Sequential Symbol Synchronizers based on Pulse Comparation at Quarter Rate

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***Abstract*- This work presents the synchronizer based on pulse comparation, between variable and fixed pulses. This synchronizer has two variants, one operating by both transitions at the bit rate and other operating by both transitions at quarter rate. Each variant has two versions which are the manual and the automatic. 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).**

Keywords - Prefilter; Synchronizers; Communication systems.

I. INTRODUCTION

This work studies the sequential symbol synchronizer, with a phase comparator based on a pulse comparation, between a variable pulse Pv and a fixed reference pulse Pf.

The synchronizer has four types supported in two variants, one operating by both transitions at rate and other operating by both transitions at quarter rate. The variant at the rate has two versions namely the manual (b-m) and the automatic (b-a). The variant at quarter rate has also two versions, namely the manual (b-m/4) and the automatic (b-a/4) [1, 2, 3, 4, 5].

The difference between them is only in the phase comparator since the other blocks are equal [6, 7, 8].

The error pulse Pe (Pv - Pf) controls the VCO (Voltage Controlled Oscillator) to synchronize with the input data.

The variable pulse Pv is common to manual and automatic versions but the fixed pulse Pf is different [9, 10].

The VCO output is the clock, with good quality, that samples the input data at the maximum opening eye diagram and retimes its bit duration [11, 12].

Fig. 1 shows the blocks diagram of the synchronizer.

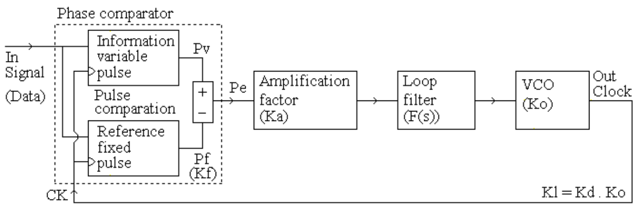

Fig. 1 Synchronizer based on pulse comparation

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.

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

After, 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, were developed various synchronizers operating, initially, at the bit rate. After, we developed synchronizers operating at half rate. Now, we present synchronizers operating at a quarter rate. This contribution increases the know-how about synchronizers.

Our motivation is to create new synchronizers and evaluate their performance. The problem is that the synchronizers have speed limitations. One solution proposes internal low frequency operation, but external high speed rate [1, 2, 3, 4].

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 $\Delta t = T/2$, that needs a previous manual adjustment (Fig. 2)

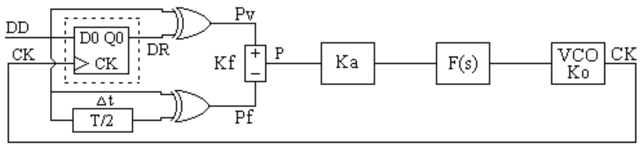

Fig. 2 Synchronizer at the rate and manual (b-m)

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

Fig. 3 shows the waveforms of the synchronizer operating at the rate and manual version.

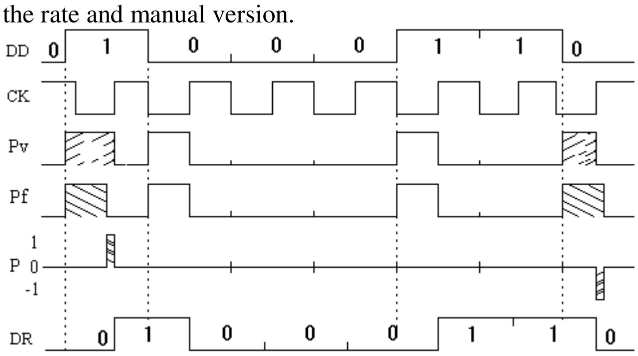

Fig. 3 Waveforms of the synchronizer at the rate and manual

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

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).

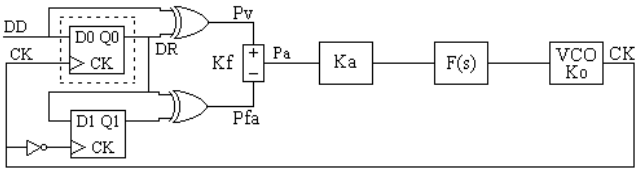

Fig. 4 Synchronizer at the rate and automatic (b-a)

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

Fig. 5 shows the waveforms of the synchronizer operating at the rate and automatic version.

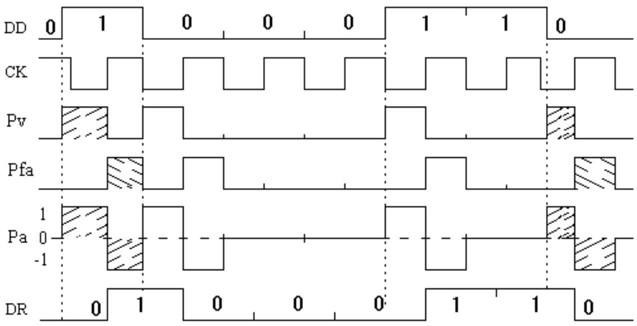

Fig. 5 Waveforms of the synchronizer at the rate and automatic

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

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. 6).

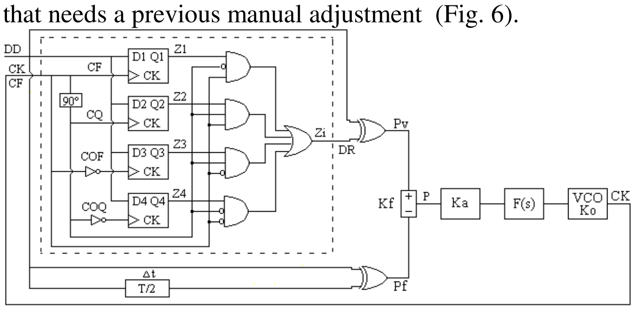

Fig. 6 Synchronizer at quarter rate and manual (b-m/4)

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

Fig. 7 shows the waveforms of the synchronizer operating at quarter rate and manual version.

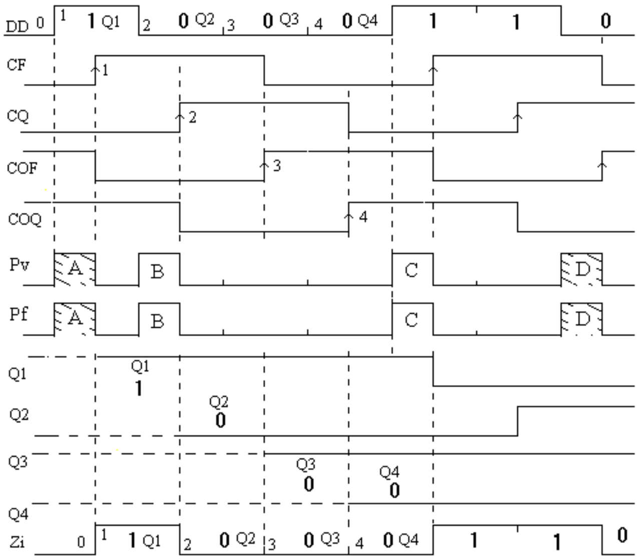

Fig. 7 Waveforms of the synchronizer at quarter rate and manual

The error pulse Pe diminishes and disappear at the equilibrium point

B. Operation at quarter rate and automatic version

The automatic version has a phase comparator, where the fixed pulse Pf is produced automatically by the seconds flip flops and multiplexer with exor, without previous adjustment (Fig. 8).

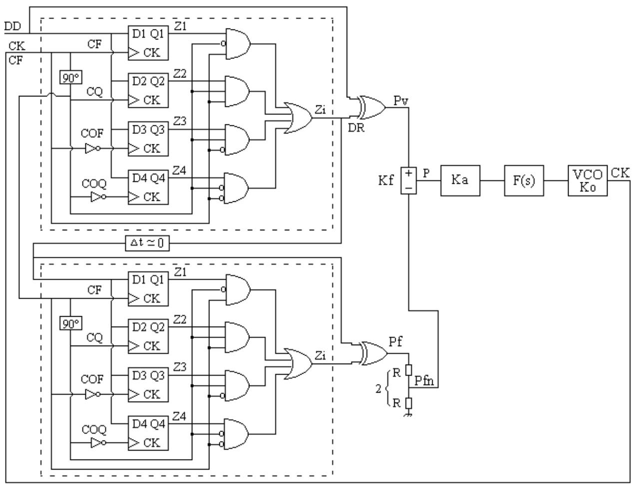

Fig. 8 Synchronizer at quarter rate and automatic (b-a/4)

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

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Fig. 9 shows the waveforms of the synchronizer at quarter rate and automatic version.

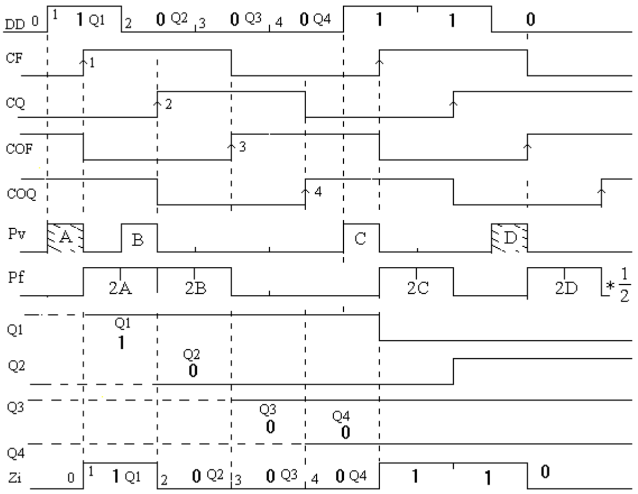

Fig. 9 Waveforms of the synchronizer at quarter rate and automatic

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

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=2σn^2.Δτ, so SNR=A^2_{ef}/(2σn^2.Δτ.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

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

the loop noise bandwidth is

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

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)

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

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)

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

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

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

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

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

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.σn^2.Δτ=$0.02*10^{-3}*2\sigma n^2/0.5^2=16*10^{-5}.\sigma n^2$
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. 10) shows the setup that was used to test the various synchronizers.

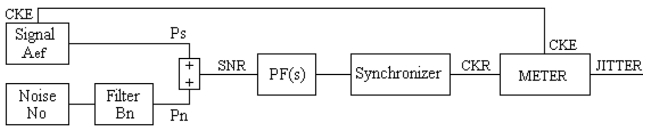

Fig. 10 Block diagram of the test setup

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. 11).

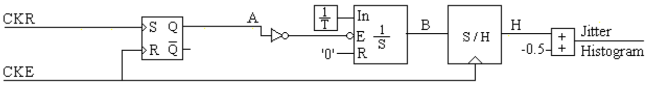

Fig. 11 The jitter measurer (Meter)

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 four synchronizer results in terms of output jitter UIRMS versus input SNR.

Fig. 12 shows the jitter-SNR curves of the four synchronizers with both transitions, at rate manual version (b-m), at rate automatic version (b-a), at quarter rate manual version (b-m/4) and at quarter rate automatic version (b-a/4).

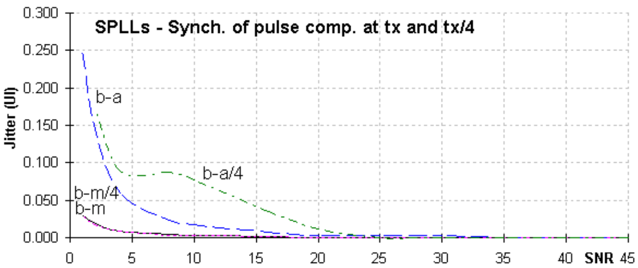

Fig. 12 Jitter-SNR curves of the 4 synchronizers(b-m,b-a,b-m/2,b-a/2)

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

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 significantly better than the automatic versions (b-a, b-a/4), the both transition at rate manual (b-m) is slightly the best. Also, for an intermediate SNR (SNR≅10), the both transitions quarter rate automatic (b-a/4) has a significant jitter perturbation, due to some losses of synchronism.

V. CONCLUSION AND FUTURE WORK

We studied four synchronizers using both transitions, with two variants, one operating at the rate that has two versions namely the manual (b-m) and the automatic (b-a) and other variant operating at quarter rate that has also two versions namely the manual (b-m/4) and the automatic (b-a/4). Then, we tested their jitter - noise curves.

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

We verified that, for high SNR, the four synchronizers jitter curves tend to be similar, this is comprehensible since the synchronizers are digital and have similar noise margin.

However, for low SNR, the manual versions (b-m, b-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 than the manual versions, then the error state propagation effects is aggravated.

The version at rate manual (b-m) is slightly the best because has less digital states. On the other hand, the version at quarter rate automatic (b-a/4) has a significant jitter perturbation (SNR≅10) 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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