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

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***Abstract*- This work studies the effects of the prefilter bandwidth before the sequential symbol synchronizers based on pulse comparation at quarter rate. We consider three prefilter bandwidth namely B1=∞, B2=2.tx and B3=1.tx, where tx is the bit rate. We consider four synchronizers, one variant operates at the rate with versions manual (b-m) and automatic (b-a) and the other operates at quarter rate with versions manual (b-m/4) and automatic (b-a/4). The objective is to study the prefilter with the synchronizers and evaluate the output jitter UIRMS (Unit Interval Root Mean Square) versus input SNR (Signal Noise Ratio).**

Keywords - Prefilter; Synchronizers; Communication systems.

I. INTRODUCTION

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

The Butterworth prefilter, applied before the synchronizer, switches their bandwidth between three values, first B1=∞, after B2=2.tx and next B3=1.tx, where tx is the bit rate [1 ,2].

The sequential symbol synchronizer has four types that can operate at rate with versions manual (b-m) and automatic (b-a) and can operate at quarter rate with versions manual (b-m/4) and automatic (b-a/4) [3, 4, 5, 6].

The difference between the four synchronizers is only in the phase comparator, since the other blocks are equal [7, 8].

The VCO (Voltage Controlled Oscillator) is the clock that samples the data and retimes its bits duration [9, 10, 11, 12]. Fig. 1 shows the prefilter followed of the synchronizer.

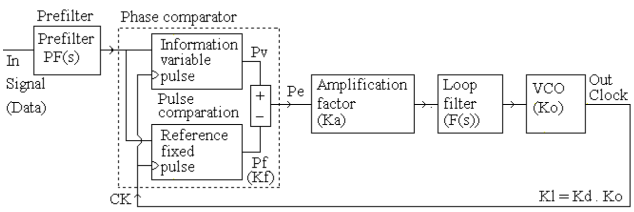

Fig. 1 Prefilter with the synchronizer based on pulse comparation

PF(s) is the prefilter. The synchronizer has various blocks, namely 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 loop characteristics.

Next, we present the state of the art. Then, we present the prefilter with three bandwidths (B1=∞, B2=2.tx, B3=1.tx).

After, we present the variant at bit rate with their manual and automatic versions. Next, we present the variant at quarter bit rate with their manual and automatic versions.

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

II. STATE OF THE ART, PROBLEM AND SOLUTION

In priori and actual-art state various synchronizers were developed, some ones operate at the rate, others at half rate and others at quarter rate. We study their performance. This contribution increases the knowledge obout synchronizers.

The motivation is to create new synchronizers operating at sub bit rate and evaluate their performance with noise [1, 2].

The problem is that the synchronizers' output jitter increaes with the input SNR decreases. To solve or to minimize this problem, we propose a prefilter that attenuates the noise but unfortunately distorts slightly the signal [3, 4, 5, 6, 7, 12].

II. PREFILTER BANDWIDTH EFFECTS

The prefilter, applied before the synchronizer, filters the noise but distorts 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.

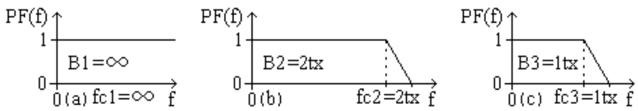

Fig. 2 Three prefilter bandwidths: a) B1=∞; b) B2=2.tx; c) B3=1.tx

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

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

c) Third, as 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 VCO operates, here, at the data transmission rate.

This variant has the manual and the automatic versions, the difference in only in the phase comparator. The variable pulse Pv consists of first flip flop with exor and is equal in the two versions, but the fixed pulse Pf is different [1, 2].

A. Operation at the rate and manual version

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)

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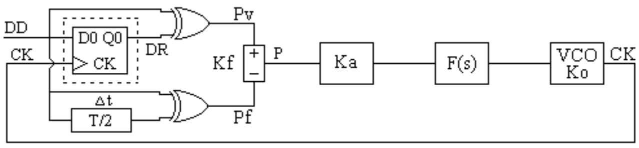

Fig. 3 Synchronizer at the rate and manual (b-m)

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

B. Operation at the rate and automatic version

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).

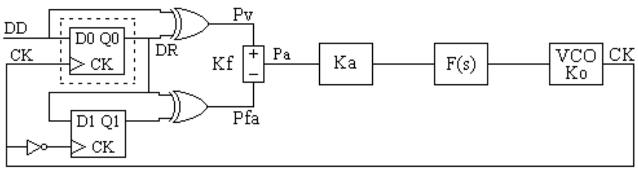

Fig. 4 Synchronizer at the rate and automatic (b-a)

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 both transitions at quarter data transmission rate.

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

A. Operation at quarter rate and manual version

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. 5).

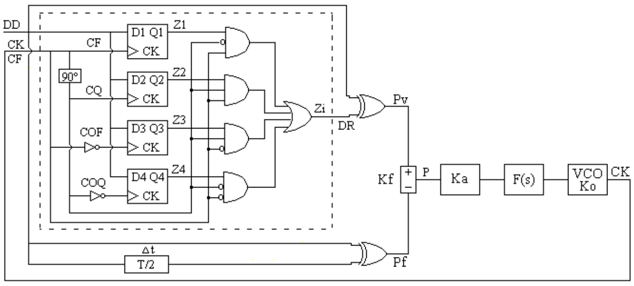

Fig. 5 Synchronizer at quarter rate and manual (b-m/4)

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

B. Operation at quarter rate and automatic version

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

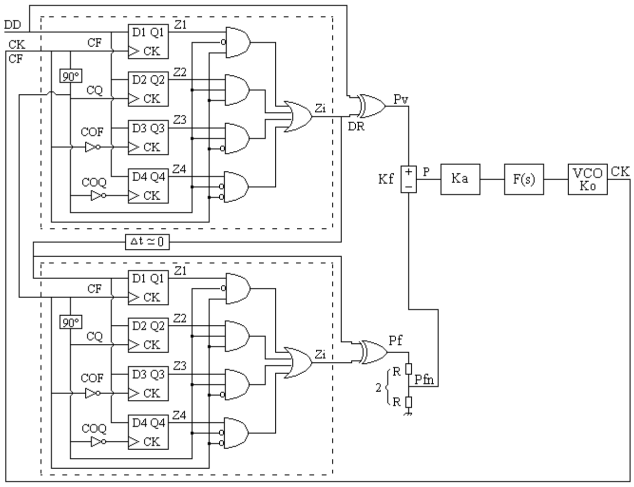

Fig. 6 Synchronizer at quarter rate and automatic (b-a/4)

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 Δτ=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

- 1^{st} 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.

- 2^{nd} 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.

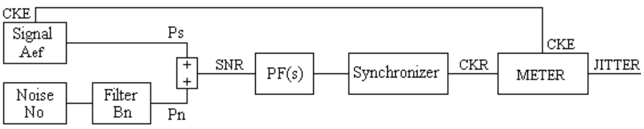

Fig. 7 Block diagram of the test setup

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).

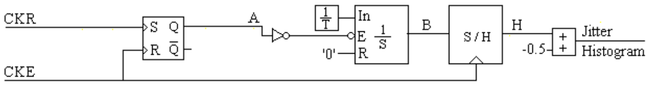

Fig. 8 The jitter measurer (Meter)

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 at the rate manual (b-m), at the rate automatic (b-a), at quarter rate manual (b-m/4) and at quarter rate automatic (b-a/4).

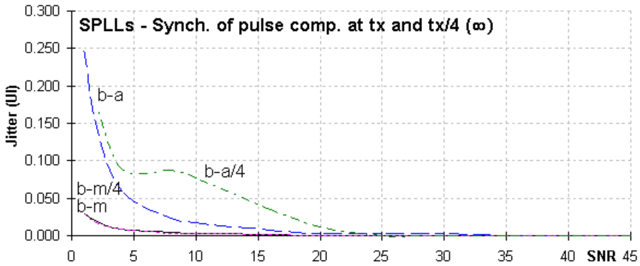

Fig. 9 Jitter-SNR curves of B1- 4 synchronizers(b-m,b-a,b-m/2,b-a/2)

We see that, in general, the output jitter UIRMS decreases gradually with the input SNR increasing. However, the type at quarter rate (b-m/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, b-m/4) are similar but slightly better than the automatic versions (b-a, b-a/4), the type at rate manual (b-m) is slightly the best. Also, for an intermediate SNR (SNR≅8), the type at quarter rate automatic (b-a/4) has a very significant jitter perturbation, due to various losses of synchronism.

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

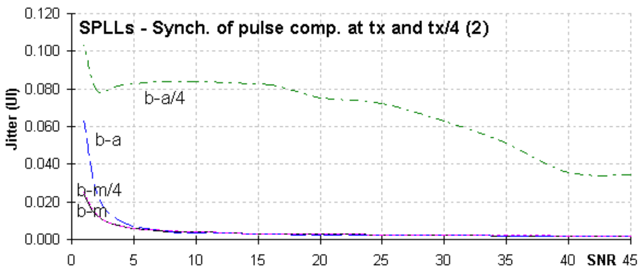

Fig. 10 Jitter-SNR curves of B2-4 synchronizers(b-m,b-a,b-m/2,b-a/2)

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For prefilter B2=2.tx, we verify that, it becomes the jitter-SNR curves more similar between themselves. For high SNR, it harms the jitter-SNR curves. However, for low SNR, it benefits significantly the jitter-SNR curves. Also, for an intermediate SNR (SNR≅10), the type both transitions at quarter rate automatic (b-a/4) has a very great jitter perturbation due to various losses of synchronism.

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

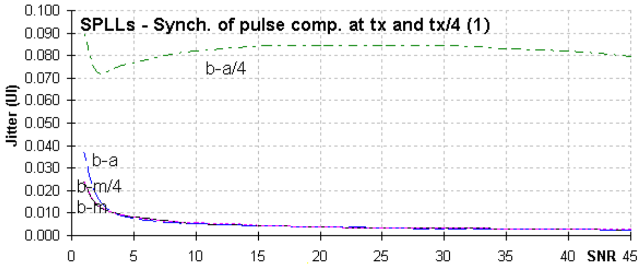

Fig. 11 Jitter-SNR curves of B3-4 synchronizers(b-m,b-a,b-m/2,b-a/2)

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≅12), the type both transitions at quarter rate automatic (b-a/4) has a very great jitter perturbation due to various losses of synchronism.

VI. CONCLUSION AND FUTURE WORK

We studied the prefilter with three bandwidths (B1=∞, B2=2.tx, B3=1.tx) followed of four synchronizers, at rate manual (b-m), at rate automatic (b-a), at quarter rate manual (b-m/4) and quarter rate automatic (b-a/4). We saw that, in general, the output jitter curves decreases gradually with the input SNR increasing. However, the type at quarter rate automatic (b-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, b-a/4), this is comprehensible since the automatic versions have more digital states, what aggravates the error state propagation. The type at rate manual (b-m) is slightly the best, because has less digital states. Also, for an intermediate SNR (SNR≅8) the quarter rate automatic (p-a/4) has a very significant jitter perturbation due to various 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 slightly the jitter-SNR curves. Also, for an intermediate SNR (SNR ≅10), the type (b-a/4) has a great jitter perturbation, due to various 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 ≅ 12), the type (b-a/4) has a great jitter perturbation, due to various losses of synchronism.

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

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