Experience in Designing Multi-Channel Time-To-Digital Converter

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Abstract

Objectives: The article presents the results of the development of multi-channel timeslot measurement system for laser radar for space application. Methods: FPGA Spartan-6 system (Xilinx, USA) was used for the development of our system. Vernier method was applied for timeslot measurement that enabled to obtain high accuracy of the results without using high-frequency signals. Findings: The result of our work was the development of time-to-digital converters (TDC) with extremely low sensitivity to temperature changes. At the same time our TDC was a complete digital device and had lower sensitivity to electromagnetic interference and noise in the supply chain. The results of this development could be interesting to a wide range of specialists focusing on the development of digital systems for both ground and space application. Improvements: A 64-channel TDC has been developed. Due to the self-measurement of characteristics in real time the developed TDC does not require additional correction and adjustment before use.

Keywords: Programmable Logic Device (PLD), Time-to-Digital Converters (TDC)

1. Introduction

Time-to-digital converters (TDC) found application in many areas, from laser location and ranging to water meters and flow meters. Basically all TDC can be divided into several types:

1. TDC based on the direct counting of the reference frequency impulses number in the measured time interval by multi-bit counters. This type of devices is simple to implement, cheap and can be used almost in any system that does not require high (from a few picoseconds to a few nanoseconds) accuracy or stability of the result.

2. Analogue TDC have various realization options, however the most common option is TDC based on the direct current capacitor charge and discharge, with digitizing the voltage of a charged capacitor and measuring the discharge time of the capacitor. Charge current is several orders of magnitude more than the discharge current which allows achieving scaling of the time interval for its more accurate measurement. Analogue TDC provide high accuracy of the measurements, but they require careful calibration and are sensitive to external influences.

3. Vernier TDC are divided into Vernier interpolator and straight Vernier TDC. Both types of TDC having a lot of differences work similarly on the principle of phase shift of the clock signal relative to the other, with little difference between the frequencies of these clock signals. Making Vernier TDC is highly complex process requiring careful calibration. Such TDC are also highly sensitive to external influences.

4. Multi-drop delay lines are often seen in TDC implemented on the basis of Programmable Logic Device (PLD). Their main disadvantages are unpredictability of characteristics and sensitivity to external influences. Unpredictability of TDC characteristics can be explained by the fact that in most cases the resulting concrete realization of TDC requires studies to determine its characteristics. However in this case any change in the scheme as well as a change of the chip

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results in a need for a new determination of characteristics.
5. Hybrid TDC are not a separate class but a counter and one of the options of a precision TDC for determining more accurate time interval between the leading edge of the clock signal of the counter and a stop event.

The article provides characteristics of our own multichannel TDC based on the PLD Spartan-6 (XILINX, USA).

2. Materials and Methods

It was said in the introduction that all kinds of TDC are sensitive to external influences especially to the temperature changes. Solution of this problem using thermostabilization is not always an option. Therefore it is highly important for the implementation of TDC to minimize the influence of temperature changes on the measurements results.

The second important problem is unpredictability of TDC characteristics. The only case when this is not an issue is a situation with industrially produced samples because the manufacturing process provides required uniformity of products characteristics. TDC implemented on the base of PLD can have a wide range of parameters which makes it significantly more difficult to create multichannel TDC (for example, TDC used in laser radars). Solution of the problems mentioned above is a basis for the development of easy in scaling and universal TDC which is able to function without additional thermostabilization.

The starting point to develop TDC insensitive to temperature changes was an idea to reject thermostabilization and replace it with constant measurement of TDC parameters during its functioning. At the same time this approach could allow to exclude long and complex calibration automating the whole process and closing it within TDC.

3. Results

Rejection of thermostabilization entails the need for the reference signal to bind the device parameters to it. Signals from satellites of the global navigation system and cesium frequency generators having high temperature stability and small sizes can be used as reference signals.

The 64-channel TDC was implemented on the basis of the PLD Spartan-6 (XILINX, USA). The basis of the device was straight Vernier TDC described in. The structure of this TDC is shown in Figure 1.

![Figure 1. Structure of straight vernier TDC.](image)

The TDC functions as follows.

When a rising front at the input “Start-pulse” appears, the generator 1 starts generating pulses with a period $T_H$. The pulses are applied to the counter input 1 and they are also applied to a first input of a phase detector. After the appearance of the rising front at the input “Start-pulse” the generator 2 starts to generate pulses with a period $T_B$. The pulses are applied to the counter input 2 and they are also applied to a second input of a phase detector. At the time of the phase match of two multi-vibrators phase detector produces a pulse, stopping the work of generators 1 and 2. Wherein state of the counters can be used to calculate the time interval measured by the formula:

$$T = (C1 - 1) \times T_H - (C2 - 1) \times T_B,$$

where

- $T$ – measured time interval,
- $C1$ – value of counter 1,
- $C2$ – value of counter 2.

One TDC which was implemented on the basis of PLD Spartan-6 takes 9 logic gates. Location of logic gates and signals is shown in Figure 2.

Location on the crystal of 64-channel TDC with the calculation logic of time slots, continuous calibration and information output interface are shown in Figure 3. To implement the calibration of the device in operation a special highly stable signal 1PPS with front uncertainties 100 ns has been provided.

All 64 channels of TDC were placed in the left side of the crystal to prevent conflicts while tracing the project. All generators in TDC channels had different generation
periods which were measured during the operation of the device. Differences in periods of generators of the each channel have been summarized in a histogram presented in Figure 4.

![Figure 2. Implementation of one TDC.](image1)

**4. Discussion**

The system developed by the authors has several major differences as compared to analogues described in other sources:

1. Our system does not require long calibration of the each channel;

2. TDC parameters are constantly measured and controlled during the operation of the device;

3. The influence of random parameters of TDC on the measurement results is minimized;

4. The problem of external influences on the measurement results is solved.

The results mentioned above make it promising to use such a TDC in systems based on PLD in in difficult climatic conditions without significantly reducing the accuracy of time interval measurements.

The result of our work is the development of 64-channel TDC based on PLD Spartan-6 (XILINX, USA). The accuracy of time interval measurement is illustrated on graph presented in Figure 5. Based on the results of the reference time interval measurement standard deviation of the measured value was calculated, which makes 48
ps. The measurements were performed at temperature changing from 15 to 50°C. The influence of the temperature on the measurement accuracy was not registered.

Figure 4. Differences in periods of generators.

Figure 5. Measurement of the reference time interval.

5. Conclusion

The use of our TDC based on PLD allows creating flexible reprogrammable systems for various tasks:

1. ranging;
2. laser ranging;
3. flow-meters and others.

Capabilities of PLD allow using one crystal to create systems with different number of channels, different sets of interfaces, to include extra opportunities for processing of measurement results.

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