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The DDS Synthesizer (for FPGA Platform) for the Purpose of Research and Education

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Abstract. The paper concerns the construction scheme of Direct Digital Synthesis (DDS) generator based on widely developed Field Programmable Gate Arrays (FPGA) technology. Firstly, the division of all generators is presented regarding the fact whether they generate sinusoidal or non-sinusoidal signals and whether the they have positive or negative feedback. Next chapter concerns how to generate frequency directly and indirectly synthesis and how to integrate these types of sytheses into the hybrid one. According to the blueprint, DDS generator if fully digital, which facilitates the control enabling to change almost at will the oscillation while the system works. Next chapters contain the conclusions and some proposals regarding practical application. DDS synthesizer has been made in accordance to the assumptions of the project, which was confirmed in practice. Control program enables us to fuse some measuring systems together into one, which facilitates simultaneous gathering of the data from several devices. Hence, the overall efficiency rises and the costs of carried out experiments are reduced. In the case of foreigners, it will be supplied by editors.

Keywords: frequency synthesis, digital oscillations, field programmable gate arrays systems, FPGA.

1. Introduction

Development of advanced micro-circuits is primarily due to modern ways of making DC current waveforms in electronic devices smooth and stable. Universal Complex

Programmable Logic Device (CPLD) or Field Programmable Gate Arrays (FPGA) circuits with embedded memory enable us for easy and fast reconfiguration and reprogramming; therefore, they are more and more commonly used. Apart from that, it is crucial to provide some software controller associated with the device

The proposed Direct Digital Synthesis (DDS) generator can be controlled from the computer operating system with the associated software. Therefore, one can join some research and testing systems together and reduce the time necessary for measurements and gathering data. It makes research work more flexible and reduces costs. DDS Syntezer using reprogrammable FPGA PC compatible circuit is a universal module which can be adjusted to user's needs without any loss of functionality. It consists of the following function modules and communication interfaces:

- DDS generator;
- DDS control unit;
- LCD display controller;
- PS2 interface for controlling of the generator directly with a keyboard;
- 3-wire interface;
- digital potentiometer controller;
- USB to establish connection between the computer and the generator.

Initial chapters are devoted to the basic messages connected with generators. They contain the description of basic types of generators, their internal architecture and parameters. Later on the issues are discussed related to the manufacturing techniques of electrical waveforms. The production of electrical waveforms by means of DDS method is described, including sample solutions. The essential chapters of the article is a description of the creation of the signals of any shapes along with the presentation of the results obtained. The summary discusses the possibility of development of the system and contains some conclusions on the designed and manufactured synthesizer.

2. Basic information about generators

Generators are electronic systems that transform direct current energy (power) into electric impulses or periodic electric waveforms changing their shape in regular cycles. In everyday life divers systems of generators are embedded into a variety of appliances ranging from microwave ovens, TV sets, computers to mobile phones . When it comes to design, one of the simplest systems of generators is a rectangular wave generator. Systems generating sinusoidal, deformed triangular or step waveforms, are far more complex to the design and implement. In is hardly possible for a designer of create the device able to generate a shape which is atypical or requested by the user and still stable in time.

Such systems are used in test equipment, prototypes and wherever some unconventional approach is required.

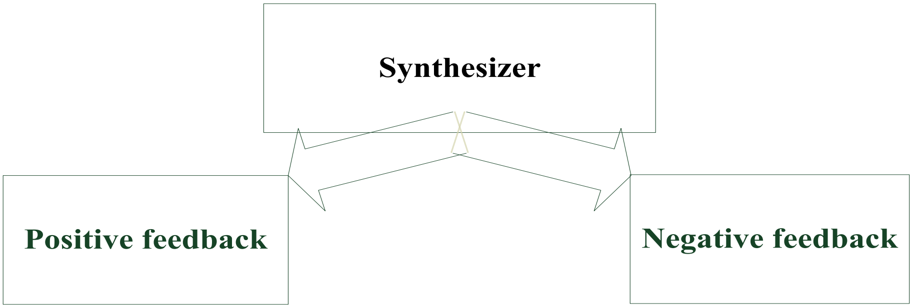

Figure 1. The division of generators due to the shape of the waveform.

Regarding the principle of operation, there are generator systems with positive feedback and negative resistance.

According to the type of four-terminal network in a positive feedback, there are LC generators having inductive elements L and capacitive elements C in the loop, and RC generators consisting of resistors and capacitors, and generators employing quartz crystal resonator. Among the basic LC generators are:

- Hartley's oscillator with split inductance;
- Colpitts oscillator with split capacity;
- Meissner oscillator with transformer coupling RC generators include:
  - RC Generator with Wien bridge;
  - RC generator with TT bridge.

2.1. The basic parameters of the generators

The frequency of the generated waveform (f0) is the frequency of the output signal. It may slightly deviate from the nominal value as some elements of the system become hot. It is expressed in Hz, kHz, MHz, GHz.

Stability of the frequency of the generated waveform is the ratio of the average value of the frequency deviation to the nominal value. It is expressed with dimensionless quantity.

Total Harmonic Distortion (THD) is the ratio of the effective value of higher harmonics to the effective value of the fundamental, measured for sinusoidal signal. It is expressed as percentage [%].

$$THD = \frac{\sqrt{\sum_{k=2}^{n} U_k^2}}{U_1} \tag{1}$$

where

- U_1 – effective voltage of the fundamental;
- U_k – effective voltage of the k-th harmonic component;
- Range of frequency tuning – boundary values between which one can change the frequency of the generator;
- Waveform shapes – shapes of waveforms produced by the generator i.e., sinusoidal, rectangular, sawtooth.

3. Direct and indirect frequency synthesis

In direct frequency synthesis digital techniques are used to generate the output signal frequency.

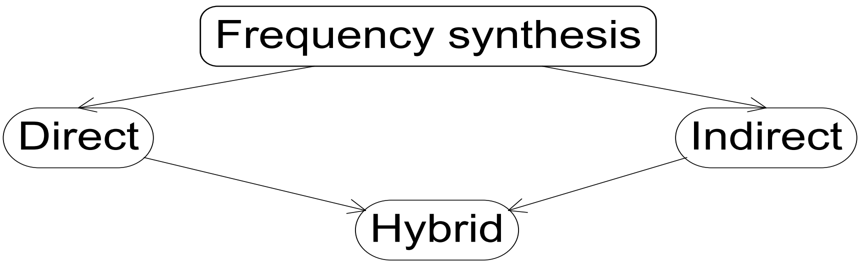

Figure 2. Types of frequency synthesis.

In indirect synthesis synchronous phase loops are used to multiply the input timing frequencies of the clock. Output clock frequency is much higher and one uses it for the timing of frequency synthesizer.

The combination of both above mentioned methods is called 'hybrid method'. In this synthesis PLL (Phase-locked loop) systems, DDS method and RF conversion (Radio Frequency conversion) method are used to achieve high frequency and signal power. DDS method is a completely digital way to generate periodic signals. Its internal structure virtually lacks analog elements, and the values of the output waveform are calculated. In the DDS method base signal to generate is a rectangular one (created by tuning oscillator whose main task is to provide the waveform of appropriate frequency). The frequency of the output waveform depends on the tuned oscillator, and the frequency control is obtained via controlling the level of split (counter). Tuned generator system should work stably and be provided with stable output frequencies, being as independent on temperature as possible. Frequency patterns are set by means of quartz resonators.

Currently, many integrated circuits (based on DDS technique) for generating recurring waveforms is available on the market, for example: AD9833, AD9854ASTZ or AD9832BRUZ.

Such systems can be distinguished regarding the layout of the controlling interface, the retuning range and various resolution of built-in digital-to-analog converter. Due to abundance of additional functions hardly met in similar systems and the need to quickly rearrange the hardware structure of the designed generator, the implementation was based on FPGA (Field Programmable Gate Array) reprogrammable systems.

4. Implementation of DDS system in the designed synthesizer

The designed DDS system consists of two independent layers: FPGA configuration and high-level application. The system was intended to work autonomously in order to avoid the necessity of maintaining generator control by means of the computer system. This approach forced us to use some additional elements controlling the correctness of the operation of such a system. Therefore, the internal unit responsible for controlling the work of DDS synthesizer was expanded and several elements that are not typical of DDS integrated circuits were added.

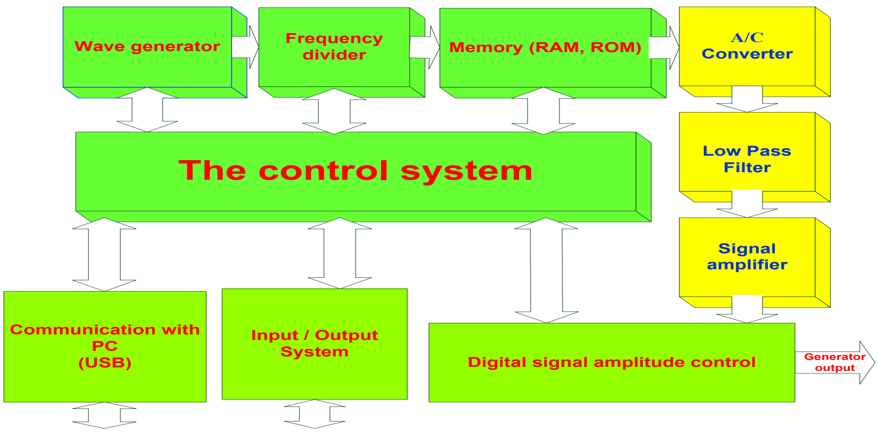

Figure 3. Block diagram of the generator.

As well as the specialized integrated circuits, our solution contains the basic functional blocks: frequency standard, counter, memory, digital to analogue converter, the output amplifier or low pass filter.

The most important features of the EP1C3T100C8N system are: embedded PLL loop for frequency duplication, embedded SRAM memory module of 59 kb total capacity and flash memory configurator of 1 MB capacity (EPCS1). The internal structure of the system is based on 2910 programmable logical cells LE (Logic Element). The system has 60 i/o lines (5 with the ability to bring the voltage up to 5 V, other up to 3.3 V), which can be freely configured as input or output.

The DDS generator structure was designed regarding the above-mentioned specification. As in ISP mode (In System Programming) reprogramming takes place directly in the system, it is very fast and enables the user for adding corrections and experimenting with many variants od the designed system in statu nascendi.

4.1. Sample waveform shapes programmed in FPGA system

Generator is able to create 15 pre-defined waveform shapes and one shape that can be freely modified by the user. The following oscillograms present selected waveform shapes produced by the DDS generator.

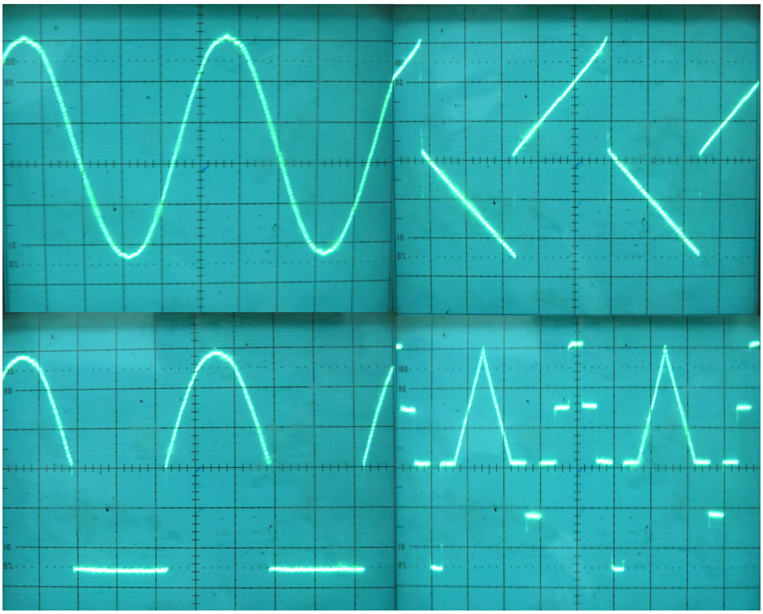

Figure 4. Oscillograms present selected waveform shapes.

4.2. Application for controlling synthesizer from the PC level

Controlling applications for generators or measuring equipment (acquisition systems) can be chosen of common ones because they are ergonomic and intuitive to use. However, the creation of dedicated software should be taken into account to provide the user with much more sophisticated control over the parameters of the generator and to reduce costs (of course, it has some training aspect for the programmers, too) The graphical interface is much more ‘digestible’ for the average user, and hence the training does not require big financial effort. If we combine these two elements, it results in the above-mentioned DDS generator control application.

5. Conclusions and directions of evelopment

The presented solution has been implemented in accordance with the assumptions. Moreover, additional functions were obtained related to the implementation of DDS generator system based on the programmable FPGA systems. The assumptions have been confirmed in practical system tests and obtained oscillograms were presented in Chapter 4.1.

As in FPGA system lots of cells is still unused (approx. 40%) the implementation of additional features is possible as well as developing the existing ones e.d., increasing the number of embedded waveform shapes. Using a newer version of the FPGA system provided with higher frequency clock can facilitate increasing the range of retuning of the generator. The current range of frequency retuning varies from 1 Hz to 10 kHz whereas the signal amplitude varies from 0 to 5 V.

Generator code for FPGA batch was written according to the VHDL 1993 language standard and is not connected with any particular architecture (like Cyclone by Altera or Spratan-III by Xilinx), which makes it easy to transfer without serious modifications. Using a different type of system with more logical cells one can duplicate the number of generators in the FPGA structure and manage them independently.

Thanks to impleneted prototype of the generator the user can easily create and modify waveform shapes and change the frequency in a fluent manner. One can use this system for the purposes of scientific research or in prototype devices whose control is based on changing the waveform shape and not just the frequency or amplitude.

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