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Effects of Prefiltering on Symbol Synchronizer Performance

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Resumo - **Neste artigo estudamos os efeitos do prefiltro no jitter dum sincronizador de dados.**

Veremos o prefiltro como um parâmetro que pode influenciar a curva do jitter de saída versos ruído entrada.

Mostraremos como o prefiltro é benéfico para baixas relações sinal ruído (SNR) e prejudicial para altas SNR

Para baixas quantidades de ruído o sincronizador opera no modo linear, mas o incremento do ruído distorce a linearidade do sincronizadores e dificulta as análises.

Abstract - **In this paper we study the effects of the prefilter on the jitter of a data synchronizer.**

We will see the prefilter as the parameter that can influence the curve of the output jitter versus input noise.

We will show as the prefilter is beneficial for low signal to noise ratios (SNR) and prejudicial for high SNR.

For low noise quantities the synchronizer operates in the linear mode but the increasing of the noise distorts the synchronizers linearity and difficults the analysis.

I. INTRODUCTION

The prefilter acts on the signal and on the noise at the same time. The ideal filter would be the one that only passes the signal without any distortion and eliminates completely the noise.

However there aren't ideal filters and the real ones sometimes distorts the signal and only attenuates the noise.

Fig.1 illustrates the prefilter that many times precedes the synchronizer.

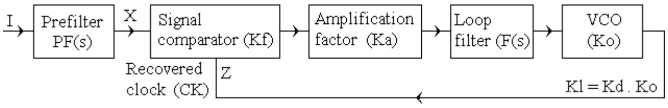

Fig.1 Block diagram of the synchronizer with prefilter

The synchronizer can be implemented with analog components, hybrid components, combinational logic and sequential logic.

We will use the sequential data synchronizer since it will be used as reference for synchronizers operating at sub data rates. However this synchronizer present great nonlinearity with the noise and maybe the combinational data synchronizer could be a better choice. We dimensioned the normalized loop with a data rate tx=1baud an external noise bandwidth Bn=5txHz, a loop noise bandwidth Bl=0.02txHz.

We will analyze the effects, on the jitter-noise curves, of various types of prefilters namely the perfect, the Butterworth, raised cosine and the matched.

Although be relevant the real case with the prefilter acting on the signal corrupted by noise we also observe the prefilter acting separately only on the signal and only on the noise.

Finally we present the setup of the real case analyzing the effects of the different prefilters as parameter on the jitter-noise curves. We establish comparisons and conclusions.

II. PARTICULAR IMPLEMENTATIONS

A. Synchronizer with input square wave

Fig.2 shows the sequential data synchronizer. The phase comparator is based on a synchronous circuit, where a variable pulse Pv is compared with a fixed one Pf.

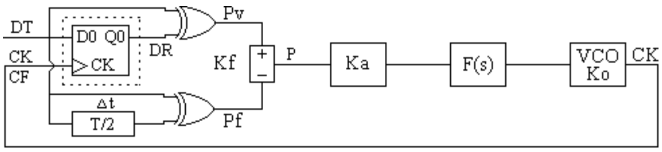

Fig.2 Sequential data synchronizer

Kf is the phase gain, Ka is the amplification factor, F(s) is the loop filter and Ko is the VCO gain.

Fig.3 illustrates the operation of the sequential data synchronizer.

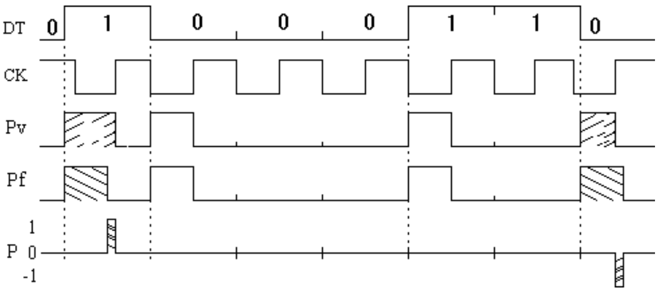

Fig.3 Waveforms at the sequential data synchronizer

At the equilibrium point, the two pulses are equal and then the error pulse vanishes. When the VCO (clock) delays relatively the data is generated a positive error pulse that advances the VCO. When the VCO advances is generated a negative error pulse that delays the VCO.

B. Prefilters types

For implement the prefilter we used each one of the low pass prototypes of Fig.4. So Fig.4a shows the wideband, Fig.4b shows the Butterworth, Fig.4c shows the raised cosine and Fig.4d shows the matched low pass prefilter.

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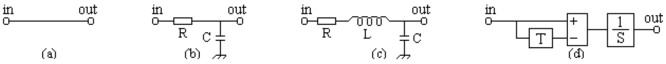

Fig.4 Prefilter types

The prefilters can mathematically be approximated by the following expressions.

r(t)= $\sum_{K=0}^{n-1} a_k g_T(t-kT) = \sum_{K=0}^{n-1} g_T(t-kT)$ for deterministic signals

Where a_k is equal 1 for existence of pulse and equal 0 for absence of pulse, gT is the pulse shape.

So that there isn't symbol interference g(t) must satisfy the following property

$$g(t) = \begin{cases} 1 & t = 0 \\ 0 & t = \pm T \;;\; \pm 2T \;;\; \pm NT \end{cases}$$

We impose that the pulse spectral g(t) be limited band, such that

$$P(f) = 0 \quad |f| > B.$$

The wideband (perfect or ideal) prefilter with high bandwidth is a perfect conductor with infinite bandwidth. Then the output signal is equal to the input.

$$y(t) = 1\ x(t)$$

The Butterworth prefilter can be approximated by the low pass RC filter.

$$H(f) = 1/(1+jf/B) \text{ where } B=1/2\pi RC$$

The raised cosine prefilter with theoretical formula

$$P(f)=\begin{cases} 1 & ;\ |f| < \frac{1}{2T}(1-r) \\ \cos^2\left[\frac{\pi}{2r}\left(|f|T - \frac{1}{2}(1-r)\right)\right] & ;\frac{1}{2T}(1-r) < |f| < \frac{1}{2T}(1-r) \\ 0 & ;\ |f| < \frac{1}{2T}(1-r) \end{cases}$$

can in the practical be approximated by a polynomial of 2nd, 3th, 4th, etc here we used the 2nd polynomial.

The normalized polls are -2.5076 ± j2.5076 that gives the following transfer function

$$H(s) = \frac{2}{s^2 0.159 + s0.7976 + 2}$$

A good approximation of the raised cosine needs a high order polynomial but the 2nd one is sufficient for our analyzes.

The matched prefilter can be approximated by

$$s(t) = \sum_{K=0}^{n-1} a_k g_T(t-kT)\frac{1}{s}$$

The prefilter wideband causes the minimum distortion on the signal, followed by the butterworth and raised cosine and the maximum distortion is caused by the matched filter.

III. POSSIBLE SETUPS

A. Changing the position of the prefilter

Normally in the real case the prefilter acts on the signal with the overlapped noise. Then it is placed in a point that precedes the synchronizer as shown in Fig.5X.

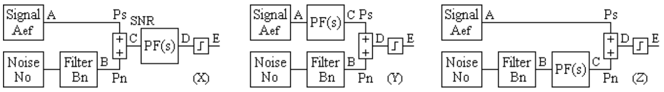

Fig.5 Possible positions of the prefilter on the setup

Fig.6 shows the waveforms corresponding to the setup of Fig.5X with the various prefilters previously mentioned.

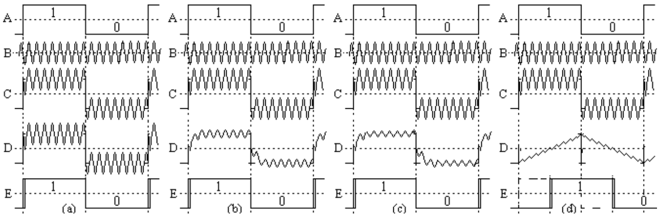

Fig.6 Waveforms corresponding to the setup of Fig.5X

Fig.7 shows the waveforms corresponding to the setup of Fig.5Y with the various prefilters previously mentioned.

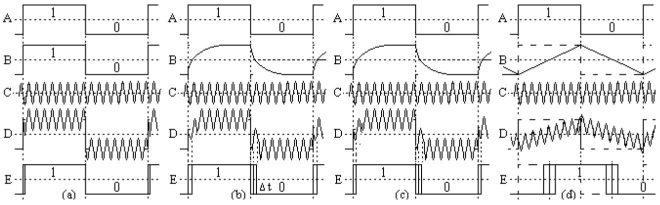

Fig.7 Waveforms corresponding to the setup of Fig.5Y

Fig.8 shows the waveforms corresponding to the setup of Fig.5Z with the various prefilters previously mentioned.

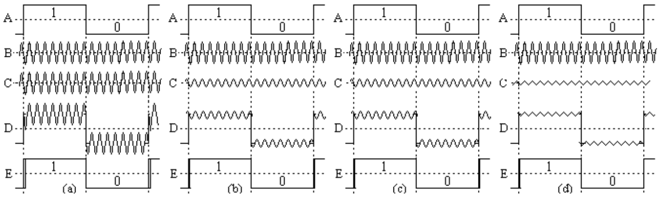

Fig.8 Waveforms corresponding to the setup of Fig.5Z

In this work we are only interested on the setup of Fig.5X, therefore is the unique studied and analyzed here. However the matter presented here can be superiority understood since Fig5X posses the combined effects of Fig.5Y and Fig.5Z.

The setup of Fig.5Y can be related with [2] where the same noise is summed to a square (wideband), sinusoidal (Butterworth and raised cosine) and triangular (matched). The squared correspond to the better case and the triangular to the worst case.

The setup of Fig.5Z is evident as the bigger the prefilter effects the lower the noise and consequently the jitter. Then the wideband is the worst case and the matched the better.

IV. TESTS, DESIGN AND RESULTS

A. Test setup used

To get the jitter-noise curve of the synchronizer we used the setup of Fig.8.

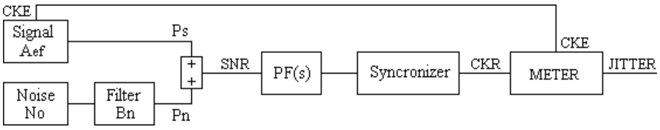

Fig.9 Block diagram of the test setup

The signal to noise ratio SNR is given by Ps/Pn, where Ps is the signal power and Pn is the noise power. They are defined as $Ps=A_{ef}^2$ and $Pn=No.Bn=2\sigma_n^2\Delta\tau.Bn$. A_{ef} is equivalent to the RMS amplitude, Bn is the noise bandwidth, No is the noise power spectral density, σ_n is the noise standard deviation and $\Delta\tau$ is the sampling period (inverse of samples per unit time).

The prefilter (PF(s)) is each one of the mentioned previously [2].

B. Jitter measurer

The jitter measurer (METTER) of Fig.9 consists of a RS flip-flop which detects the recovered clock phase variation (VCO) relatively to the fix phase of the emitter clock. That relative phase variation is the recovered clock jitter.

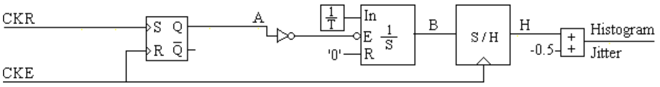

Fig.10 The jitter measurer device

The following blocks convert this phase variation into an amplitude variation which is the histogram jitter. This is then sampled and processed by a software program giving its average, jitter variance in radians, jitter standard deviation in root mean squared unit intervals UIRMS and jitter standard deviation in peak to peak unit intervals UIPP.

C. Loop parameters dimensioning

To perform comparisons, it is necessary to design all the loops with identical linearized transfer functions.

The loop gain is given by Kl=Kd.Ko=Ka.Kf.Ko where Kd is the phase detector gain, Ko is the VCO gain and Kf is the phase comparator gain. All these referred parameters are fixed, and so the loop amplification factor Ka is the controlling parameter that acts in the roots location, allowing the desired characteristics.

We used a normalized operating frequency fo=1, that implies relative normalized values for the others parameters, simplifying the analysis. So we have a frequency clock fCK =1fo Hz =1Hz, a noise bandwidth Bn = 5fo Hz = 5 Hz and a loop noise bandwidth Bl = 0.02fo Hz = 0.02 Hz.

The relation between SNR and σn is $SNR = Aef^2/No.Bn = Aef^2/(2\sigma n^2 .\Delta\tau.Bn) = (0.5)^2/(2\sigma n^2 * 10^{-3} * 5) = 25/\sigma n^2$.

We will now present the 1st and 2nd order loop dimensioning. The loop filter does not exist in the 1st order loop but is important in the dimensioning of the 2nd one.

- 1st order Loop

In the 1st order loop the filter F(s) eliminates only the high frequency perturbation terms, produced by the phase comparator, without influencing the loop characteristics. Thus we used a cut-off frequency for F(s) equal to 0.5Hz which is 25 times higher than Bl=0.02Hz (normalized).
In this loop the transfer function is

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

and the loop noise bandwidth is

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

so for the sequential PLL we have

$$Ka\frac{KfKo}{4} = Ka\frac{(1/2\pi)2\pi}{4} = 0.02\text{Hz} \dashrightarrow \text{Ka} = 0.08 \qquad (3)$$

- 2nd order loop

The transfer function with $F(s) = \frac{1+sT2}{sT1}$ is

$$\text{H(s)} = \frac{sKdKo(T2/T1) + KdKo/T1}{s + sKdKo(T2/T1) + KdKo/T1} \qquad (4)$$

$$= \frac{sA+B}{s^2 + s2\xi Wn + Wn^2} \qquad (5)$$

and the loop noise bandwidth is

$$\text{Bl} = \frac{\xi Wn}{2}\left(1+\frac{1}{4\xi^2}\right) \qquad (6)$$

Taking (ξ=1 and Bl=0.02) and solving the above equations we obtain for F(s)

$$\text{F(s)} = \frac{1+s63}{s977} \qquad (7)$$

so for the sequential PLL we have

$$\text{Kd=KaKf=Ka}\frac{1}{2\pi} = \frac{1}{2\pi} \dashrightarrow \text{Ka} = 1 \qquad (8)$$

The same process will be used for any other synchronizer.

G. Results of the prefiltering effects

We inserted a prefilter PF(s) in a point that precedes the synchronizer. These filters were the wideband (s-filt) Butterworth (Butt), the matched (adap) and the raised cosine (c-el). In Fig.11, for the case of the sequential digital synchronizer, we show the jitter-SNR curves corresponding to those prefilters.

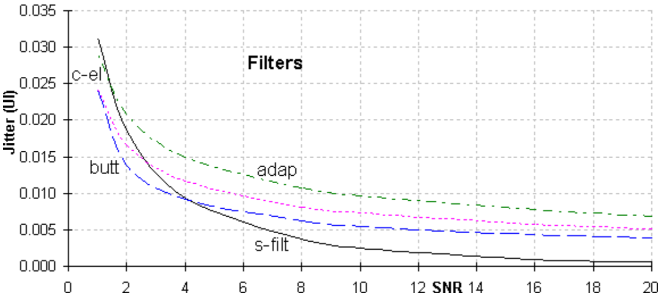

Fig.11 RMS jitter for some types of prefiltering

We verify that for signal to noise ratios SNR>4 the version without prefilter (s-filt) is advantageous over the others. However for high noise levels (low signal to noise ratio SNR<4) the prefilter is beneficial. As the signal to noise ratio decreases the Butterworth filter is the first to take advantage over the absence of filter situation (SNR=4.2), then the raised cosine (SNR=2.7) and at last the matched (SNR=1.5).

V. CONCLUSIONS

In this work we have considered the effect of the prefilter on the jitter of a sequential data synchronizer. This synchronizer type is very nonlinear with the noise causing by error states with noise spikes. Maybe a synchronizer more linear as the combinational data synchronizer could be a better example and we would can see better the real effect of the prefilter, however at this moment we have only the results when the synchronizer used was the sequential type.

For high SNR the synchronizer operates in the linear mode for witch it was designed. For low SNR the loop can no more be considered in the linear mode.

We analyzed the position of the prefilter on he signal way on the noise way and on the both way. Although the last case is the real case the first two are important to understand better the situation. Thus in the first case the prefilter only distorts the signal then the prefilter that causes more distortion is the worst case. In the second case the prefilter only attenuates the noise then the prefilter that cause more attenuation is the better case. So the better in the first case is the worst in the second case. The third case combines the first two, is the real case and was carefully analyzed and studied.

We observe that when we go (from the wideband, passing by the Butterworth and raise cosine until the matched), the transition slope of the signal decreases, diminishing its immunity to the noise but at same time the attenuation of the noise increases.

The results show that the prefilter causes a diminution of the input transition slope which tends to increase the jitter, but on the other hand it filters the overlapped noise which tends to decrease the jitter. This is the reason why the prefilter is advantageous for low SNR and disadvantageous for high SNR [2]. For very high SNR there is no noise and then the prefilter only distorts the input signal.

ACKNOWLEDGMENTS

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