Asynchronous Sequential Symbol Synchronizers based on Pulse Comparison by Both Transitions at Quarter Bit Rate

Antonio D. Reis, Jose F. Rocha, Atilio S. Gameiro and Jose P. Carvalho

***Abstract*— This work studies the asynchronous sequential symbol synchronizers based on pulse comparison by both transitions at quarter bit rate. Their performance will be compared with the standard reference asynchronous symbol synchronizers based on pulse comparison by both transitions at bit rate. For the reference and proposal variants, we consider two versions which are the manual (m) and the automatic (a).**

The objective is to study the four synchronizers and evaluate their output jitter UIRMS (Unit Interval Root Mean Square) versus input SNR (Signal Noise Ratio).

***Index Terms*—Synchronism, Digital Communications**

I. INTRODUCTION

This work studies the asynchronous sequential symbol synchronizer based on pulse comparison operating by both transitions at quarter bit rate (ab/4). Their jitter is compared with the reference asynchronous synchronizers operating by both transitions at bit rate (ab) [1, 2].

For both, reference and proposal variant, we consider the versions manual (m) and automatic (a) [3, 4, 5, 6, 7].

The difference between the reference and proposal synchronizer is in the symbol phase comparator since the other blocks are similar. The phase comparator compares the input variable pulse duration Pv with the intern reference fixed pulse duration Pf and the error pulse Pe synchronizes the VCO (Voltage Controlled Oscillator) [8, 9].

The synchronizer regenerates the data, recovering a clock (VCO) that samples and retimes the data [10, 11, 12, 13].

Fig.1 shows the blocks of the general symbol synchronizer.

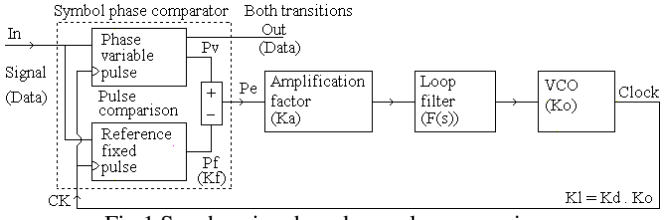

Fig.1 Synchronizer based on pulse comparison

Kf is the phase comparator gain, F(s) is the loop filter, Ko is the VCO gain and Ka is the loop amplification factor that controls the root locus and then the loop characteristics.

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In priori and actual state of the art was developed various synchronizers, now is necessary to know their performance.

The motivation of this work is to create new synchronizers and evaluate their performance with nnoise. To get good jitter curves. This contribution increases the knowledge on synchronizers. Following, we present the standard reference variant, asynchronous sequential symbol synchronizers based on pulse comparison by both transitions at bit rate, with versions manual (ab-m) and automatic (ab-a). Next, we present the proposal variant, asynchronous sequential symbol synchronizer based on pulse comparison by both transitions at quarter bit rate, with versions manual (ab-m/4) and automatic (ab-a/4). After, we present the design and tests. Then, we present the results. Finally, we present the conclusions.

II. REFERENCE BY BOTH AT BIT RATE

The standard comparison reference, asynchronous sequential symbol synchronizers based on pulse comparison operating by both transitions at bit rate has two versions which are the manual (ab-m) and the automatic (ab-a) [1, 2].

The versions difference is in the phase comparator, the variable pulse Pv is common but the fixed Pf is different.

A. Reference by both at rate manual (ab-m)

The block Pv, shown below, produces a variable pulse Pv between the input bits and VCO. The manual adjustment delay with Exor produces a manual fixed pulse Pf (Fig.2).

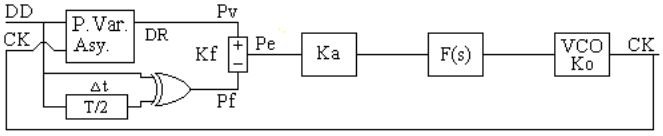

Fig.2 Asynchronous by both at rate and manual (ab-m)

The comparison between the pulses Pv and Pf provides the error pulse Pe that forces the VCO to synchronize the input. The block Pv is an asynchronous circuit (Fig.3).

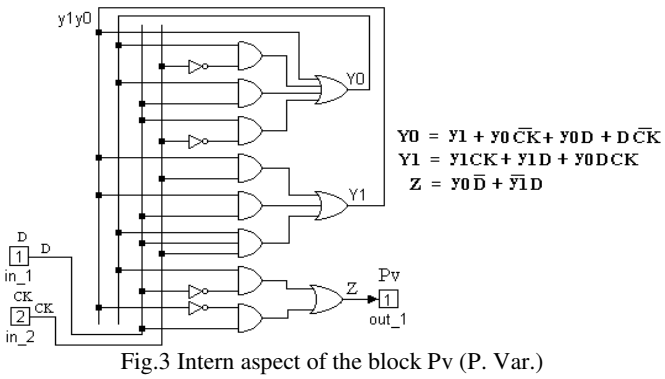

Fig.3 Intern aspect of the block Pv (P. Var.)

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Fig.4 shows the waveforms of the reference manual (equal to the corresponding synchronous version) [3].

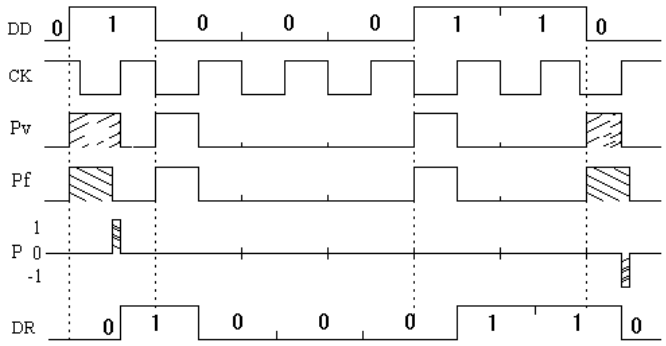

Fig.4 Waveforms of the asynchronous by both at rate manual

The error pulse Pe diminishes during the synchronization time and disappear at the equilibrium point.

B. Reference by both at rate automatic (ab-a)

The block Pv, common with anterior, produces the variable pulse Pv between input and VCO. The block Pf, shown below, produces the comparison fixed pulse Pf (Fig.5).

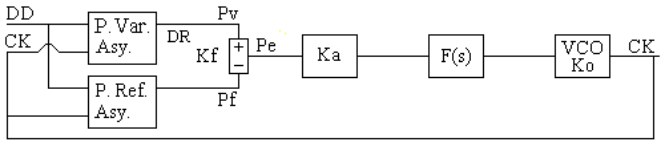

Fig.5 Asynchronous by both at rate and automatic (ab-a)

The comparison between the pulses Pv and Pf provides the error pulse Pe that forces the VCO to follow the input. The block Pf is an asynchronous circuit (Fig.6).

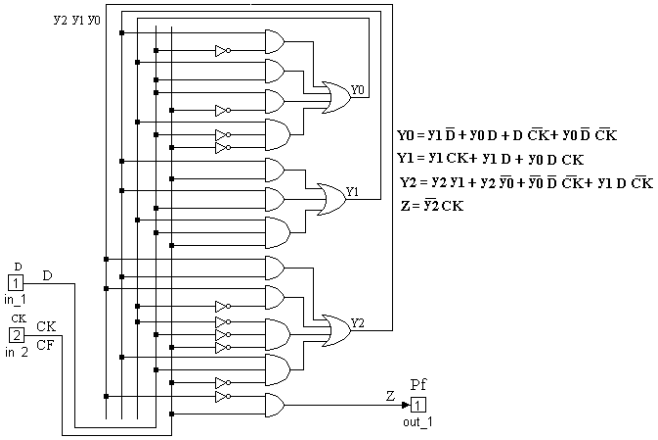

Fig.6 Intern aspect of the block Pf (P. Ref.)

Fig.7 shows the waveforms of the reference automatic (equal to the corresponding synchronous version) [3].

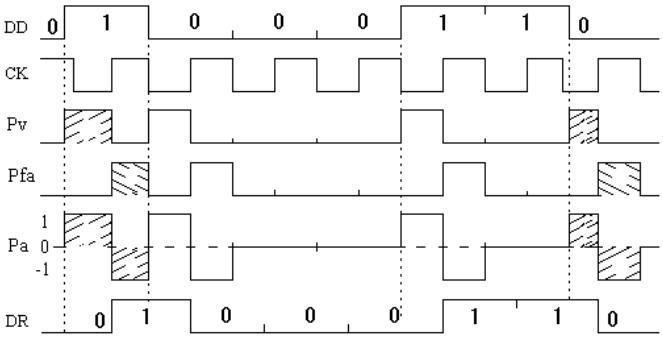

Fig.7 Waveforms of the asynchronous by both at rate automatic

The error pulse Pe don't disappear, but the variable area Pv is equal to the fixed Pf at the equilibrium point.

III. PROPOSAL BY BOTH AT QUARTER BIT RATE

The new proposal, asynchronous sequential symbol synchronizers based on pulse comparison operating by both transitions at quarter bit rate has also two versions namely the manual (ab-m/4) and the automatic (ab-a/4) [3, 4].

The versions difference is in the phase comparator, the variable pulse Pv is common but the fixed Pf is different.

A. Proposal by both at quarter manual (ab-m/4)

The block Pv produces the variable pulse Pv between input transitions and VCO. The manual adjustment delay T/2 with Exor produces a fixed pulse Pf (Fig.8).

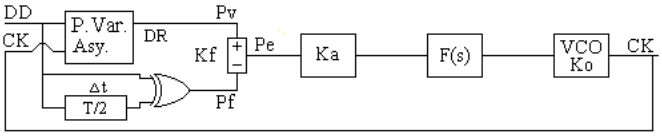

Fig.8 Asynchronous by both at quarter rate and manual (ab-m/4)

The comparison between pulses Pv and Pf provides the error pulse Pe that forces the VCO to synchronize the input. The block Pv is an asynchronous circuit (Fig.9).

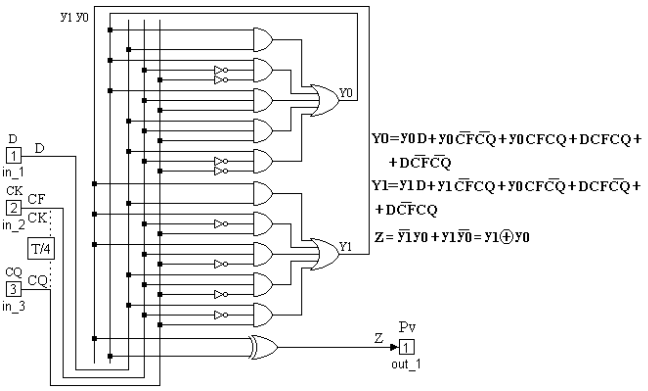

Fig.9 Intern aspect of the block Pv (P. Var.)

Fig.10 shows the waveforms of the proposal manual (equal to the corresponding synchronous version) [3].

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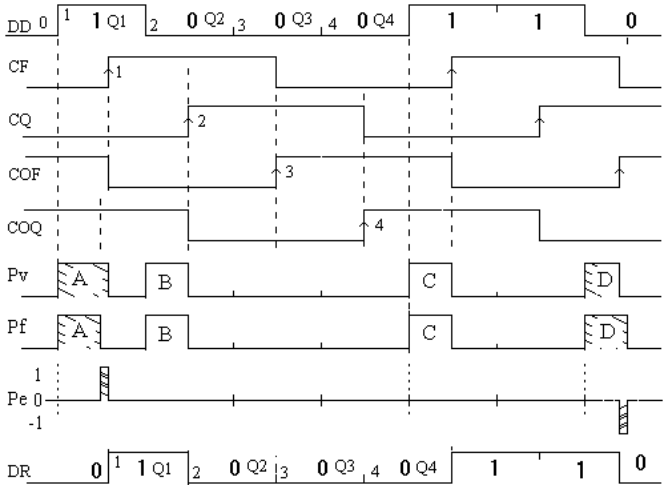

Fig.10 Waveforms of the asynchronous both at quarter rate manual

The error pulse Pe diminishes during the synchronization time and disappear at the equilibrium point.

B. Proposal by both at quarter automatic (ab-a/4)

The block Pv, common, produces the variable pulse Pv between input and VCO. The block Pf, shown below, produces the comparison fixed pulse Pf (Fig.11).

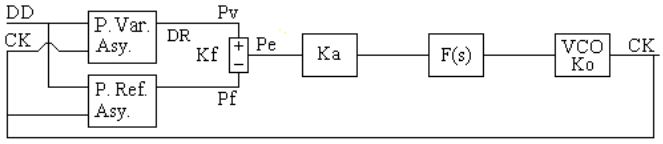

Fig.11 Asynchronous by both at quarter rate and automatic (ab-a/4)

The comparison between the pulses Pv and Pf provides the error pulse Pe that forces the VCO to follow the input. The block Pf is an asynchronous circuit (Fig.12).

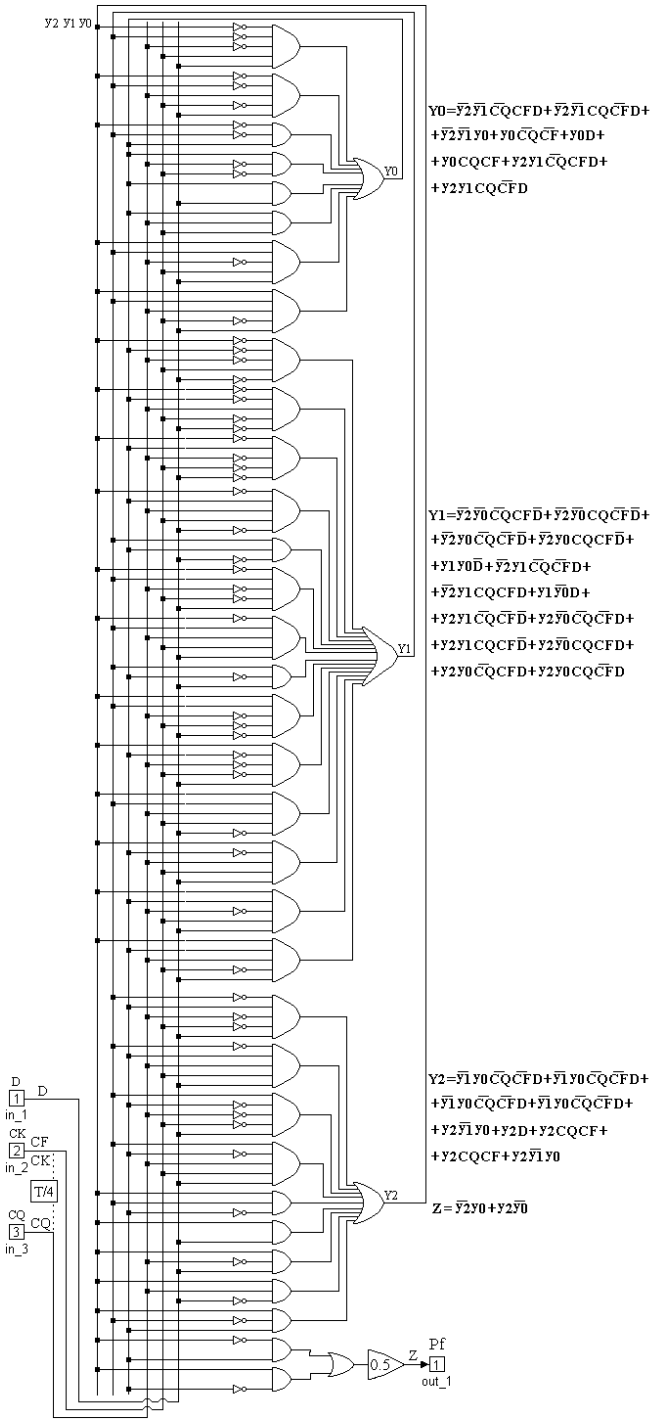

Fig.12 Intern aspect of the block Pf (P. Ref.)

Fig.13 shows the waveforms of the proposal automatic (equal to the corresponding synchronous version) [3].

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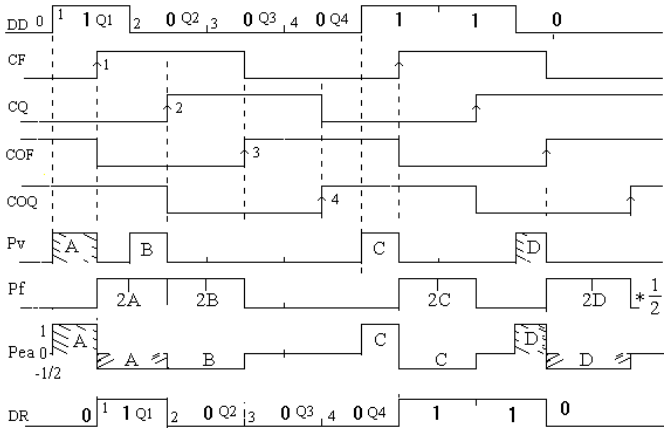

Fig.13 Waveforms of the asynchronous both at 1/4 rate automatic

The error pulse Pe don't disappear, but the variable area Pv is equal to the fixed Pf at the equilibrium point.

IV. DESIGN, TESTS AND RESULTS

We present the design, tests and results of the various synchronizers [5].

A. Design

To have guaranteed results, is necessary to dimension all the synchronizers with equal conditions. Then, the loop gain Kl=KdKo=KaKfKo must be equal in all the synchronizers. The phase detector gain Kf and the VCO gain Ko are fixed. Then, the loop gain amplification Ka controls the root locus and consequently the loop characteristics.

For analysis facilities, we use normalized values for the transmission rate tx=1baud, clock frequency fCK=1Hz, extern noise bandwidth Bn=5Hz and loop noise bandwidth Bl=0.02Hz. Then, we apply a signal power Ps= A^2_{ef} and a noise power Pn= No= $2\sigma n^2.\Delta\tau$, where σn is the noise standard deviation and $\Delta\tau$ =1/fSamp is the sampling period. The relation between SNR and noise variance σn^2 is

$$SNR= A^2_{ef}/(No.Bn) = 0.5^2/(2\sigma n^2*10^{-3}*5)= 25/\sigma n^2 \quad (1)$$

Now, for each synchronizer, is necessary to measure the output jitter UIRMS versus the input SNR

- 1st order loop:

We use a cutoff loop filter F(s) = 0.5Hz, is 25 times greater than Bl= 0.02Hz, what eliminates the high frequency but maintain the loop characteristics. The transfer function is

$$H(s)=\frac{G(s)}{1+G(s)}=\frac{KdKoF(s)}{s+KdKoF(s)}=\frac{KdKo}{s+KdKo} \quad (2)$$

the loop noise bandwidth is

$$Bl=\frac{KdKo}{4}=Ka\frac{KfKo}{4}=0.02Hz \quad (3)$$

So, with (Km=1, A=1/2, B=1/2, Ko=2π) and loop bandwidth Bl=0.02, we obtain respectively the Ka, for analog, hybrid, combinational and sequential synchronizers, then

$$Bl=(Ka.Kf.Ko)/4 = (Ka.Km.A.B.Ko)/4 \rightarrow Ka=0.08*2/\pi \quad (4)$$

$$Bl=(Ka.Kf.Ko)/4 = (Ka.Km.A.B.Ko)/4 \rightarrow Ka=0.08*2.2/\pi \quad (5)$$

$$Bl=(Ka.Kf.Ko)/4 = (Ka*1/\pi*2\pi)/4 \rightarrow Ka=0.04 \quad (6)$$

$$Bl=(Ka.Kf.Ko)/4 = (Ka*1/2\pi*2\pi)/4 \rightarrow Ka=0.08 \quad (7)$$

For the analog PLL, the jitter is

$$\sigma_\phi^2=Bl.No/Aef^2=0.02*10^{-3}*2\sigma n^2/0.5^2=16*10^{-5}.\sigma n^2 \quad (8)$$

For the others PLLs, the jitter formula is more complicated.

- 2nd order loop:

Is not used here, but provides similar results.

B. Tests

We used the following setup to test synchronizers (Fig.14)

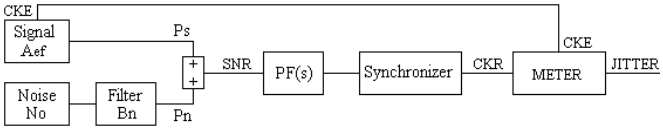

Fig.14 Block diagram of the test setup

The receiver recovered clock with jitter is compared with the emitter original clock, the difference is the jitter.

C. Results

We present the results in terms of output jitter UIRMS versus input SNR. Fig.15 shows the jitter - SNR curves of the four synchronizers which are the both rate manual (ab-m), the both rate automatic (ab-a), the both quarter rate manual (ab-m/4) and the both quarter rate automatic(ab-a/4).

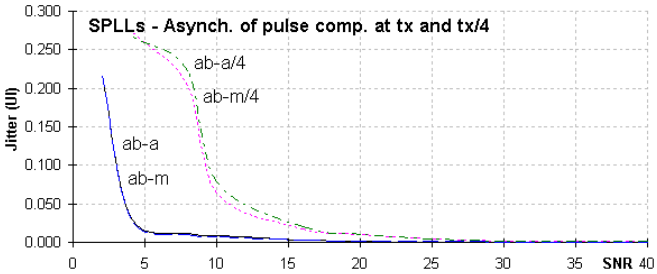

Fig.15 Jitter-SNR curves of the 4 synchronizers (ab-m, ab-a, ab-m/4, ab-a/4)

We observe that, in general, the output jitter UIRMS decreases gradually with the input SNR increasing. The curves are monotone without jitter resonance zones.

We verify that, for high SNR, where normally the systems operate, the four jitter curves tend to be similar. However, for low SNR, the variant asynchronous both at rate manual (ab-m) and automatic (ab-a) are better than the variant asynchronous both at quarter rate manual (ab-m/4) and automatic (ab-a/4).

V. CONCLUSIONS

We studied four synchronizers involving the standard reference variant asynchronous by both transitions at bit rate with versions manual (ab-m) and automatic (ab-a) and the new proposal variant asynchronous by both transitions at quarter bit rate with versions manual (ab-m/4) and automatic (ab-a/4). Then, we tested and compared their jitter-SNR curves. We observed that, in general, the output UIRMS jitter curves decrease gradually with the input SNR increasing.

We verified that, for high SNR, the four synchronizers jitter curves tend to be similar, this is comprehensible since all the synchronizers are digital, with equal noise margin. However, for low SNR, the variant asynchronous by both at rate with their versions manual (ab-m) and automatic (ab-a) are better than the variant asynchronous by both at quarter rate with their versions manual (ab-m/4) and automatic (ab-a/4), this is comprehensible because the variant by both transitions at bit rate has minus states than the variant by both transitions at quarter bit rate and then, the time to pass from the error state to the correct state is lesser in 1st case.

The automatic asynchronous synchronizers at subrates have good performance, without jitter resonance zones.

In the future, we are planning to extend the present study to other types of synchronizers.

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