Four Carrier Phase Synchronizers Tested with Three Input Waves

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Resumo - Neste trabalho, estudaremos quatro tipos de sincronizadores de fase de portadora, nomeadamente o analógico, o hibrido, o combinacional e o sequencial.

Estes quatro sincronizadores de fase de portadora serão operados primeiro com a onda sinusoidal, depois com a triangular e por último com a rectangular.

O principal objectivo é estudar os quatro tipos de sincronizadores com as três ondas e observar o seu jitter UIRMS (Unidades Intervalo da Raiz Média Quadrática) em função da entrada SNR (Relação Sinal Ruído).

Palavras chave: Sincronismo em Comunicações

Abstract - In this work, we will study four carrier phase synchronizer types namely the analog, the hybrid, the combinational and the sequential.

The four carrier phase synchronizers will be operated first with the sinusoidal wave, after with the triangular wave and last with the rectangular wave.

The main objective is to study the four synchronizer types with the three input waves and to observe its jitter UIRMS (Unit Interval Root Mean Squared) as function of the input carrier SNR (Signal to Noise Ratio).

I. INTRODUCTION

The carrier phase synchronizer, also known as carrier phase Lock Loop (CPLL), synchronizes its VCO (Voltage Controlled Oscillator) with the input signal. Then the VCO signal follows the input signal phase and frequency. So, the VCO input is the base band signal that modulates the carrier.

Here, we will present four carrier phase synchronizers namely the analog, the hybrid, the combinational and the sequential [1, 2, 3, 4, 5, 6, 7, 8, 9, 10].

These four synchronizers will be operated with the three input waves, which are the sinusoidal, the triangular and the rectangular [10, 11, 12, 13, 14, 15, 16, 17].

Fig.1 shows the general aspect of the carrier phase synchronizer.

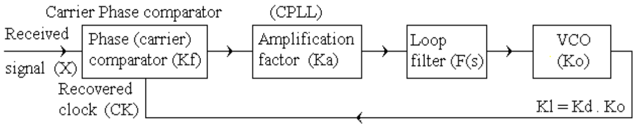


Fig.1 General aspect of the carrier Phase Synchronizer

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

Following, we present the four carrier phase synchronizers which are the analog, the hybrid, the combinational and the sequential.

After, we will show the three carrier waves which are the sinusoidal, triangular and rectangular.

Next, we will present the design and the tests of the four synchronizers, with the three input waves, in the presence of noise.

Then, we present the results with some comparisons.

Finally, we present some conclusions.

II. THE FOUR CARRIER PHASE SYNCHRONIZERS

We will present the four carrier synchronizer types namely, the analog, the hybrid, the combinational and the sequential. The difference between them is inside of the carrier phase comparator [1, 2].

A. Analog type

The carrier phase comparator is based on a multiplier (ideal analog multiplier) which is an analog component (Fig.2).

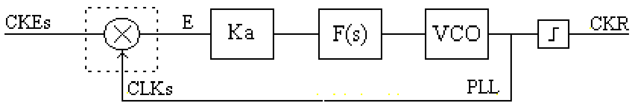


Fig.2 Analog carrier phase synchronizer

The phase comparator inputs (main input and VCO output) are both analog.

B. Hybrid type

The carrier phase comparator is based on a switch (real hybrid multiplier) which is an hybrid component (Fig.3).

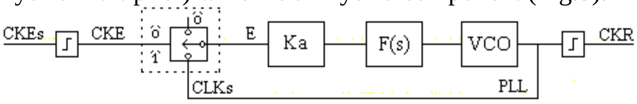


Fig.3 Hybrid carrier phase synchronizer

The phase comparator main input is, now, digital but the input coming from the VCO output continues to be analog.

C. Combinational type

The carrier phase comparator is based on an exor gate which is a combinational component (Fig.4).

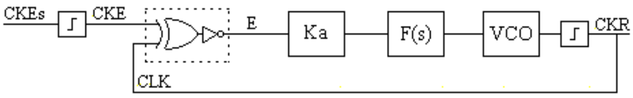


Fig.4 Combinational carrier phase synchronizer

The phase comparator inputs (main input and VCO output) are both digital, but its output is only function of the inputs (circuit without memory).

D. Sequential type

The carrier phase comparator is based on a flip flop which is a sequential component (Fig.5).

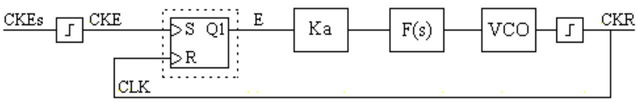


Fig.5 Sequential carrier phase synchronizer

The phase comparator inputs (main input and VCO output) are both digital, but its output is simultaneously function of the inputs and of the phase comparator state (circuit with memory).

III.THE THREE INPUT WAVES

We will observe the behavior of the four synchronizers when the input carrier changes between the sinusoidal wave, triangular wave and rectangular wave [3, 4].

Fig.6 shows the input carrier, when its form changes, but maintaining its signal power.

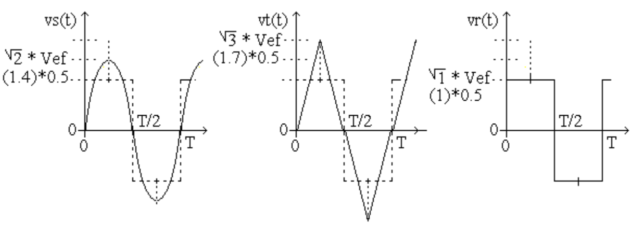


Fig.6 The three input waves: sinusoidal, triangular and rectangular

In the three waves, we wish the same signal to noise ratio SNR in order to have equal conditions.

Since the noise power Pn=No*Bn is equal in the three cases, then the signal power $Ps=Aef^2$ must also be equal in the three waves. Where, No is the noise spectral density, Bn is the extern bandwidth and Aef=Arms is the signal root mean squared signal amplitude.

So, in order to have the same signal power $Ps= Arms^2$ and consequently the same RMS amplitude for the three waves, the sinusoidal wave must have a peak amplitude Ap= √2*Aef, the triangular wave must have a peak amplitude Ap=√3*Aef and the rectangular wave must have a peak amplitude Ap=√1*Aef. In the last figure, we considered Aef=Arms=0.5V.

IV. DESIGN, TESTS AND RESULTS

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

A. Design

To have 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 characteristic 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 disnormalized this values to the appropriated transmission rate tx.

Now, we will apply a signal to noise ratio SNR, related with the signal amplitude Aef, noise spectral density No and external noise bandwidth Bn, it is $SNR = A^2_{ef}/(No.Bn)$. 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 $SNR=A^2_{ef}/(2\sigma n^2.\Delta\tau.Bn) = 0.5^2/(2\sigma n^2 * 10^{-3} * 5)= 25/\sigma n^2$.

- 1^{st} order loop:

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

The transfer function is

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

the loop noise bandwidth is

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

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 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 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 the analog PLL the jitter is

$$\sigma\phi^2=Bl.No/Aef^2=Bl.2.\sigma n^2.\Delta\tau/Aef^2=0.02*2\sigma n^2*10^{-3}/0.5^2 =16*10^{-5}.\sigma n^2$$

For the others PLLs the jitter formula is more complicated.

- 2^{nd} order loop:

The second order loop is not considered here, but the results are similar with the ones obtained above.

B. Tests

Fig.7 shows the setup that was used to test the various synchronizers.

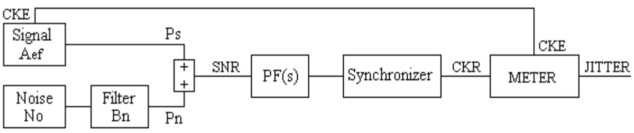


Fig.7 Block diagram of the test setup

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

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).

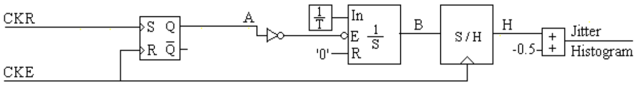


Fig.8 The jitter measurer (Meter)

The others 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 separately the jitter-noise curves of the four carrier synchronizers for the three input waves.
Fig.9 shows the UI jitter - SNR curves of the four synchronizers (ana, hib, cmb, seq) for the input sinusoidal wave (in sinusoidal).

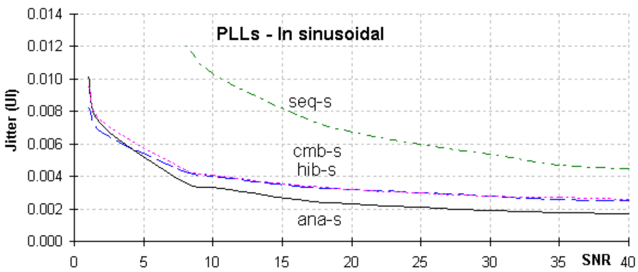


Fig.9 Jitter-SNR curves of the four synchronizers (in sinusoidal)

We verify, that generally the analog type has the best performance followed of the hybrid and combinational types that are similar and the sequential type has the worst performance.
Fig.10 shows the UI jitter - SNR curves of the four synchronizers (ana, hib, cmb, seq) for the input triangular wave (in triangular).

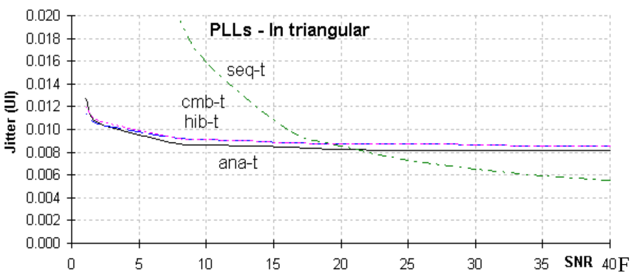
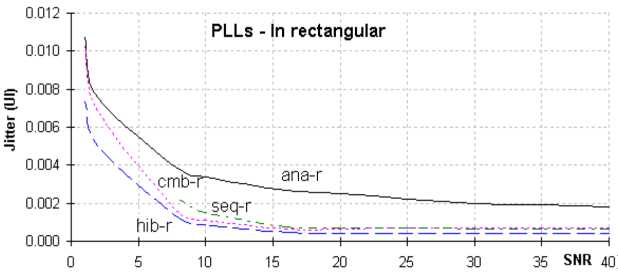


Fig.10 Jitter-SNR curves of the four synchronizers (in triangular)

We verify that for low SNR the sequential type has the worst performance and for high SNR the sequential type has the best performance. The analog, hybrid and combinational are similar.
Fig.11 shows the UI jitter - SNR curves of the four synchronizers (ana, hib, cmb, seq) for the input rectangular wave (in rectangular).



ig.11 Jitter-SNR curves of the four synchronizers (in rectangular)

We verify, that for high SNR the analog type has the worst performance and the hybrid, the combinational and the sequential are similar. However, for low SNR the sequential type has synchronism problems what increases quickly the jitter.

V. CONCLUSIONS

We studied four types of synchronizers namely the analog, the hybrid, the combinational and the sequential. Then, for the three different input carrier waves: sinusoidal, triangular and rectangular, we observed their output jitter UIRMS versus input SNR.

Generically for all cases, the output jitter UIRMS diminishes almost exponentially with the input SNR increasing.

For the sinusoidal wave, the analog is the best followed similarly of the hybrid and combinational and the sequential is the worst. This is comprehensible in the sequential type since the noise at the threshold zone produces output spikes that increases the jitter.

For the triangular wave, the analog, hybrid, combinational and sequential are similar and have similar curves. The sequential has a higher slope curve, this is comprehensible since for low SNR the error state increases the jitter and for high SNR the noise margin diminishes the jitter.

For the rectangular wave, for high SNR, the analog is the worst and the hybrid, combinational and sequential are similar. This is comprehensible since the limiter of the types (hybrid, combinational and sequential) has noise margin what ignores low noise spikes. For low SNR, the sequential type has synchronism problems that increases the jitter.

ACKNOWLEDGMENTS

The authors are grateful to the program FCT (Foundation for sCience and Technology).

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