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FAST FREQUENCY SYNCHRONIZATION SYSTEMS

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Abstract—*The new methods of acceleration harmonic signal frequency tracking based on estimates of instantaneous frequency and phase, are proposed and investigated. Better efficiency of new systems e.g. quicker transient process and bigger frequency range is proved in comparison with conventional system of frequency synchronization.*

Index Terms—FLL; PLL; fast frequency discriminator; frequency and phase tracking; instantaneous frequency estimation; nonlinear control systems.

I. STATEMENT OF THE PROBLEM

The problem of frequency stability is important in many radio-, electrical and mechanical devices. Usually thereto closed control loops are used that provide frequency and phase synchronization of the voltage control oscillator (VCO) output signal (OS) to some external reference signal (RS) [1].

The most versatile frequency tracking method, which is almost fully independent on the waveform, based only on the zero-crossing points. But the transitional adjustment process can take up to several tens of periods of the signal, because these moments distance from each other on the half of period.

In the case of harmonic signal it is appropriate to use additional information contained in its form. On this principle is based typical phase-locked loop (PLL) system shown in Fig. 1, which synchronous phase detector consists of a sequential multiplier and low pass filter (LPF). Such a system is static in phase, because phase difference Δφ between the signals S_R and S_O cannot be null to ensure the necessary level of control signal (CS) V at the VCO output.

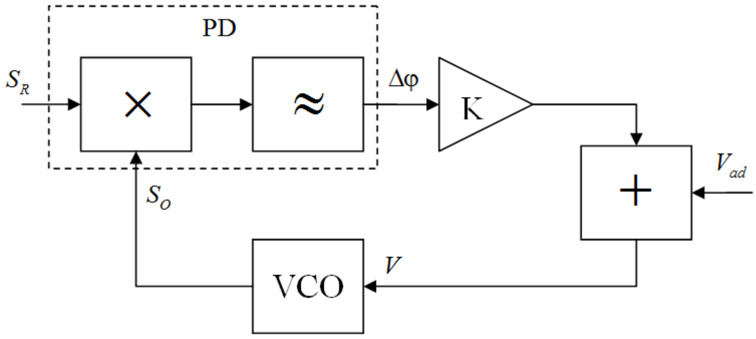

Fig. 1. Typical phase-locked system

An additional phase support V_{ad} is injected in a closed control loop to accelerate the transient process. Since its value is fixed and is determined by the lowest possible frequency of the input signal range, for greater frequencies its impact proportionally reduced.

The fundamental need for the low-pass filter in a closed control loop leads to latency in the transient process in examined PLL.

For example, Fig. 2 shows the time diagram of VCO frequency deviation, which was obtained by computer simulation at following conditions: one realization of a mixture of the reference signal with white Gaussian noise, turning on the system is at the zero point, VCO adjusting characteristic is linear, the reference signal initial frequency F_0= 1 MHz , the reference signal frequency jumps to 670 kHz at 0.02 ms and then to 1.5 MHz at 0.04 ms; SNR=-20 dB, sampling frequency – F_S= 50 MHz there is used exponential loop filter with cut-off frequency $F_{co} = 0.08 \cdot F_0 = 0.08$ MHz; system gain $K = 1.$, $V_{ad} = 0{,}5 \cdot V_0$, where V_0 is nominal control signal value for the nominal frequency F_0.

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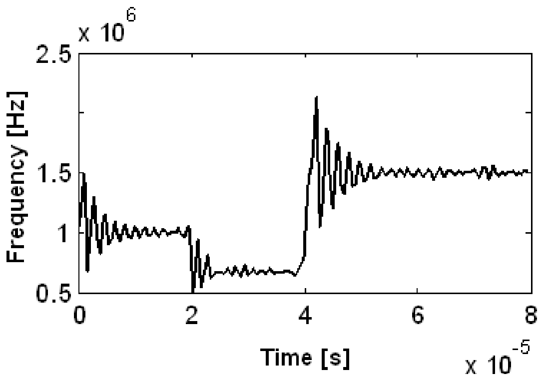

Fig. 2. Typical PLL's transient process

This figure shows the maximum available frequency variation (working range) that equals approximately 2.2 times. This range can be taken for an arbitrary basic frequency, but this requires cut-off frequency and system gain value fitting. The feature is presence of damped oscillating processes that are caused by fundamental need of low pass filter to reject high-frequency harmonic component. The transient process duration by maximum frequency change exceeds 0.012 ms (12 cycles of the nominal frequency signal) and doesn't vary significantly in other realizations. The influence of noise appears in presence of some frequency swinging after the completion of transient processes.

The system research with the 1st order low-pass Butterworth filter has shown results that are similar to exponential filter, when the 2nd order low-pass Butterworth filter narrows system dynamical range and considerably drags out the transient process.

II. FAST FLL

The aim of this work is the creation and investigation of new methods that provide acceleration of VCO frequency adjustment using digital algorithms for estimating instantaneous frequency and instantaneous phase of a harmonic signal. These algorithms have been described and investigated [2, 3] for a fixed size sample that corresponds to single running window.

The proposed frequency estimation algorithm is based on an auto regression model of sine wave and supposes to calculate normalized frequency, which actually is phase shift between samples

$$\gamma^*_{1(2)} = \arccos\left(B(\bar{x}) \pm \sqrt{B(\bar{x})^2 + 2/2}\right),$$

where $B(*)$ is signal statistics

$$B(\bar{x}) = 0.5\sum_{i=2}^{N-1}\left[(x_{i+1}+x_{i-1})^2 - 2x_i^2\right] / \left[\sum_{i=2}^{N-1}(x_i(x_{i+1}+x_{i-1}))\right].$$

Among two roots of square equation we should elect the value γ^* that is located in the zone of the method uniqueness $(0, \pi/2)$. And finally real frequency is calculated as

$$F^* = \gamma^* F_S / 2\pi .$$

At Fig. 3 there is shown a block diagram of the proposed fast frequency-lock loop (FLL) that uses only frequency estimates of signals S_O and S_R. Presence of the summator in the loop is caused by the requirement to frequency astaticism and low-pass filter is not needed. Feature of the procedure is the instantaneous frequency estimation sequentially at each sampling step in running windows of equal size.

The transient process (Fig. 4) is obtained under above-mentioned modeling conditions and at the running window size of one period (50 samples). Frequency moves down from nominal value to 100 kHz at 0.02 ms and then comes up to 12.5 MHz at 0.04 ms. One can see that the system becomes stabilized in approximately 3 μs (3 cycles of the nominal frequency signal) practically with no overshoot that is a few times less than typical PLL system. Another advantage is much wider working range (approximately 100 times from lower to higher frequency bounds). Moreover, transient process duration does not depend on value of frequency step.

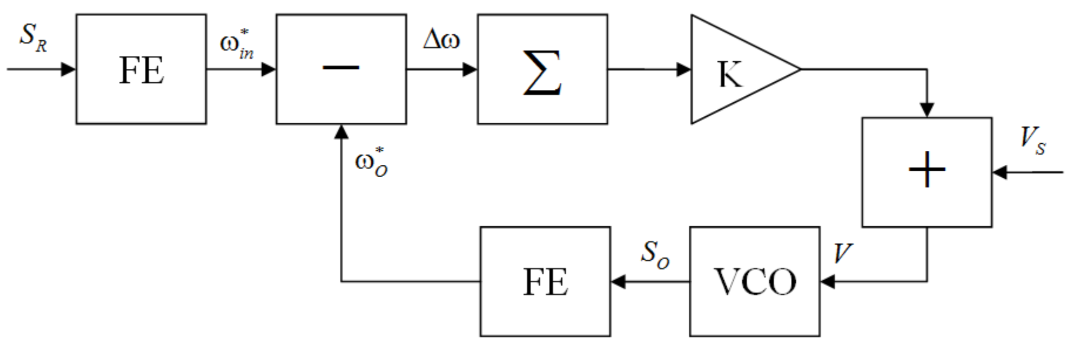

Fig. 3. Proposed frequency-locked system

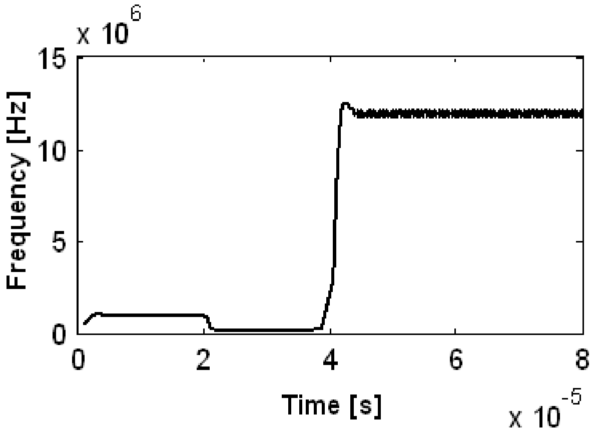

Fig. 4. Proposed FLL transient process

Although this system averaged stabilizes harmonic signal frequency, but has local phase-jitter that can be replaced only by phase tracking.

III. Fast PLL

The next PLL system (Fig. 5) which uses instant phase estimates is proposed and investigate. According to [3] for their receipt the instantaneous frequencies estimates are needed.

Estimates of phase (and amplitude) can be calculated analytically by solution of two equations system

$$\begin{cases} \partial\Lambda(\rho,\gamma,\varphi)/\partial\rho = 0; \\ \partial\Lambda(\rho,\gamma,\varphi)/\partial\varphi = 0, \end{cases}$$

where

$$\Lambda(\rho,\gamma,\varphi \mid x_0,\dots,x_{N\text{-}1}) = \sum_{i=0}^{N-1}(x_i - \rho\sin(\gamma i+\varphi))^2,$$

is reduced likelihood function.

The proposed scheme is static for the phase difference the value of which depends directly on the frequency of the input signal.

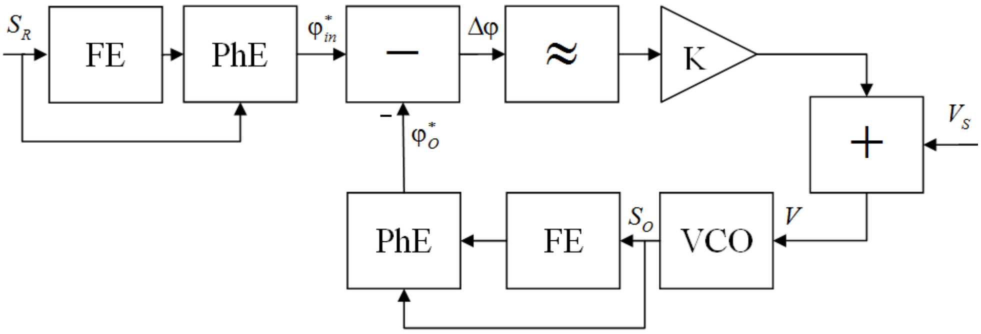

Fig. 5. PLL with phase estimation

Transient process of the scheme under the same modeling conditions is shown in Fig. 6.

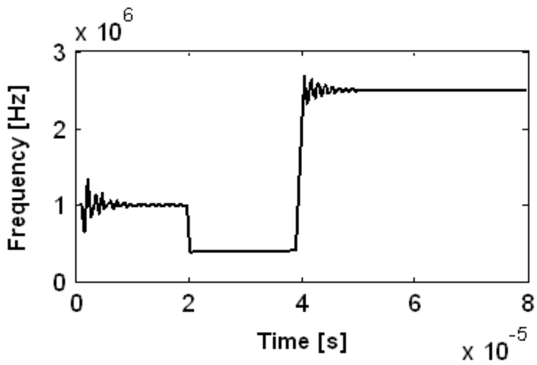

Fig. 6. Proposed PLL transient process

There is deterioration of the transient process parameters in comparison with the previous scheme: overshoot growth and decreased to 6 times work range. This is a payment for using of additional procedures for phase estimation. Also it corresponds to general fact that PLL systems have narrower working range in comparison with FLL ones.

IV. Conclusion

The proposed FLL-method using instantaneous frequencies estimations reduces in a few times the transient process duration and almost fully eliminates overshoot. The proposed PLL-system using instantaneous phase estimations provides the steady-state phase under conditions of low SNR.

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І. Г. Прокопенко, І. П. Омельчук, Ю. Д. Чирка, К. І. Прокопенко. Швидкі системи синхронізації частоти
Запропоновано та досліджено нові методи прискорення відслідковування частоти гармонійного сигналу на основі оцінок миттєвої частоти та фази. Краща ефективність запропонованих систем, а саме коротші перехідні процеси та більший частотний діапазон, доведена у порівнянні з типовою системою частотної синхронізації.
Ключові слова: ЧАПЧ; ФАПЧ; швидкий частотний дискримінатор; відслідковування частоти та фази; оцінювання миттєвої частоти; нелінійні системи управління.

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И. Г. Прокопенко, И. П. Омельчук, Ю. Д. Чирка, К. И. Прокопенко. Быстрые системы синхронизации частоты

Предложены и исследованы новые методы ускорения отслеживания частоты гармонического сигнала на основе оценок мгновенной частоты и фазы. Лучшая эффективность, а именно более короткие переходные процессы и больший частотный диапазон, доказана в сравнении с типовой системой синхронизации частоты.

Ключевые слова: ЧАПЧ; ФАПЧ; быстрый частотный дискриминатор; отслеживание частоты та фазы; оценивания мгновенной частоты; нелинейные системы управления.

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