Source of Synchronously Digitally Controlled Pure Harmonic Signal for Precise Measurement

KAREL HÁJEK*, JIŘÍ SEDLÁČEK**, BOHUMIR SVIEZENY***
*Department of Theoretical and Experimental Electroengineering
**Department of Electrical Engineering,
***Department of Telecommunication-Signal-Images
*University of Defence Brno, **University of Technology Brno
*Kounicova 65, 623 00 Brno, ** Kolejni 4, 612 00 Brno
***Institut Superieur d'Electronique de Paris
*,**CZECH REPUBLIC, ***FRANCE

Abstract: - This article solves the problem of generating of the pure harmonic signal with high accuracy of synchronization with sampling signal. This problem is very important for example for a fast and precise impedance measurement. The compound square wave signal with rejected 3rd harmonic component was derived and chosen. In comparison with other possibilities it has the best phase synchronization and simplicity of realization. It is discussed and minimized the magnitude and phase instability of output low-pass filter. Practically measured frequency spectrum of generated signals is also shown.

Key-Words: - harmonic signal generator, phase synchronized signal, square wave signal, magnitude and phase stability

1 Introduction

In the practice there are requirements to measure a precise vector value (magnitude and phase shift) in some tasks, especially by the fast and precise impedance measurement. In this case it is necessary to use the pure harmonic wave signal with the precise phase synchronization to sampling signal. Therefore we have to use a source of the harmonic wave signal not only with excellent magnitude stability, but also with high phase stability.

To reach required accuracy of measurement it is very important to use the signal source with the limited value of magnitude and phase error of generated signal.. We require, as an example, the measurement of impedance with maximum inaccuracy 0.1%. In this case the error of the measurement of voltage and current vectors has to be 3 -10 times lower, approximately 0,03 – 0,01%. It corresponds to necessary stability of magnitude and phase in measuring time (during one period of harmonic signal). The maximum instability of magnitude corresponds to basic require. On the other side the maximum permissible phase instability has to be expressed. For small phase shift we can consider that

$$\mathrm{tg}\,\varphi = \varphi \,. \qquad (1)$$

Therefore the relative instability of magnitude $\Delta V/V$ corresponds to $\Delta\varphi$. In the case of maximum inaccuracy 0.01% we obtain:

$$\Delta\varphi = 0.0001 \text{ r} = 0.005^{o} \,. \qquad (2)$$

By similar way we can obtain the maximum value of THD, approximately 0,03% (70 dB).

These requirements and the requirement of maximum phase instability of synchronism with sampling signal limit selection of possible sources of the harmonic signal. We can consider three types of signal sources:

- DDS generator,
- PLL synchronized generator,
- filtered square wave signal .

The DDS generator can be used, but there is problem with simply and precise definition of integer relation of control frequency and output frequency (to reach necessary phase stability). This solution needs output filter and it is somewhat complicated solution (it needs control microprocessor). The second possibility, the PLL generator has also problem with the low phase stability and it also needs the output filter.

The third solution, the filtered square wave signal has advantage in precise phase synchronism with a control signal. On the other hand it needs output filter with high steepness and therefore it has high sensitivity to element value instability. This filter needs to reject the 3rd harmonic component (c. 60-70 dB) and on the other hand the cut-off frequency has to be more higher then 1st harmonic component for amplitude stability. Therefore the sum of two square wave signals with eliminated 3rd harmonic component is considered. By this way we obtain higher spacing between 1st and rejected 5th

harmonic component. It means lower requirement to the filter steepness and lower sensitivities to the element value instability.

2 Compound square wave signal with eliminated 3rd harmonic component

Basic idea of this method of signal generation consists in addition two square wave signals. Rejection of the 3rd harmonic component of the square wave signal is reached using addition to the identical signal with time delay corresponding the π shift of 3rd harmonic component. This principle is shown in Fig. 1. There are both square wave signals and their sum with corresponds frequency spectrums. The relative value of magnitudes and values of phase shifts are numerically expressed in Tab. 1. By this way we obtain signal with exactly zero value of 2nd, 3rd and 4th harmonic component. The relations between magnitudes of 1st, 5th, 7th and 11th components are the same as for one signal, the 9th component is zero as 3rd component. It is very important to use precise time shift between both signals, which corresponds to 1/6 of basic period T.

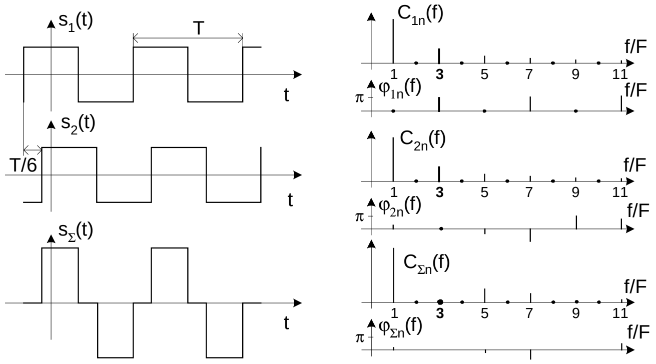

Fig. 1 Square wave signal with zero 3rd harmonic component as a sum of two shifted square wave signals.

Tab. 1 Magnitudes and phases of signals from Fig. 1

	1st signal		2nd signal		Σ	
	C_{1n}/C_{11}	φ_{1n}	C_{2n}/C_{11}	φ_{2n}	$C_{\Sigma n}/C_{11}$	$\varphi_{\Sigma n}$
0	0	-	0	-	0	-
1	1	0	1	π/3	√3	π/6
2	0	-	0	-	0	-
3	**1/3**	**π**	**1/3**	**0**	**0!**	**-**
4	0	-	0	-	0	-
5	1/5	0	1/5	−π/3	√3/5	−π/6
6	0	-	0	-	0	-
7	1/7	π	1/7	−2π/3	√3/7	−5π/6
8	0	-	0	-	0	-
9	1/9	0	1/9	π	0	-
10	0	-	0	-	0	-
11	1/11	π	1/11	2π/3	√3/11	5π/6

One possibility of a circuit realization of the signal generator based on the compound square wave signals is shown in Fig. 2. It consists of two parts. The digital part (Fig. 2a) is controlled by digital signal with frequency $6.f_s$ and it produces synchronous sampling signal f_s and switching signal (outputs A and B) generating synchronous compound square signal with frequency $f_s/4$. Therefore in the circuit there are frequency dividers (f/4, f/3, f/2) and two exclusive-or circuits.

The analogue part (Fig. 2 b) generates the compound square signal by summing of switched positive and negative reference voltage. In second step, the analogue LP filter produces synchronous pure harmonic signal.

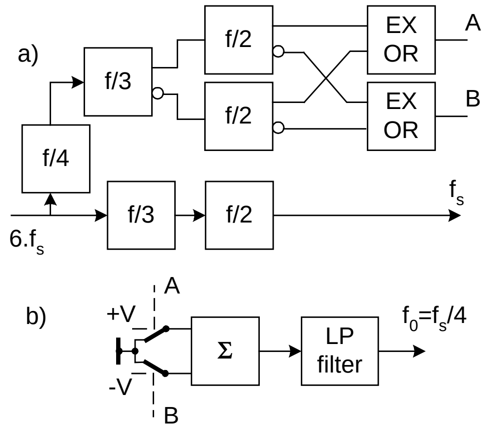

Fig. 2 a) digital part, b) analog part of a generator of the compound square wave signal with rejected 3rd harmonic component

3 Filtration of the compound square wave signal

On the first look, dominant function of the LP filter from Fig. 2 b) is to realize a sufficient rejection of 5th and higher harmonic components. On the other hand, the adequate amplitude and phase stability is also necessary for good function of whole source of measuring harmonic signal.

The design of the LP filter for sufficient attenuation in a stop-band is a standard task and it has more solutions. The values of the high harmonic components and required attenuation (75dB) needs filter attenuation 65 dB in case normal square wave signal and 60 dB in case compound square wave signal.

The design for maximum magnitude and phase stability is more problematic in comparison with attenuation task because it is very difficult to express exactly the magnitude and phase sensitivities.

The analysis of this problem can be simplified by these premises:

a) the cascade connection of ARC LP filters is used,
b) magnitude and phase sensitivity to $\Delta\omega/\omega$ of 2nd order blocks are c. 10 times higher then to $\Delta Q/Q$,
c) supposed short-term instability $\Delta\omega/\omega$ of 2nd order blocks is lower then 10^{-3}.

Therefore the magnitude and phase instability will be tested as relative sensitivity of magnitude and semirelative sensitivity of phase:

$$S_\omega^H = \frac{dH}{H} \cdot \frac{\omega}{d\omega} \quad , \qquad (3)$$

$$S_\omega^\varphi = \frac{d\varphi}{d\omega}\omega = \tau_g \omega \, . \qquad (4)$$

The first step of filter design is solution of approximation task. As it was mentioned above, it is ambiguous task from the point of view of magnitude and phase sensitivity. Therefore the various solutions were compared as it is expressed in Tab. 2. Because the phase sensitivity corresponds to normalized group delay $\omega\tau_g$ (4), the simpler comparison or various solutions sensitivity can be realized as comparison group delay.

The first part of table shows values for classical square wave signal with attenuated frequency $3f_o$. The second part shows values for new solution with attenuated frequency $5f_o$.

The comparison realized by program NAFID [2] declares very important knowledge - that it is necessary to use cut-off frequency higher than f_0, because it brings lower phase sensitivity and minimum magnitude sensitivity. On the other hand this solution requires higher order of filter. The approximations with transfer zeros (e.g. inverse Chebyshev approximation) offer better results. The using of approximations with higher steepness (Chebyshev or Cauer approximation with very low ripple) doesn't bring lower sensitivities. Resulting magnitude instabilities ΔH/H and phase instabilities Δφ are calculated for the considered instantaneous frequency instability $\Delta\omega/\omega = 10^{-4}$. As we can see, the optimum solution brings the use of 5th order LP filter with inverse Chebyshev approximation and relative cut-off frequency $f_c/f_0 = 2$. The practically measured frequency spectrum of the compound square wave signal before and after filtration is shown in Fig. 3.

Tab. 2. Comparison of magnitude and phase sensitivities for various approximations

f_a/f_0	approx.	ord.	f_c/f_0	S_ω^H	ΔH/H ‰	$\tau_g\omega$	Δφ [°]
3	Butterw.	7	1	3.50	0.35	7.77	0.0222
	Butterw.	9	1.3	0.05	0.005	6.04	0.0173
	Inv. Cheb.	6	1.3	0.17	0.017	4.11	0.0118
5	Butterw.	5	1	2.40	0.24	5.05	0.0145
	Butterw.	7	1.8	0.01	0.0005	2.85	0.0082
	Butterw.	9	2.2	0	0	2.83	0.0081
	Inv. Cheb.	5	1	0.17	0.017	3.86	0.0111
	Inv. Cheb.	5	2	0.01	0.0005	1.63	0.0047
	Inv. Cheb.	7	3	0	0	1.28	0.0037

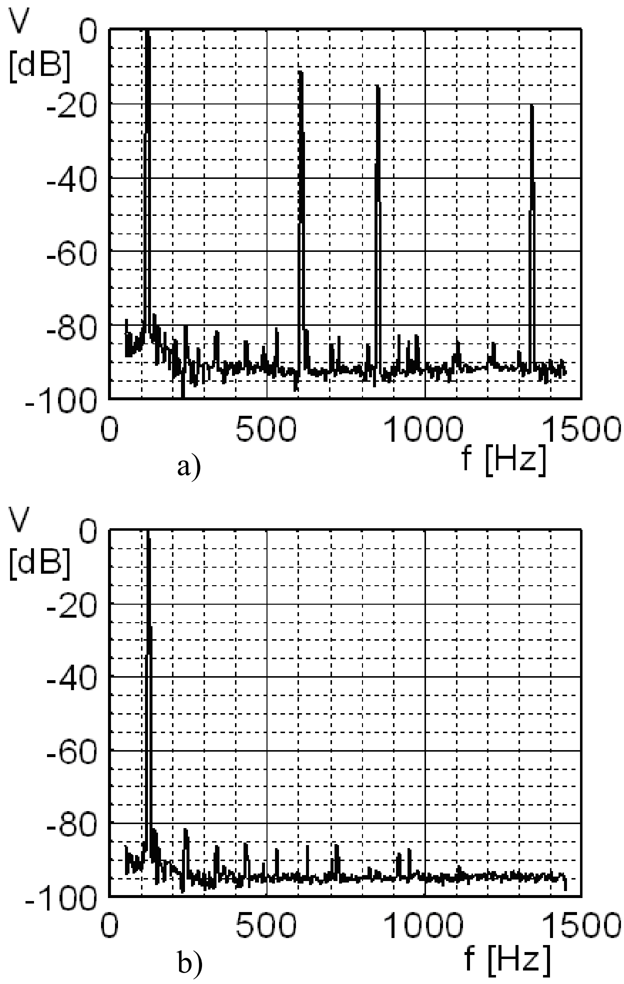

Fig. 3 Frequency spectrum of compound square wave signal a) before filtration b) after filtration

4 Conclusion

This paper solves the problem of generating of the pure harmonic wave signal with high accuracy of synchronization with sampling signal. It is developed the circuit realization based on a compound square wave signal with rejected 3rd harmonic component and subsequent optimized low-pass filter. Their magnitude and phase instability is also discussed. In comparison with other possibilities the new method of signal generation enable to reach best phase synchronization and simplicity of circuit realization. Practically measured frequency spectrum of generated signals is also shown.

This work was supported by the Grant Agency of the Czech Republic under Grants 102/03/1181 and 102/04/0442.

References:

[1] Power Inverters 12V to 230V. http://www.qsl.net/dg5sga/inverter.htm

[2] Hájek K., Sedláček J. Nafid Program as Powerful Tool in Filter Education Area. International *Conference CBLIS '97* Leicester July 1997. pp 75-78