output signal over a period, thus removing the remaining part of the carrier. Decision direction consists of a signum block and a multiplier. Then, in the middle branch, output of the lower branch is subtracted from that of the upper branch, and integration over a longer period comes that averages noise.

In Fig. 2, correlation coefficients between the transmitted and received I and Q signals are shown as a function of time. In ideal case, correlation is one, the deviation is a result of noise and the imperfect demodulation.

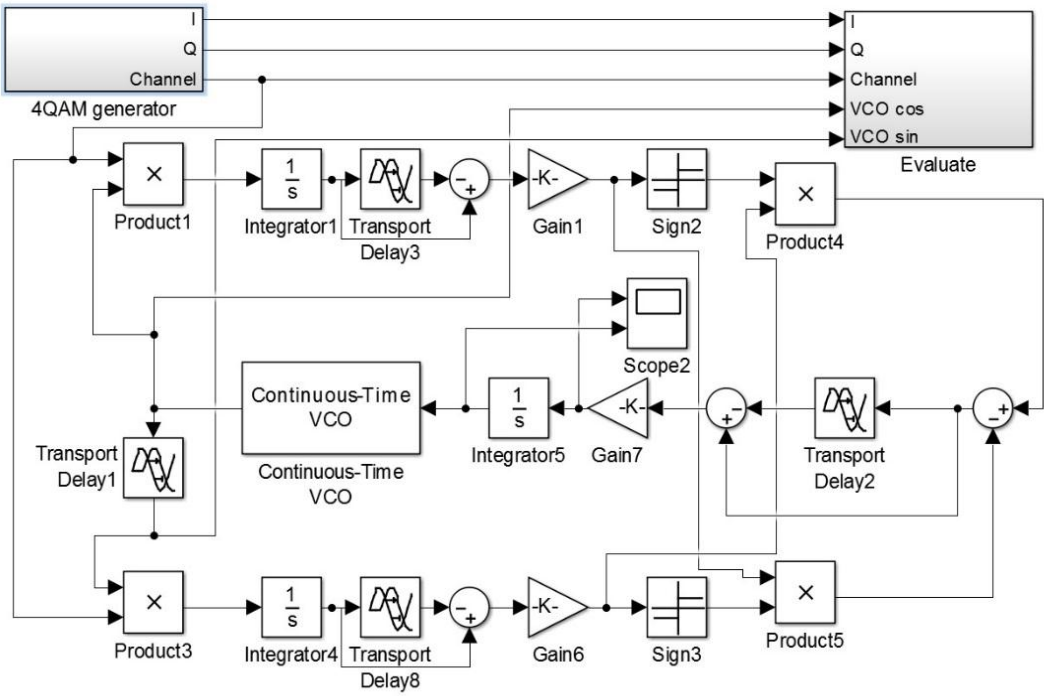

Fig-1. Decision directed demodulator system containing a Costas loop

Source: Original, from MATLAB/Simulink

In Fig. 2, the noisy signal has been obtained by the 4QAM generator block, and the output signals of the Costas loop have been evaluated by the Evaluate block. Details of the decision directed Costas loop are shown. The channel signal goes to two mixers followed by an averaging circuit. The averaging circuit consists of an integrator, delay and sum blocks, and a gain block. Decision direction has been realized by sign and multiply blocks. Then the branch signals are subtracted from each other and again an averaging circuit comes. Output of the averaging controls the VCO of the system. The VCO output drives the mixers, at the lower branch, delayed. The amount of delay is chosen to realize a 90 deg phase shift.

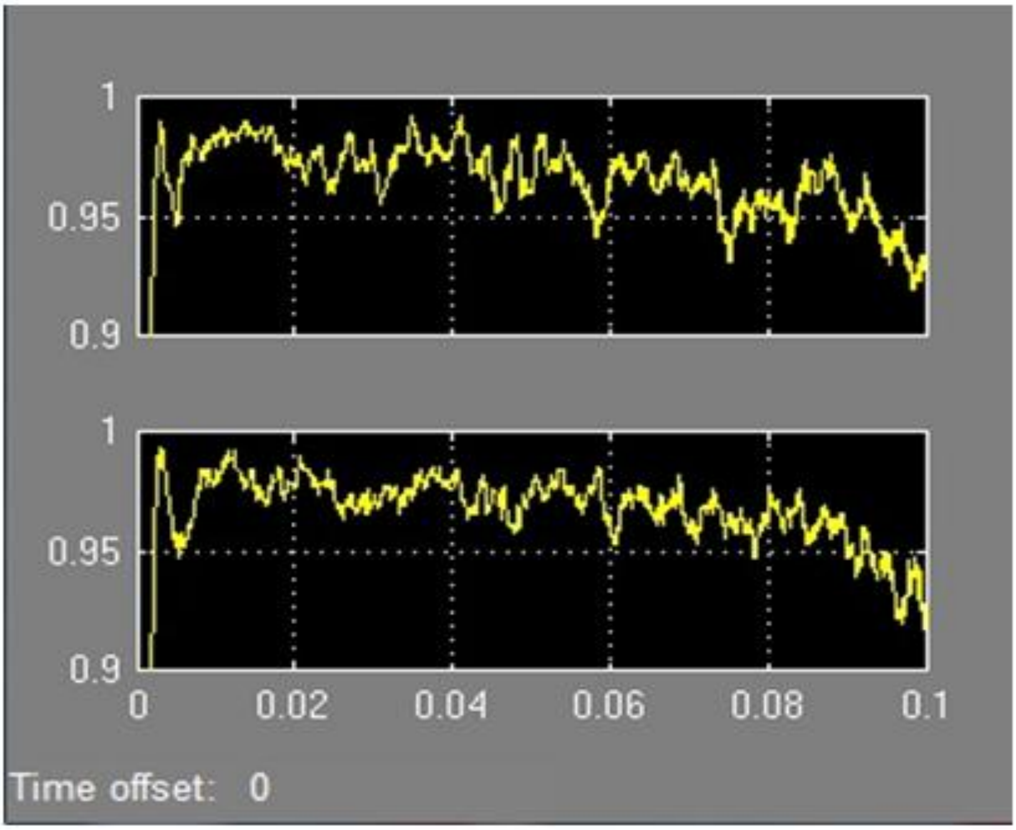

Fig-2. Correlation between the transmitted and received I and Q signals in large noise. Horizontal scale: Time in seconds. Vertical scale: Value of the correlation coefficient (dimensionless). Conditions: sin and cos amplitudes: 1, frequency: 5 MHz, sample time: 10 ns, noise power: 10 nW/Hz, in band limited white noise block in MATLAB/Simulink

Source: Original, from our Simulink simulation

3. CARRIER RECOVERY BY 4th POWER METHOD

The well known 4th power method serves for improved carrier recovery of 4QAM signals, Fig. 3.

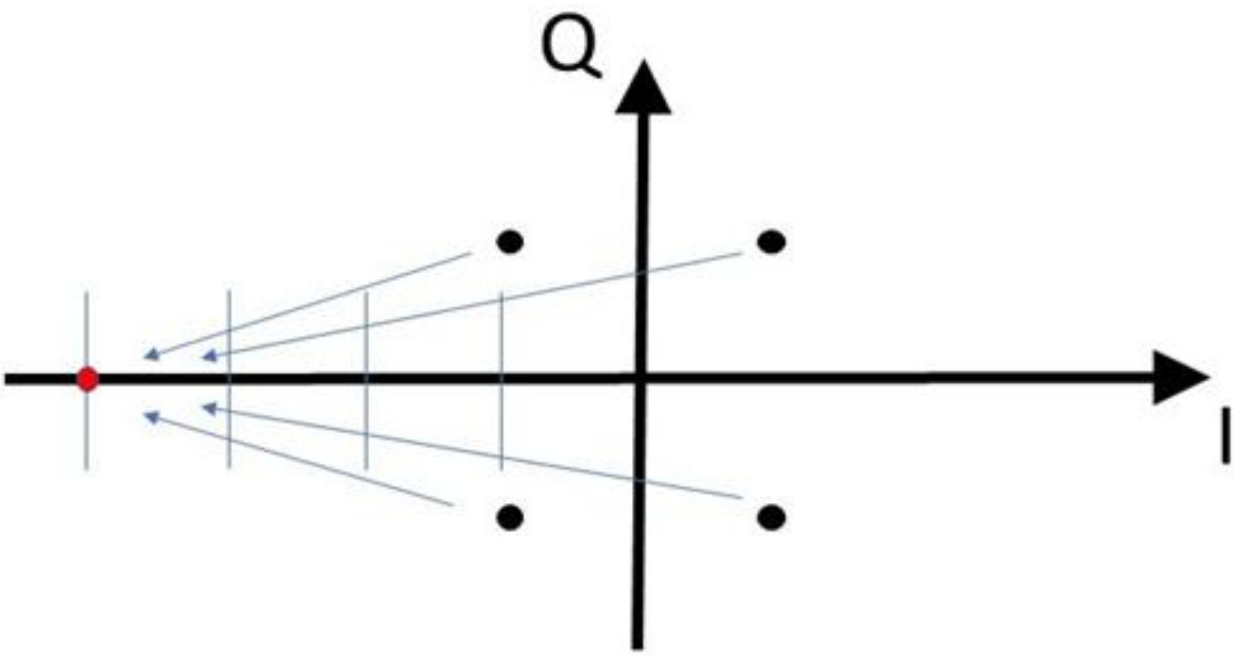

Fig-3. Basis of the 4th power method applied for 4QAM constellation. Effect of rising to the 4th power is denoted by arrows

Source: Original

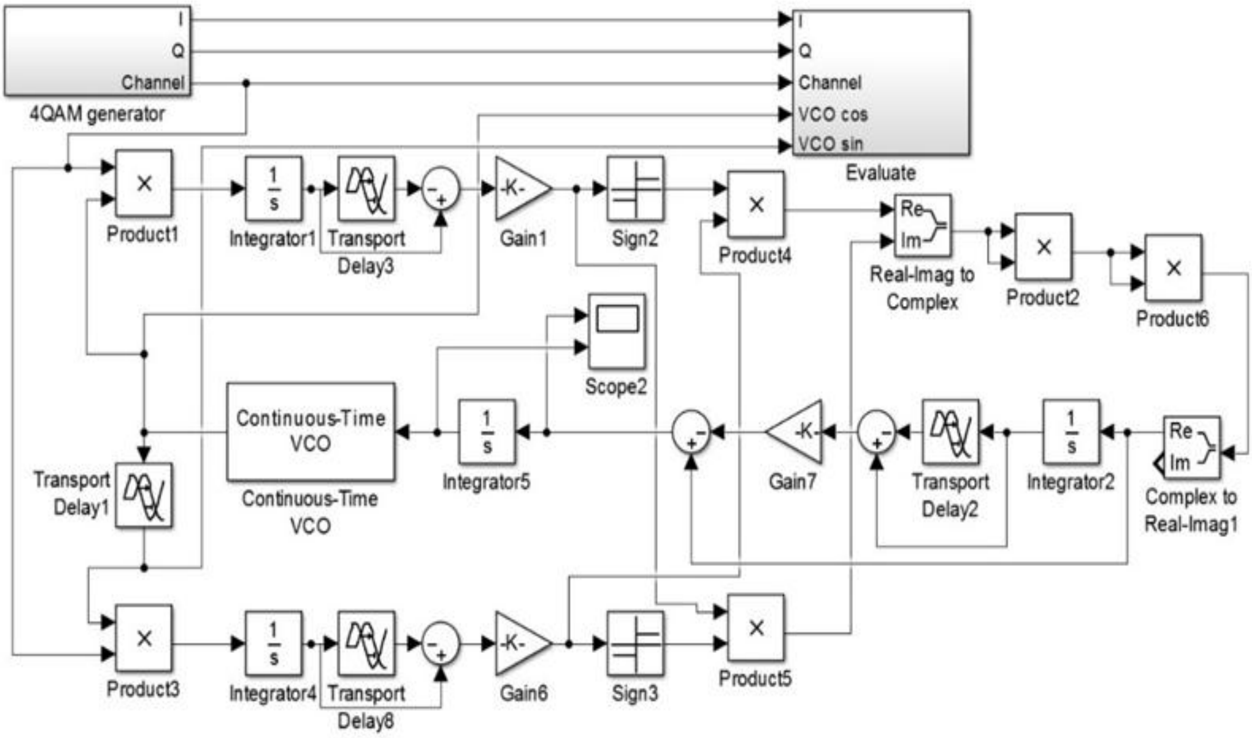

Fig-4. Decision directed Costas loop with 4th power method. Generator and evaluate blocks are the same as in Fig. 7a, b
Source: Original, from our Simulink simulation

In Fig. 4, rising to 4th power has been realized by the Real-Imag to Complex block and two multipliers. Other parts of the Costas loop are very similar to those at Fig. 2.

Rising to the 4th power removes information, that remains is only the carrier. Without I and Q bits on the carrier, it is much easier to recover. However, some possibility of error still remains as shown in Fig. 5.

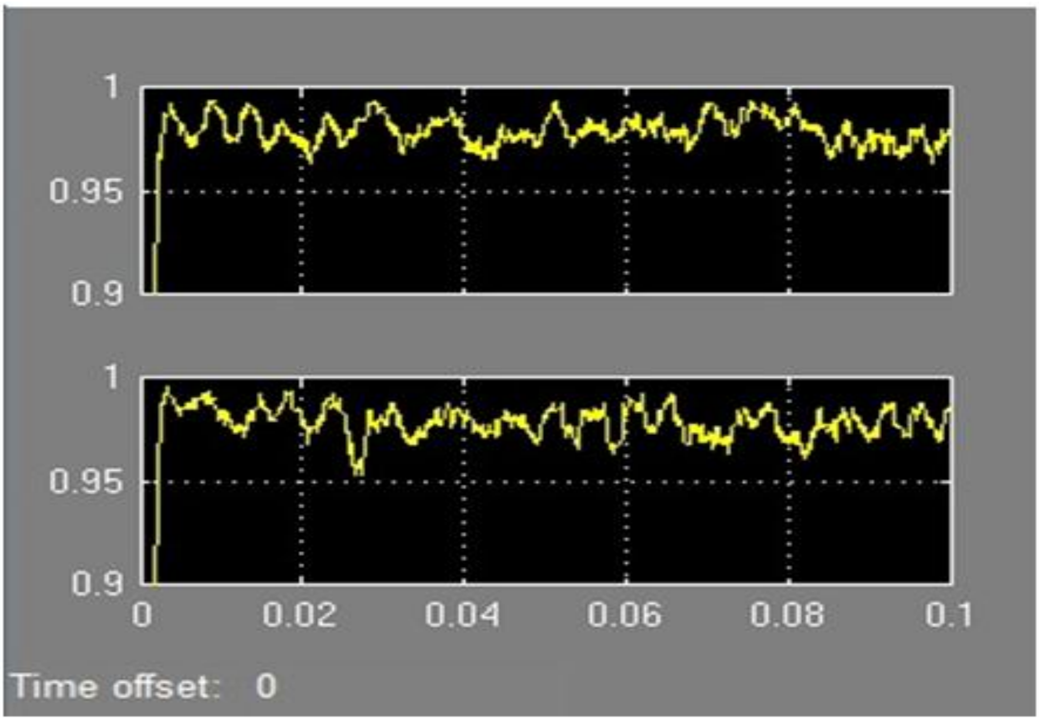

Fig-5. Correlation between transmitted and received I and Q signals for the decision directed Costas loop with 4th power method. Conditions: sin and cos amplitudes: 1, frequency: 5 MHz, sample time: 10 ns, noise power: 10 nW/Hz, in band limited white noise block in MATLAB/Simulink
Source: Original, from our Simulink simulation

We can conclude that the 4th power method is noise sensitive and this characteristics should be improved.

4. CARRIER RECOVERY BY FOLDING METHOD

In contrary to the 4th power method, where constellation points are rotated around the origin, in case of the folding method, the constellation diagram is folded alternatively around the real and imaginary axis, and then the result is shifted so that the remaining points are centrally symmetrical to the origin. This procedure is done until 1 point remains.

As a result of folding, noise is averaged and this is the explanation for the high resistance against noise.

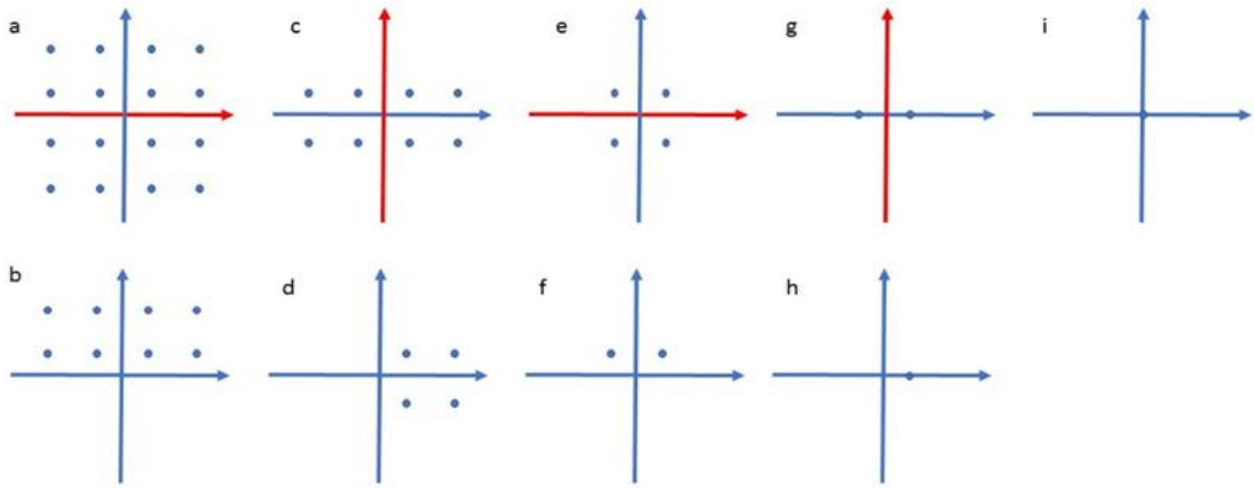

Fig-6. Basis of the folding method. We show here the steps ont he example of the 16QAM modulation. Reference line to the folding is denoted by red color.
Source: Original

Compared to the 4th power method, an advantage of the folding method is that without any modifications, folding method is applicable to QAM of arbitrary order.

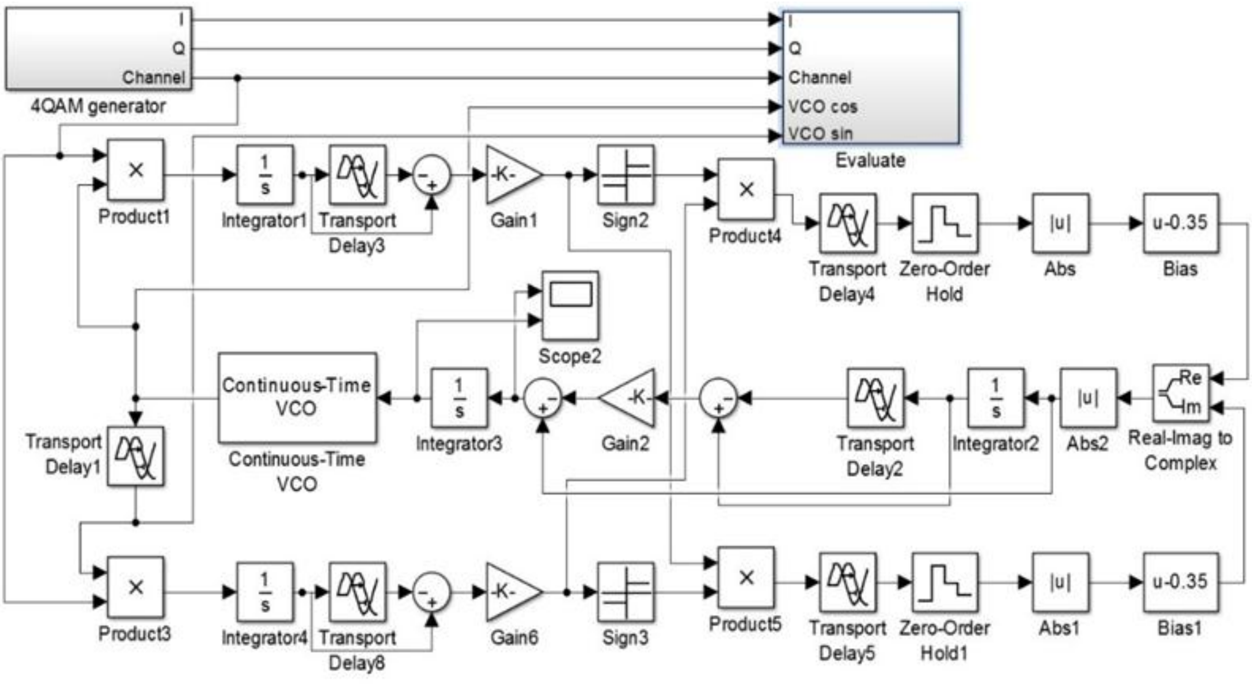

Fig-7. Decision directed Costas loop with folding method
Source: Original, from our Simulink simulation

In Fig. 7, folding is realized by absolute value blocks followed by Bias block for centering the signal. The difference between centering in the upper, lower and VCO branches is that in the upper and lower branches, center value is fixed and in the VCO branch, it is calculated by averaging.

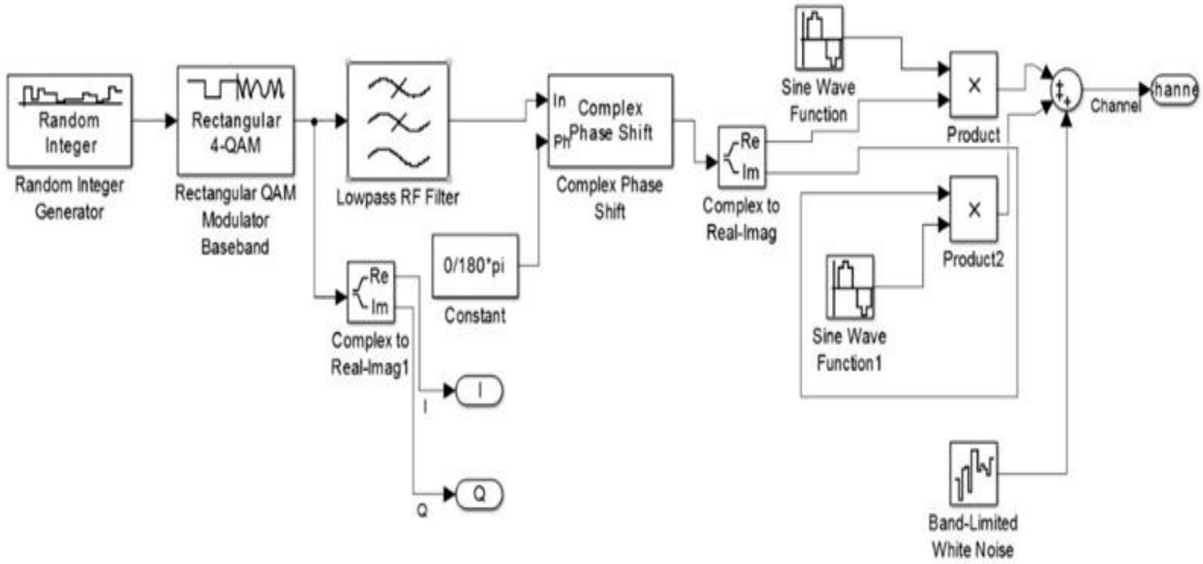

Fig-7a. 4QAM generator

Source: Original, from our Simulink simulation

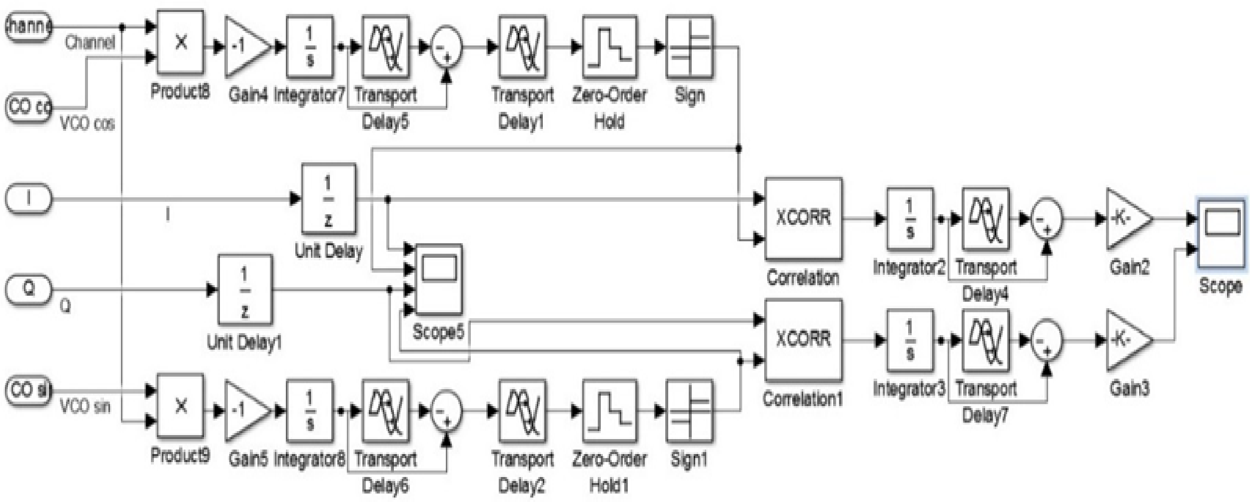

Fig-7b. Evaluate block

Source: Original, from our Simulink simulation

The essential part is the inclusion of the delay and hold blocks that take a sample at about the middle of the bit period.

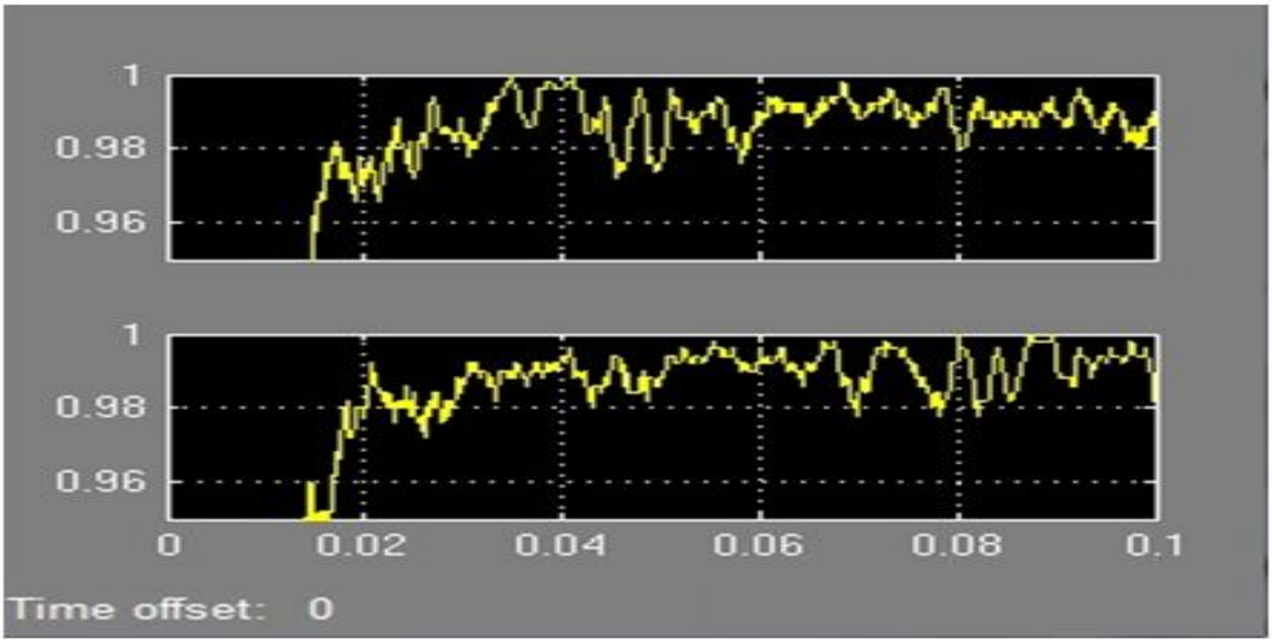

Fig-8. Correlation between transmitted and received I and Q signals for the decision directed Costas loop with folding method. Conditions: sin and cos amplitudes: 1, frequency: 5 MHz, sample time: 10 ns, noise power: 10 nW/Hz, in band limited white noise block in MATLAB/Simulink
Source: Original, from our Simulink simulation

A comparison between Fig. 5 and 8 results in the conclusion that the folding method is less noise sensitive than the 4th power method.

5. SER VS. SNR PERFORMANCE

The above mentioned three Costas loop versions have been compared from the viewpoint of SER vs. SNR in Fig. 9. Comparison is made based on the system analysis feature of AWR.

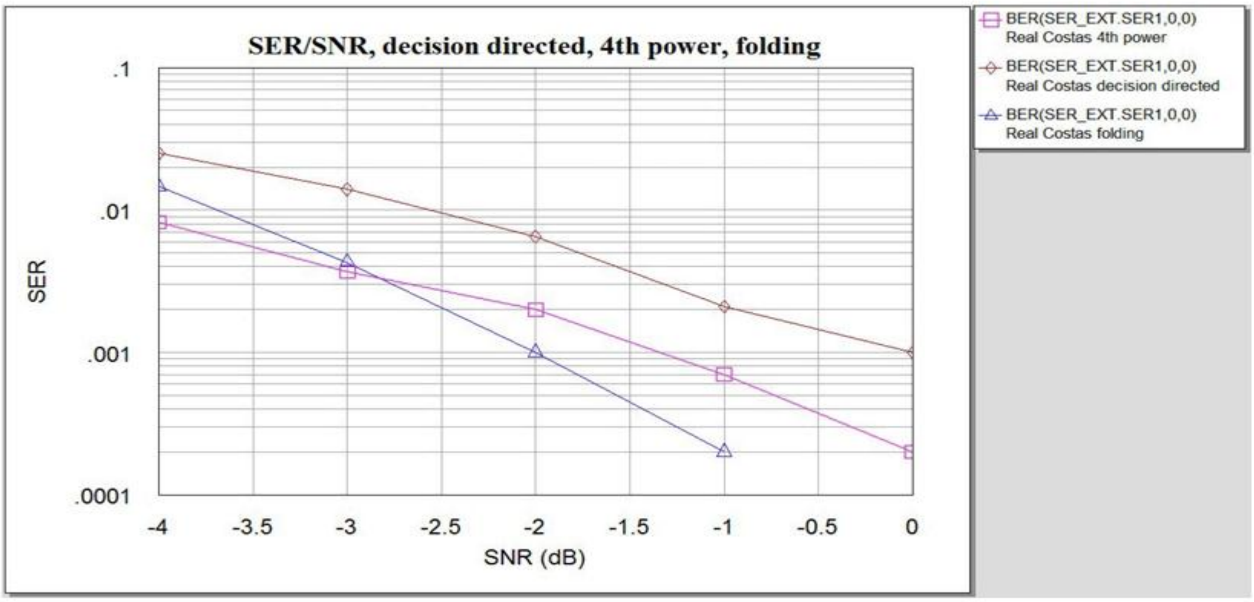

Fig-9. Comparison between the three methods mentioned above. Brown diamonds – decision directed, violet squares – 4th power, blue triangles - folding.
Source: Original, from our AWR simulation

In the Figure the superiority of the folding method above the other two is shown for SNR>-3 dB. At SNR=-1 dB, folding is 3.5 and 10 times better than the 4th power and the decision directed versions, respectively.

6. CONCLUSIONS

A new method called as folding method has been proposed with application to sharpen the properties of a Costas loop within noisy conditions. The decision directed, 4th power and folding methods can provide at SNR of -1 dB, SER of 0.002, 0.0007, 0.0002, respectively. Big advantage of our folding method over the 4th power method is that the latter cannot be generalized above 4QAM, while the folding method can.

The interested reader can be provided three Simulink files, one about each method mentioned here. The diagrams and Figures in this paper were obtained using these files.

Funding: This study received no specific financial support.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.
Contributors/Acknowledgement: The author is grateful for different supports from Prof. T. Berceli, Dr. E. Simonyi, Mr. V. Beskid and Dr. B. Kovács.The review by the St. Petersburg group (N.V. Kuznetsov, M.V. Yuldashev, R.V. Yuldashev) is greatly acknowledged.

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