Prefilter Bandwidth Effects in Sequential Symbol Synchronizers based on Pulse Comparation by Positive Transitions at Quarter Rate

Antonio D. Reis[1,2], Jose F. Rocha[1], Atilio S. Gameiro[1] and Jose P. Carvalho[2]

Abstract – **This work studies the effects of the prefilter bandwidth in the sequential symbol synchronizers based on pulse comparation at bit rate and at half bit rate. 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 operating by both transitions at bit rate and other operating by positive transitions at quarter rate. Each variant has two versions namely the manual and the automatic. The objective is to study the prefilter bandwidth with four synchronizers and to evaluate their output jitter UIRMS (Unit Interval Root Mean Square) versus input SNR (Signal Noise Ratio).**

Keywords – **Prefilter, Synchronism, 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 their 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 types supported in two variants, one operating by both transitions at the rate with versions manual (b-m) and automatic (b-a) and other operating by positive transitions at quarter rate with versions manual (p-m/4) and automatic (p-a/4). The difference between the four synchronizers is only in the phase comparator, since the other blocks are equal. The synchronizer VCO (Voltage Controlled Oscillator) is the clock whose performance determines, in good part, the system quality [5, 6, 7, 8].

Fig.1 shows the prefilter followed of the synchronizer.

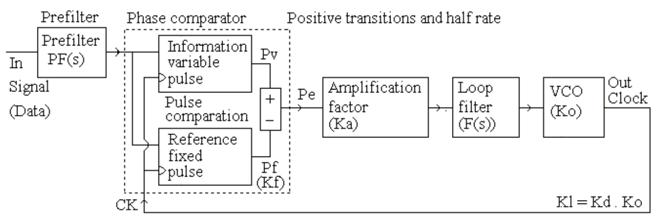

Fig.1 Prefilter with the synchronizers based on pulse comparation

PF(s) is the prefilter (low pass filter). 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.

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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. This contribution increases the knowledge about synchronizers.

Following, we present the prefilter with their three different bandwidths (B1=∞, B2=2.tx, B3=1.tx) [9, 10, 11, 12].

After, we present the variant by both transitions at rate with their manual (b-m) and automatic (b-a) versions. Next, we present the variant by positive transitions at quarter rate with their manual (p-m/4) and automatic (p-a/4) versions.

After, we present the design and tests. Then, we present the results. Finally, we present the conclusions.

II. PREFILTER BANDWIDTH EFFECTS

The prefilter, applied before the synchronizer, filters the noise but disturbs slightly the signal. The prefilter bandwidth B switches between three values (B1=∞, B2=2.tx, B3=1.tx).

Fig.2 shows the prefilter with their three bandwidths.

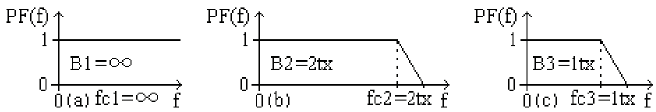

Fig.2 Three prefilter bandwidths: a) B1=∞; b) B2=2.tx; c) B3=1.tx

a) First, as shown in Fig.2a, the prefilter has a bandwidth equal to infinite (B1= ∞).

b) Second, as shown in Fig.2b, the prefilter has a bandwidth equal to times the bit rate (B2 = 2.tx).

c) Third, as shown in Fig.2c, the prefilter has a bandwidth equal to the bit rate (B3 = 1.tx).

We will evaluate the three bandwidth effects (B1, B2, B3) on the jitter-SNR curves of the four symbol synchronizers.

III. SYNCHRONIZERS OPERATING AT THE RATE

The synchronizer with its phase comparator operates, here, by both transitions at the data transmission rate.

This variant has the manual (b-m) and automatic (b-a) versions, the difference is in phase comparator. The variable pulse Pv, produced by the first flip flop with exor, is equal in the two versions, but the fixed pulse Pf is different [1, 2].

A. Both transitions, at the rate and manual

The manual version has a phase comparator, where the fixed pulse Pf is produced by an exor with a delay Δt=T/2, that needs a previous manual adjustment (Fig.3)

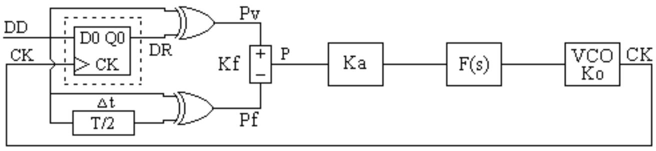

Fig.3 Synchronizer both at the rate and manual (b-m)

The variable pulse Pv minus the fixed pulse Pf (Pv-Pf) determines the error phase that controls the VCO.

B. Both transitions, at the rate and automatic

The automatic version has a phase comparator where the fixed pulse Pf is produced automatically by the second flip flop with exor, without previous adjustment (Fig.4).

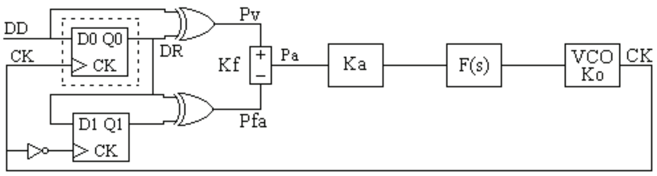

Fig.4 Synchronizer both at the rate and automatic (b-a)

The variable pulse Pv minus the fixed pulse Pf (Pv-Pf) determines the error phase that controls the VCO.

IV. SYNCHRONIZERS OPERATING AT QUARTER RATE

The synchronizer with its phase comparator operates, here, by positive transitions at quarter data transmission rate.

This variant has the manual (p-m/4) and the automatic (p-a/4) versions, the difference is only in the phase comparator. The variable pulse Pvp, based in the four first flip flops with multiplexer, is equal in the two versions, but the fixed pulse Pfp is produced from a different way [3, 4].

A. Positive transitions, at quarter rate and manual

The manual version has a phase comparator, where the fixed pulse Pf is produced by an exor with a delay $\Delta t = T/2$, that needs a previous manual adjustment (Fig.5).

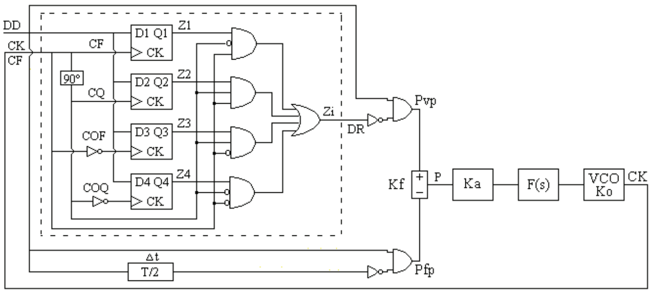

Fig.5 Synchronizer positive at quarter rate and manual (p-m/4)

The variable pulse Pv minus the fixed pulse Pf (Pv-Pf) determines the error phase that controls the VCO.

B. Positive transitions, quarter rate and automatic

The automatic version has a phase detector, where the fixed pulse Pf is produced automatically by the seconds flip flops and multiplexer with exor, without previous adjustment (Fig.6).

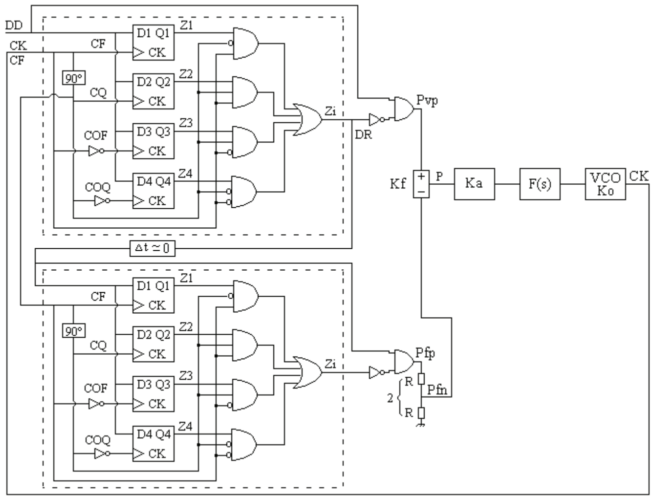

Fig.6 Synchronizer positive at quarter rate and automatic (p-a/4)

The variable pulse Pv minus the fixed pulse Pf (Pv-Pf) determines the error phase that controls the VCO.

V. DESIGN, TESTS AND RESULTS

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

A. Design

To get guaranteed results, it is necessary to dimension all the synchronizers with equal conditions. Then it is necessary to design all the loops with identical linearized transfer functions.

The general loop gain is Kl=Kd.Ko=Ka.Kf.Ko where Kf is the phase comparator gain, Ko is the VCO gain and Ka is the control amplification factor that permits the desired characteristics.

For analysis facilities, we use a normalized transmission rate tx=1baud, what implies also normalized values for the others dependent parameters. So, the normalized clock frequency is fCK=1Hz.

We choose a normalized external noise bandwidth Bn = 5Hz and a normalized loop noise bandwidth Bl = 0.02Hz. Later, we can disnormalize these values to the appropriated transmission rate tx.

Now, we will apply a signal with noise ratio SNR given by the signal amplitude Aef, noise spectral density No and external noise bandwidth Bn, so the $SNR = A^2_{ef}/(No.Bn)$. But, No can be related with the noise variance σn and inverse sampling $\Delta\tau = 1/Samp$, then $No = 2\sigma n^2.\Delta\tau$, so $SNR = A^2_{ef}/(2\sigma n^2.\Delta\tau.Bn) = 0.5^2/(2\sigma n^2 * 10^{-3} * 5) = 25/\sigma n^2$.

After, we observe the output jitter UI as function of the input signal with noise SNR. The dimension of the loops is

- 1st order loop:

The loop filter F(s)=1 with cutoff frequency 0.5Hz (Bp=0.5 Hz is 25 times bigger than Bl=0.02Hz) eliminates only the high frequency, but maintain the loop characteristics.

The transfer function is

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

the loop noise bandwidth is

$$Bl=\frac{KdKo}{4}=Ka\frac{KfKo}{4}=0.02Hz \quad (2)$$

Then, for the analog synchronizers, the loop bandwidth is $Bl=0.02=(Ka.Kf.Ko)/4$ with (Km=1, A=1/2, B=1/2; Ko=2π)

$$(Ka.Km.A.B.Ko)/4 = 0.02 \rightarrow Ka=0.08*2/\pi \quad (3)$$

For the hybrid synchronizers, the loop bandwidth is $Bl=0.02=(Ka.Kf.Ko)/4$ with (Km=1, A=1/2, B=0.45; Ko=2π)

$$(Ka.Km.A.B.Ko)/4 = 0.02 \rightarrow Ka=0.08*2.2/\pi \quad (4)$$

For the combinational synchronizers, the loop bandwidth is $Bl=0.02=(Ka.Kf.Ko)/4$ with (Kf=1/π; Ko=2π)

$$(Ka*1/\pi*2\pi)/4 = 0.02 \rightarrow Ka=0.04 \quad (5)$$

For the sequential synchronizers, the loop bandwidth is $Bl=0.02=(Ka.Kf.Ko)/4$ with (Kf=1/2π; Ko=2π)

$$(Ka*1/2\pi*2\pi)/4 = 0.02 \rightarrow Ka=0.08 \quad (6)$$

The jitter depends on the RMS signal Aef, on the power spectral density No and on the loop noise bandwidth Bl.
For analog PLL the jitter is
$\sigma\phi^2=Bl.No/Aef^2=Bl.2.\sigma n^2.\Delta\tau=0.02*10^{-3}*2\sigma n^2/0.5^2=16*10^{-5}.\sigma n^2$
For the others PLLs the jitter formula is more complicated.

- 2nd order loop:

The second order loop is not shown here, but the results are identical to the ones obtained above for the first order loop.

B. Tests

The following figure (Fig.7) shows the setup that was used to test the various synchronizers.

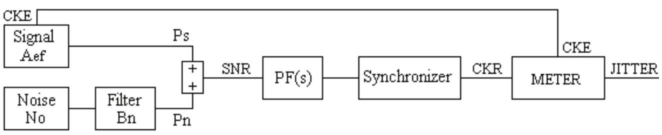

Fig.7 Block diagram of the test setup

The receiver recovered clock with jitter is compared with the emitter original clock without jitter, the difference is the jitter of the received clock.

C. Jitter measurer (Meter)

The jitter measurer (Meter) consists of a RS flip flop, which detects the random variable phase of the recovered clock (CKR), relatively to the fixed phase of the emitter clock (CKE). This relative random phase variation is the recovered clock jitter (Fig.8).

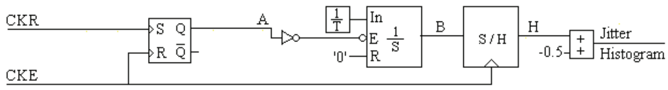

Fig.8 The jitter measurer (Meter)

The other blocks convert this random phase variation into a random amplitude variation, which is the jitter histogram.

Then, the jitter histogram is sampled and processed by an appropriate program, providing the RMS jitter and the peak to peak jitter.

D. Results

We will present the results (jitter - noise graphics) for the prefilter with the four synchronizers.

Fig.9 shows the jitter-SNR curves of the prefilter bandwidth B1=∞ with the four synchronizers namely both transitions at rate manual (b-m), both transitions at rate automatic (b-a), positive transitions at quarter rate manual (p-m/4) and positive transitions at quarter rate automatic (p-a/4).

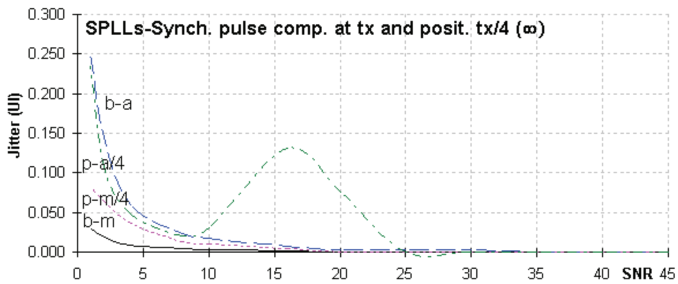

Fig.9 Jitter-SNR curves of B1+ 4 synchronizers(b-m,b-a,p-m/4,p-a/4)

We see that, in general, the output jitter UIRMS decreases gradually with the input SNR increasing. However, the positive at quarter rate (p-a/4) has some irregularities.

For prefilter B1=∞, for high SNR, the four synchronizer jitter curves tend to be similar. However, for low SNR, the manual versions (b-m, p-m/4) are significantly better than the automatic versions (b-a, p-a/4), the both transitions at rate manual (b-m) is slightly the best. Also, for an intermediate SNR (SNR ≅ 16), the positive transitions at quarter rate automatic (p-a/4) has a very significant jitter perturbation, due to some losses of synchronism.

Fig.10 shows the jitter-SNR curves of the prefilter bandwidth B2=2.tx with the four synchronizers namely both transitions at rate manual (b-m), both transitions at rate automatic (b-a), positive transitions at quarter rate manual (p-m/4) and positive transitions at quarter rate automatic (p-a/4).

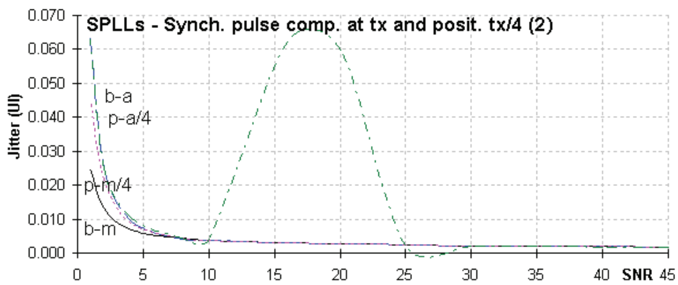

Fig.10 Jitter-SNR curves of B2+ 4 synchronizers(b-m,b-a,p-m/4,p-a/4)

For prefilter B2=2.tx, we verify that, it becomes the jitter-

SNR curves more similar between themselves. For high SNR, it harms slightly the jitter-SNR curves. However, for low SNR, it benefits significantly the jitter-SNR curves. Also, for an intermediate SNR (SNR ≅ 20), the positive transitions at quarter rate automatic (p-a/4) has a great jitter perturbation, due to some losses of synchronism.

Fig.11 shows the jitter-SNR curves of the prefilter bandwidth B3=1.tx with the four synchronizers namely both transitions at rate manual (b-m), both transitions at rate automatic (b-a), positive transitions at quarter rate manual (p-m/4) and positive transitions at quarter rate automatic (p-a/4).

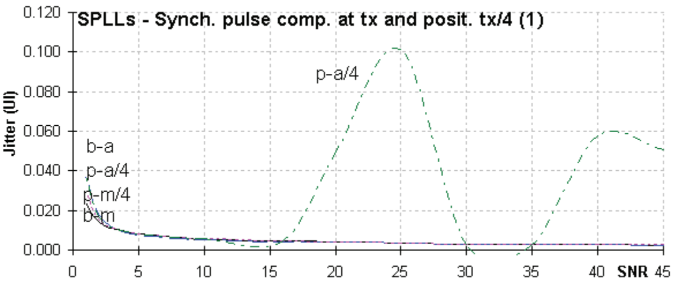

Fig.11 Jitter-SNR curves of B3+ 4 synchronizers(b-m,b-a,p-m/4,p-a/4)

For prefilter B3=1.tx, we verify that, it becomes the jitter-SNR curves still more similar between themselves. For high SNR, it harms more the jitter-SNR curves. However, for low SNR, it benefits less the jitter-SNR curves. Also, for an intermediate SNR (SNR ≅ 25), the positive transitions at quarter rate automatic (p-a/4) has a great jitter perturbation, due to some losses of synchronism.

VI. CONCLUSIONS

We studied three prefilter bandwidths (B1=∞, B2=2.tx, B3=1.tx) with four synchronizers, one variant operates by both transitions at the rate with two versions namely the manual (b-m) and automatic (b-a) and other variant operates by positive transitions at quarter rate with two versions namely the manual (p-m/4) and automatic (p-a/4). Then, we tested their jitter - SNR curves.

We observed that, in general, the output jitter curves decreases gradually with the input SNR increasing. However, the positive transitions at quarter rate (p-a/4) has some undesired irregularities.

For prefilter B1=∞, 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 manual versions (b-m, p-m/4) are significantly better than the automatic versions (b-a, p-a/4), this is comprehensible since the automatic versions have more digital states, then the error state propagation is aggravated. The version both transitions at rate manual (b-m) is slightly the best, because has less digital states. Also, for an intermediate SNR (SNR ≅ 16) the positive transitions at quarter rate automatic (p-a/4) has a very significant jitter perturbation due to some losses of synchronism.

For prefilter B2=2.tx, we verify that, it becomes the jitter-SNR curves more similar between themselves. For high SNR, it harms slightly the jitter-SNR curves. However, for low SNR, it benefits significantly the jitter-SNR curves. Also, for an intermediate SNR (SNR ≅20), the synchronizer (p-a/4) has a great jitter perturbation, due to some losses of synchronism.

For prefilter B3=1.tx, we verify that, it becomes the jitter-SNR curves still more similar between themselves. For high SNR, it harms more the jitter-SNR curves. However, for low SNR, it benefits less the jitter-SNR curves. Also, for an intermediate SNR (SNR ≅ 25), the synchronizer (p-a/4) has a great jitter perturbation, due to some losses of synchronism.

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

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