Prefilter Bandwidth Effects in 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 prefilter bandwidth effects in four asynchronous sequential symbol synchronizers. We consider three prefilter bandwidths namely B1=∞, B2=2.tx and B3=1.tx, where tx is the bit rate. The synchronizer has two variants one asynchronous by both transitions at bit rate and other asynchronous by both transitions at quarter bit rate. Each variant has two versions namely the manual and the automatic. The objective is to study the prefilter with the four synchronizers and to evaluate their output jitter UIRMS (Unit Interval Root Mean Square) versus input SNR (Signal Noise Ratio).**

***Index Terms*—Prefilter, Digital Communication Systems**

I. INTRODUCTION

This work studies the prefilter bandwidth effects on the jitter-SNR behavior of four sequential symbol synchronizers.

The prefilter, applied before the synchronizer, switches its bandwidth between three values namely first B1=∞, after B2=2.tx and next B3=1.tx, where tx is the bit rate [1, 2, 3, 4]. The synchronizer has four versions supported in two variants, one asynchronous by both transitions at bit rate with versions manual (ab-m) and automatic (ab-a) and other asynchronous by both transitions at quarter bit rate with versions manual (ab-m/4) and automatic (ab-a/4) [5, 6, 7, 8].

The difference between the four synchronizers is in the phase comparator. The clock is the VCO (Voltage Controlled Oscillator) that samples appropriately and retimes correctly the input data, guarantying good quality [9, 10, 11, 12, 13].

Fig.1 shows the prefilter followed of the synchronizer.

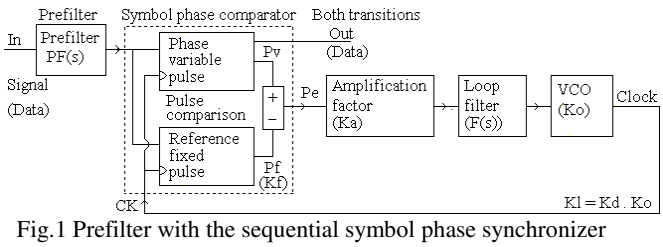

Fig.1 Prefilter with the sequential symbol phase synchronizer

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PF(s) is the prefilter (low pass). The synchronizer has various blocks, namely Kf is the phase detector gain, F(s) is the loop filter, Ko is the VCO gain and Ka is the loop gain factor that controls the root locus and loop characteristics.

In priori and actual-art state was developed various synchronizers, but is necessary to know their performance.

The motivation of this work is to create new synchronizers and evaluate their performance with noise. To see the prefilter effects. To get good jitter curves. This contribution increases the know-how about synchronizers. Following, we present the prefilter with their three different decreasing bandwidths (B1=∞, B2=2.tx, B3=1.tx). After, 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 new proposal variant, asynchronous sequential symbol synchronizers 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. PREFILTER BANDWIDTH EFFECTS

We apply a prefilter before the synchronizer, we switches its bandwidth B between three values (B1=∞, B2=2.tx, B3=1.tx), then we study the effects on the four jitter-SNR curves. Fig.2 shows the three prefilter bandwidths.

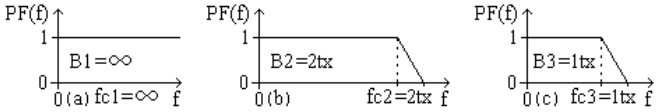

Fig.2 Three prefilter bandwidths: a) B1=∞; b) B2=2.tx; c) B3=1.tx

Following, we describe the prefilter with its three bandwidths (B1=∞, B2=2.tx, B3=1.tx).

A. Prefilter with Bandwidth equal infinite (B1=∞)

This prefilter (Fig.2a) has a bandwidth equal infinite (B=∞). We will see its effects on the four synchronizers.

B. Prefilter with Bandwidth equal two tx (B2=2.tx)

This prefilter (Fig.2b) has a bandwidth equal two times the bit rate (B=2.tx). We will see its effects on the four synchronizers.

C. Prefilter with Bandwidth equal one tx (B3=1.tx)

This prefilter (Fig.2c) has a bandwidth equal one time the bit rate (B=1.tx). We will see its effects on the four synchronizers.

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III. 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.3).

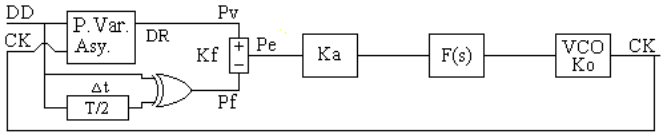

Fig.3 Asynchronous by both at rate and manual (ab-m)

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.4).

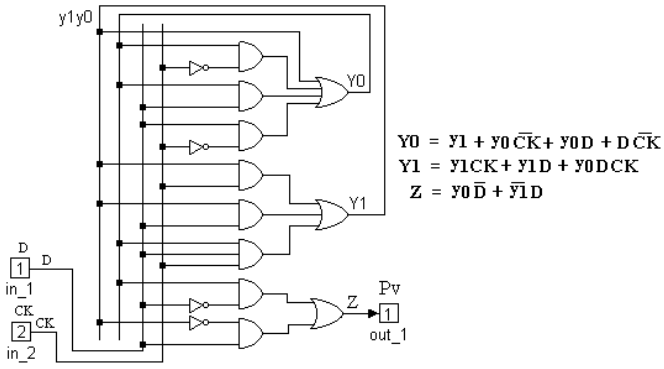

Fig.4 Intern aspect of the block Pv

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).

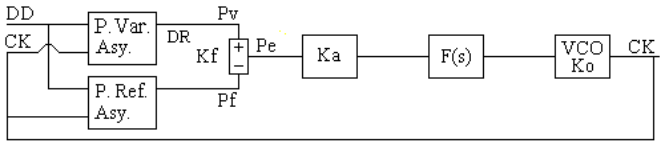

Fig.5 Asynchronous by both at rate and automatic (ab-a)

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).

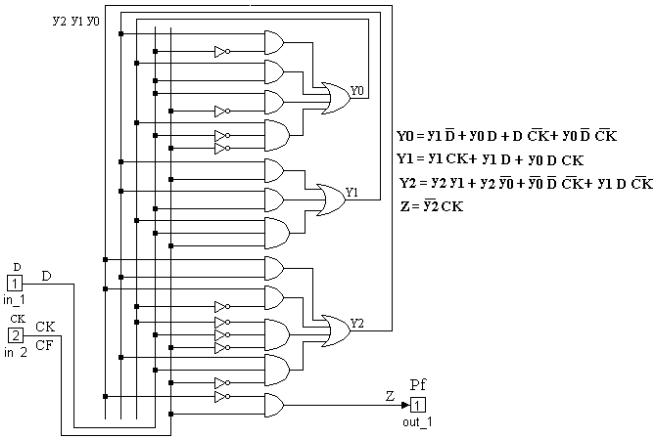

Fig.6 Intern aspect of the block Pf

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

IV. PROPOSAL BY BOTH AT QUARTER BIT RATE

The new proposal, asynchronous sequential symbol synchronizers based on pulse comparison operating by both transitions at half rate has also two versions namely the manual (ab-m/2) and the automatic (ab-a/2) [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.7).

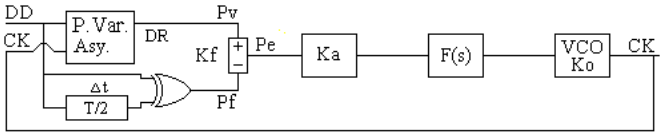

Fig.7 Asynchronous by both at quarter rate and manual (ab-m/4)

The comparison between pulses Pvp and Pfp provides the error pulse Pe that forces the VCO to synchronize the input. The block Pv is an asynchronous circuit (Fig.8).

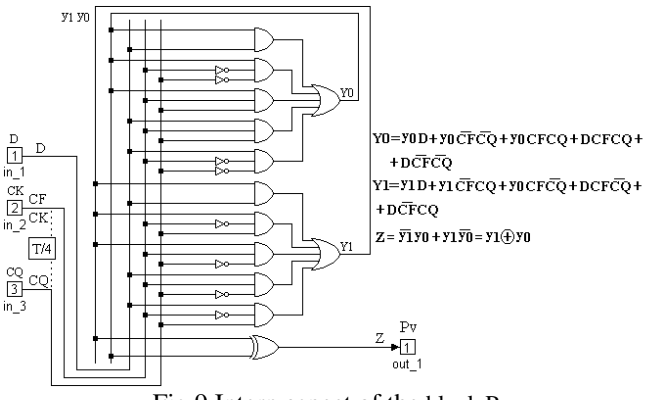

Fig.9 Intern aspect of the block Pv

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.9).

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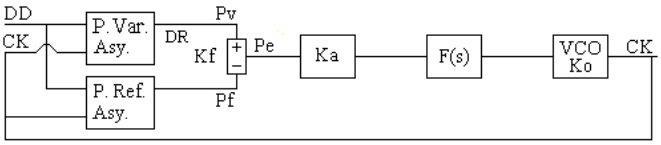

Fig.9 Asynchronous by both at quarter rate and automatic (ab-a/4)

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.10).

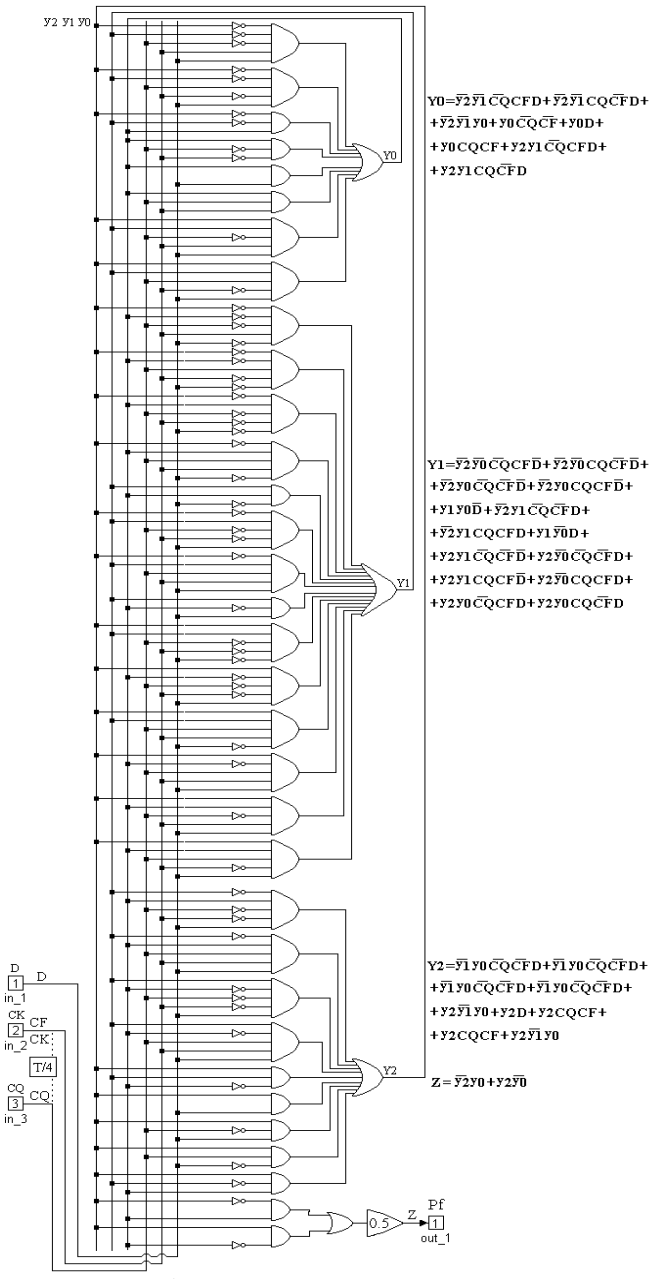

Fig.10 Intern aspect of the block Pf

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

IV. DESIGN, TESTS AND RESULTS

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

A. Design

To get 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 bit 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 input SNR

- 1st order loop:

The used 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.11)

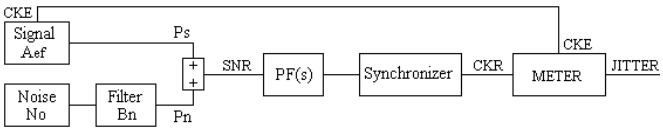

Fig.11 Block diagram of the test setup

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

C. Results

We will present the results, in terms of jitter - SNR, for each prefilter bandwidth with the four synchronizers.

Fig.12 shows the jitter-SNR curves for the prefilter bandwidth B1=∞ with the four synchronizers (ab-m, ab-a, ab-m/4, ab-a/4).

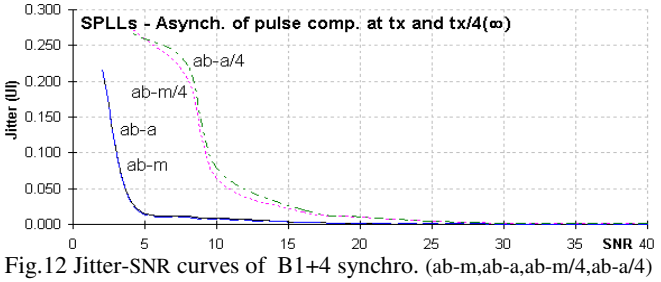

Fig.12 Jitter-SNR curves of B1+4 synchro. (ab-m,ab-a,ab-m/4,ab-a/4)

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For prefilter B1=∞, we verify that, for high SNR, the four synchronizer jitter-SNR curves tend to be similar. However, for low SNR, the variant asynchronous by both at bit rate with versions manual (ab-m) and automatic (ab-a) are better than the variant asynchronous by both at quarter bit rate with versions manual (ab-m/4) and automatic (ab-a/4).

Fig.13 shows the jitter-SNR curves for the prefilter bandwidth B2=2.tx with the four synchronizers (ab-m, ab-a, ab-m/4, ab-a/4).

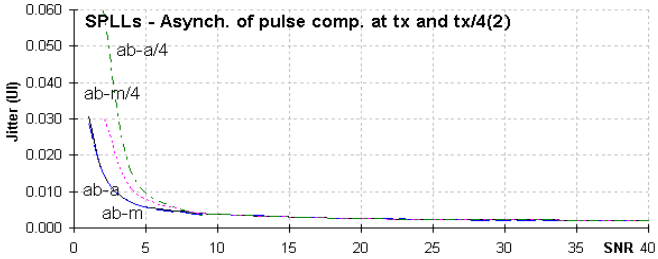

Fig.13 Jitter-SNR curves of B2+4 synchro. (ab-m,ab-a,ab-m/4,ab-a/4)

For prefilter B2=2.tx, we verify that, it becomes the jitter-SNR curves more similar between themselves. For high SNR, it degrades slightly the jitter-SNR curves. However, for low SNR it benefits significantly the jitter - SNR curves.

Fig.14 shows the jitter-SNR curves for the prefilter bandwidth B3=1.tx with the four synchronizers (ab-m, ab-a, ab-m/4, ab-a/4).

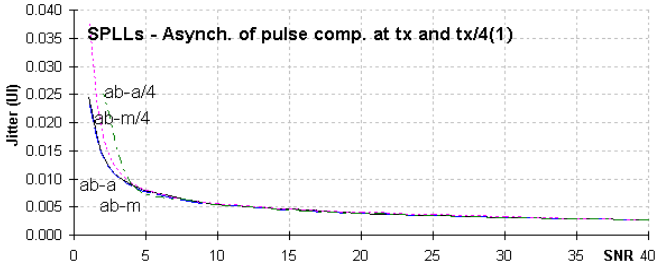

Fig.14 Jitter-SNR curves of B3+4 synchro. (ab-m,ab-a,ab-m/4,ab-a/4)

For prefilter B3=1.tx, we verify that, it becomes the jitter-SNR curves still more similar between themselves. For high SNR, it degrades more the jitter-SNR curves. However, for low SNR, it benefits less the jitter-SNR curves.

V. CONCLUSIONS

We studied three prefilter bandwidths (B1=∞, B2=2.tx, B3=1.tx) with four synchronizers, one variant asynchronous by both transitions at bit rate with versions manual (ab-m) and automatic (ab-a) and other variant asynchronous by both at quarter bit rate with versions manual (ab-m/4) and automatic (ab-a/4). Then, we measured the jitter-SNR curves.

We observed that, in general, the output jitter curves decreases gradually with the input SNR increasing.

For prefilter B1=∞ (greater), we verified that, for high SNR, the four synchronizers jitter curves tend to be similar, this is comprehensible since all the synchronizers are digital and have similar noise margin. However, for low SNR, the variant asynchronous by both at bit rate with its versions manual (ab-m) and automatic (ab-a) is better than the variant asynchronous by both at quarter bit rate with its versions manual (ab-m/4) and automatic (ab-a/4), this is comprehensible since the variant by both transitions at bit rate has minus states than the variant by both at quarter rate and then, the time to pass from the error state to the correct state is lesser in the 1st case.

For prefilter B_2=2.tx(medium), we verified that, it becomes the jitter-SNR curves more similar between themselves. For high SNR, it degrades slightly the jitter-SNR curves. However, for low SNR, it benefits significantly the jitter-SNR curves.

For prefilter B3=1.tx (lesser), we verify that, it becomes the jitter-SNR curves still more similar between themselves. For high SNR, it degrades more the jitter-SNR curves. Also, for low SNR, it benefits less the jitter-SNR curves.

So, the prefilter, for high SNR, distorts the signal what is prejudicial, for low SNR, attenuates noise what is beneficial.

The asynchronous automatic types at subrates have no jitter resonance zones.

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

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