

GENERATION AND APPLICATION OF PSEUDORANDOM BINARY SEQUENCES USING VIRTUAL INSTRUMENTATION*

UDC 681.3.042 621.317:004.42Lab VIEW

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Abstract. *A very dynamical development of virtual instrumentation in recent years has caused a very good acceptance of this concept and its use in many applications. This concept, as one flexible and cost-effective solution for test and measurement, is used in this paper for implementation and application of maximum length pseudorandom binary sequences generator. Because of their properties, the pseudorandom binary sequences are often used in development and improvement of modern pseudorandom position encoders as well as in testing of some sensors, analog-to-digital converters, etc.*

Key words: *virtual instrument, pseudorandom binary sequence, pseudorandom position encoder*

1. INTRODUCTION

The vision of virtual instrumentation changed and improved the way engineers and scientists work, delivering solutions in less development time, with lower costs, and greater flexibility. It can be noted that virtual instrumentation has had a constant and extensive development regarding hardware and software and was widely adopted mostly in test and measurement areas in the last decade. Of course, the main catalyst of that development is a very dynamical development of computer techniques and digital electronics. The presence of virtual instrumentation in industry, education, everyday life etc, is getting wider each day.

The virtual instrument concept offers the possibility for an engineer to use flexible and powerful software running on a computer combined with instrumentation hardware to define a custom test and measurement solution. The development of virtual instrumentation enables a series of new possibilities in the field of measurement techniques, research

Received May 17, 2011

* **Acknowledgement.** *The paper is a part of the research done within the project TR 32045. The authors would like to thank the Ministry of Science and Technological Development in Serbia.*

work, etc. What is important is the fact that virtual instruments are significantly cheaper than traditional. They are also very flexible, i.e. have a possibility of simple modification and upgrading. The good properties of virtual instruments are modularity and hierarchy, i.e. the possibility of dividing a complex task into simpler problems and their separate realizations and testing, and connecting them to complex virtual instrument. Virtual instrumentation also offers a possibility of communication with traditional instruments through an appropriate interface, which is widely used in development and during realization of virtual and remote laboratories.

There are different development tools and environments for realization and design of virtual instruments. One of the most often used and widespread is LabVIEW, by National Instruments [1], which as a graphical development platform enables intuitive and simple development without the need for serious previous programming knowledge. The programming is performed by a graphical programming language, which is easier for learning and debugging than textual.

The pseudorandom binary sequences (PRBS) are a useful type of periodic signals, which have the following properties: 1) the signal is bipolar, series of 1's and 0's; 2) the PRBS is a deterministic repeatable signal; 3) the PRBS exhibits a uniform power spectral density over a wide frequency band; 4) according to the "window property" of PRBS of length $2n-1$, any n -bit code word obtained by a window of width n , is unique and may fully identify the window's absolute position p relative to the beginning of the sequence. This is used in pseudorandom absolute encoders.

The area of PRBS application is wide, for example, during design and testing of pseudorandom position encoders, then for testing of measurement transducers [2, 3], AD converters testing [4], in the field of communication [5, 6], measurement of frequency response [7], navigation systems, scrambling, cryptographic applications, etc. Other example applications are found in surface characterization and 3D scene modeling, and in audio applications to measure the properties of loudspeakers.

The generator of pseudorandom binary sequences can be implemented in different ways, including using a discrete shift register and flip-flops, using a microprocessor, using a FPGA-based implementation, etc. However, methods of pseudorandom binary sequences generation based on virtual instrumentation concept are presented in this paper. Particular attention will be focused on the design of an experimental system which uses PRBS signal for testing purposes based on virtual instrumentation concept.

2. GENERATION OF PSEUDORANDOM BINARY SEQUENCES OF MAXIMUM LENGTH

The pseudorandom binary sequences of maximum length [7] can be generated by using shift register which is composed of n flip-flops and appropriate feedback connections, Fig. 1. The order of binary zeros and binary ones depends on feedback configuration. With a proper selection of feedback, a pseudorandom binary sequence of maximum length $m = 2^n - 1$ is generated, where n is the number of stages in the shift register. Also, it does not matter which state is considered to be initial, if state "zero" is turned off. In the configuration of pseudorandom sequence generator using exclusive-OR (XOR) gates is not allowed to appear the state where all outputs of shift register are zeros, because $0 \oplus 0 = 0$. A properly selected feedback provides a generation of pseudorandom sequences of maximum length, $m = 2^n - 1$. The sequences are deterministic, but exhibit noise properties similar to randomness.

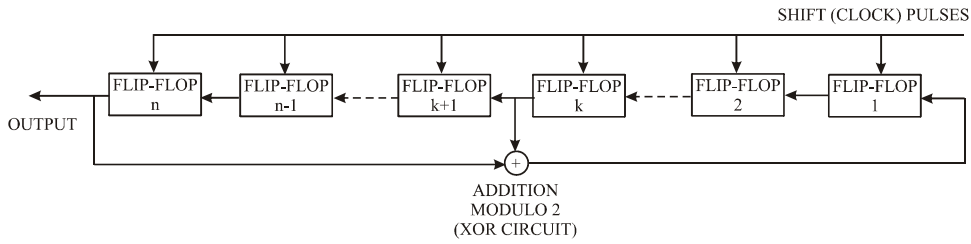


Fig. 1 Generator with n stages of pseudorandom binary sequence with single feedback configured from n and k stage

The feedback set can be much more complex and Fig. 2 shows a general block diagram configuration of a serial pseudorandom sequence generator, where you can see that the specific feedback configuration depends on which of the switches P_i is closed. The values of the coefficients P_i , in order of generating pseudorandom binary sequences of maximum length are determined by the primitive (basic) polynomials, [8].

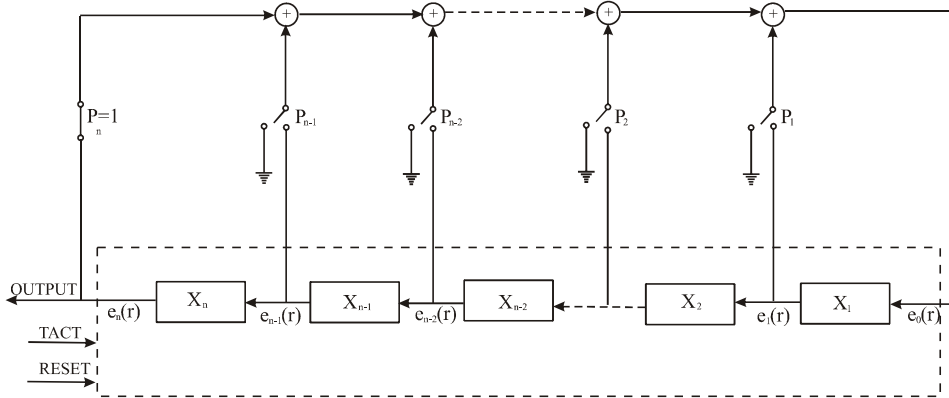


Fig. 2 Serial configuration of pseudorandom binary sequences generator of maximum length

Namely, it can be shown that by starting from the same initial state by using inverse generation law of pseudorandom binary sequence the inverted binary sequence is got in relation to that got using direct generation law. This conclusion is generally true for any n . Based on the table of primitive polynomials, relationships of direct and inverse generation law of pseudorandom binary sequences for each n can be established. In reference [9] the process is implemented for $n \leq 40$ and the derived relationships shown in Table 1, which are used in Fig 4. Based on these relationships, any generation of pseudorandom binary sequences up to length $m = 2^{40} - 1 \approx 10^{12}$ can be made easily.

A generalized pseudorandom binary sequence generator is developed by application of virtual instrumentation, and by using the derived tables, which can be modified and tested further. This is an example of software realization of logic functions and operations. A pseudorandom binary sequence can be generated not only by using XOR gates, but also by using XNOR gates.

The realized virtual instrument for generation of pseudorandom binary sequences by using the XOR gates with little modification can be used for generation of pseudorandom binary sequences using XNOR gates. In this case, the state where all outputs of shift register are equal to one is not allowed to appear, because $1 \rightarrow \oplus 1 = 1$. In reference [10], there is a table for pseudorandom binary sequences generation using XNOR circuits. Also the relationships for direct and inverse law of generation pseudorandom binary sequence for each n can be created, where the obtained relationships are used in Fig 4 and shown in Table 2.

Table 1 Feedback connections for generation of pseudorandom binary sequences using XOR gates

n	Feedback connections for direct generation of PRBS	Feedback connections for inverse generation of PRBS
3	$X(0) = X(3) \oplus X(1)$	$X(4) = X(1) \oplus X(2)$
4	$X(0) = X(4) \oplus X(1)$	$X(5) = X(1) \oplus X(2)$
5	$X(0) = X(5) \oplus X(2)$	$X(6) = X(1) \oplus X(3)$
...
20	$X(0) = X(3) \oplus X(1)$	$X(21) = X(1) \oplus X(4)$
21	$X(0) = X(4) \oplus X(1)$	$X(22) = X(1) \oplus X(3)$
22	$X(0) = X(5) \oplus X(2)$	$X(23) = X(1) \oplus X(2)$
...

Table 2 Feedback connections for generation of pseudorandom binary sequences using XNOR gates

n	Feedback connections for direct generation of PRBS	Feedback connections for inverse generation of PRBS
3	$X(0) = X(3) \rightarrow \oplus X(2)$	$X(4) = X(1) \rightarrow \oplus X(3)$
4	$X(0) = X(4) \rightarrow \oplus X(3)$	$X(5) = X(1) \rightarrow \oplus X(4)$
5	$X(0) = X(5) \rightarrow \oplus X(3)$	$X(6) = X(1) \rightarrow \oplus X(4)$
...
20	$X(0) = X(20) \rightarrow \oplus X(17)$	$X(21) = X(1) \rightarrow \oplus X(18)$
21	$X(0) = X(21) \rightarrow \oplus X(19)$	$X(22) = X(1) \rightarrow \oplus X(20)$
22	$X(0) = X(22) \rightarrow \oplus X(21)$	$X(23) = X(1) \rightarrow \oplus X(22)$
...

The front panel of the realized virtual instrument using a LabVIEW 8.0 software environment is shown in Fig. 3, and it combines the two previously presented methods of pseudorandom binary sequences generation. In the developed solution, for a given length of shift register, the generation mode of pseudorandom binary sequences can be selected, i.e. if generation is done by using XOR gates or XNOR gates.

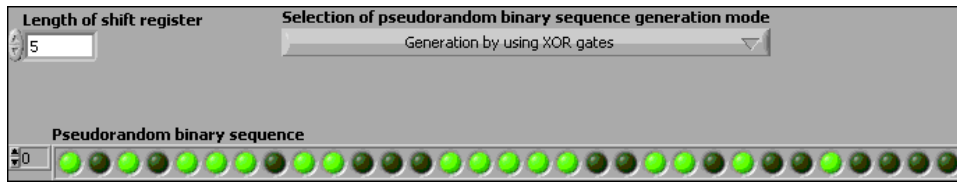


Fig. 3 The front panel of the realized pseudorandom binary sequence generator

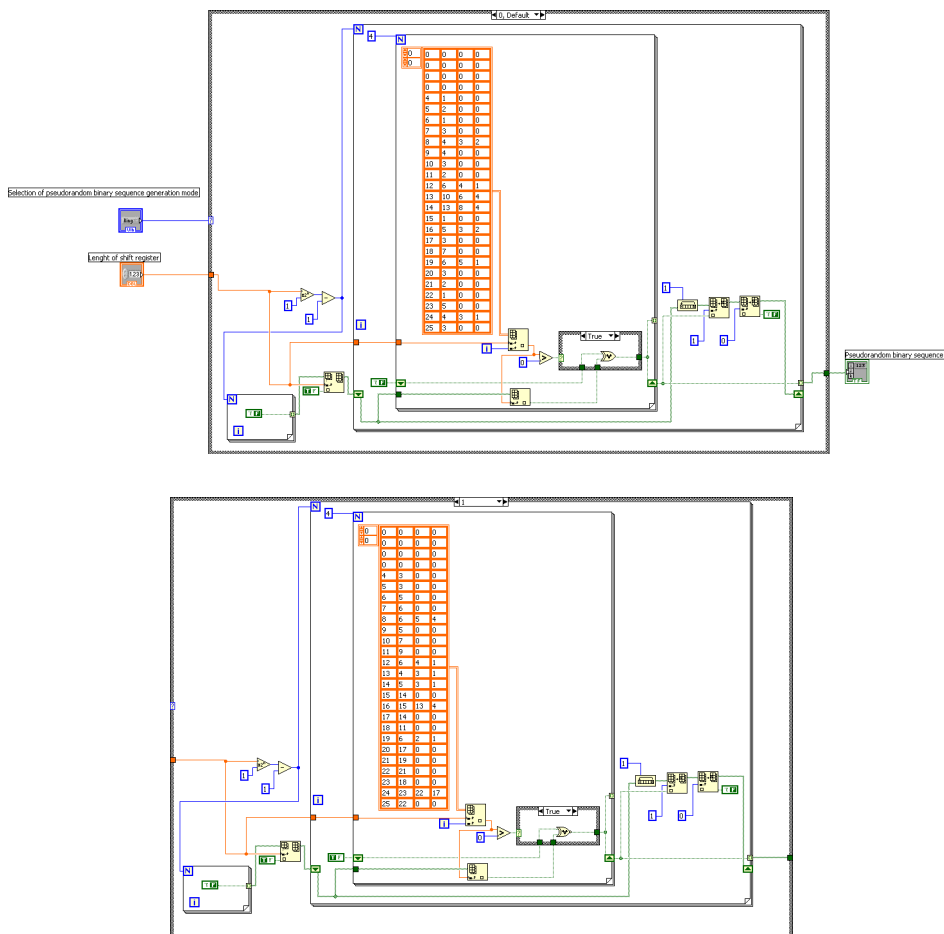


Fig. 4 Block diagram of pseudorandom binary sequences generator for generation mode with XOR and XNOR gates

As an example, the obtained pseudorandom binary sequence for length of shift register $n = 5$ is shown, which is generated by using XOR gates. A block diagram of the realized virtual instrument is shown in Fig. 4, in which we can see both ways of generating pseudorandom binary sequences and minimal differences in their implementation.

The implementation of pseudorandom binary sequence generator using discrete components has the advantage of being simple for implementation and inexpensive. The advantage of using a microprocessor is that it is easy to make changes to the program, but costs more than the previous. FPGA based implementation is flexible and very fast, but the equipment is expensive and VHDL programming is not quite easy to learn. Realization with virtual instrumentation concept is easy to modify, and graphical programming is easy to learn.

The realized pseudorandom binary sequence generator is exploited in the development of pseudorandom position encoders [3], where it is mainly used for simulation of signals from outputs of code reading heads.

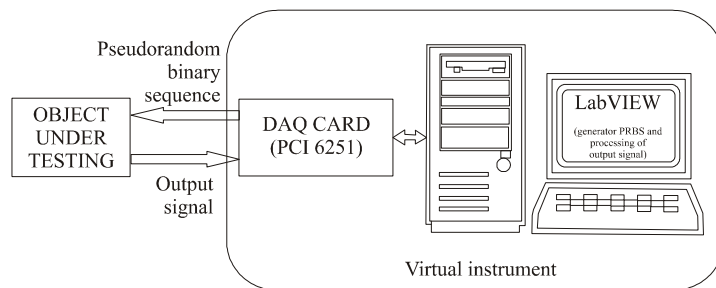


Fig. 5 Experimental system for testing of some sensors, AD converters, etc

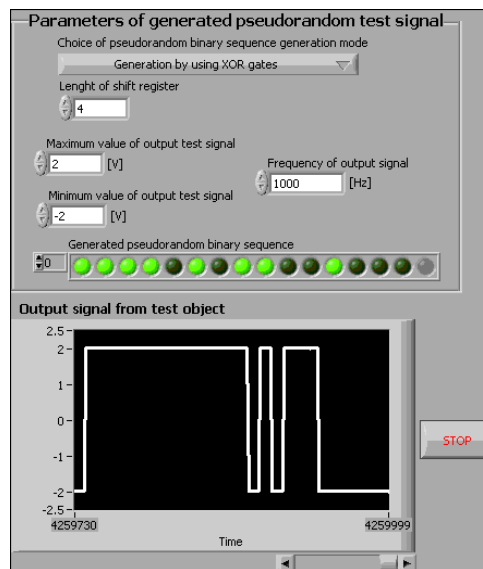


Fig. 6 Front panel for adjusting parameters of generated pseudorandom binary test signal

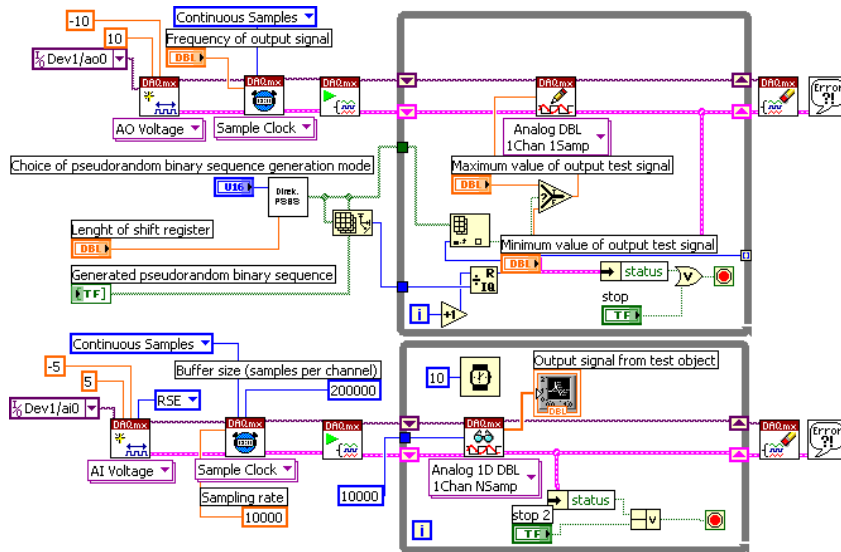


Fig. 7 Block diagram for generation of pseudorandom test signal and for acquiring output signal from test object

Also, the realized pseudorandom binary sequence generator in the form of the virtual instrument, Fig. 3, can be used in this software form or for generation of pseudorandom test signal, within the virtual instrument shown in Fig. 6. An experimental system is implemented for general purpose of testing, for example, the AD converters [4], different measurement transducers [2], measurement of frequency response [7], etc, shown in Fig. 5. National Instruments’ DAQ card PCI-6251 is used for implementation of an experimental system, and it has two analog outputs for the purpose of signal generation (Fig. 6 and Fig 7). The signal of the generated pseudorandom binary sequence from the acquisition card output is sent to the tested object input. The output signal from the tested object is returned to the input of acquisition card, where it is acquired and further processed in LabVIEW environment in accordance with current needs and requirements. PRBS signal generator can create one bit of data per clock cycle on the acquisition card’s output or can be modified to create n bits on parallel digital outputs. In the front panel, Fig. 6, the basic parameters of generated pseudorandom test signal, such as, frequency, maximum and minimum value, length of shift register, generation mode can be adjusted and also the acquired signal on the analog input can be seen. Calculating the FFT of the input pseudorandom test signal and acquired output signal, the magnitude of the frequency response or other properties of test object can be measured.

3. CONCLUSION

Pseudorandom binary sequences are a type of periodic signals with some useful properties, and can be generated in different ways. The advantages of using virtual instrumentation for generation of pseudorandom binary sequences are pointed out in the paper. The

realized PRBS generator is very flexible and can be used widely in various fields of research work. Graphical programming which is used for implementation of this generator is easier to learn than textual or VHDL programming. Changing PRBS signal parameters, such as generation mode, length of shift register, frequency, minimum and maximum value of signal, is quite easy in a user friendly interface. Uniform power spectral density over a wide frequency band of PRBS signal is used for measurement of some properties of the test object, such as frequency response.

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GENERISANJE I PRIMENA PSEUDOSLUČAJNIH BINARNIH SEKVENCI POMOĆU VIRTUELNE INSTRUMENTACIJE

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Veoma dinamičan razvoj virtuelne instrumentacije poslednjih godina je doveo do veoma dobrog prihvatanja ovog koncepta i njegove primene u mnogim aplikacijama. Ovaj koncept, kao jedno fleksibilno i isplativo rešenje za testiranje i merenje, je u ovom radu iskorišćen za implementaciju i primenu generatora pseudoslučajnih binarnih sekvenci maksimalne dužine. Zbog svojih osobina, pseudoslučajne binarne sekvence su često korišćene u razvoju i poboljšavanju modernih pseudoslučajnih pozicionih enkodera, a takođe za testiranje nekih tipova senzora, analogno-digitalnih konvertora, itd.

Ključne reči: virtuelni instrument, pseudoslučajna binarna sekvenca, pseudoslučajni pozicioni enkoder