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Incremental Encoder Macromodel for Educational Purpose

Marieta Kovacheva[1] and Peter Yakimov[2]

Abstract – **In this paper a macromodel of incremental rotary encoder is described. The basic characteristics and the behaviour of the encoders are studied. A digital electronic circuit generating the output signals of the incremental encoder and simulating its operation is designed. Results of the macromodel simulations are given.**

Keywords – **Rotary incremental encoder, Macromodelling, Digital circuits design, Simulation.**

I. INTRODUCTION

In the past decade, the simulation has taken on an increasingly important role within electronic circuit design. The most popular simulation tool for this is PSpice A/D, which is available in multiple forms for various computer platforms. However, to achieve meaningful simulation results, designers need accurate models of many system components.

Simulation and modelling are investigations approaches which take place in different fields of scientific and applications developments [4, 5]. First the behaviour of a circuit or module is simulated and the parameters are adjusted and then they are verified by investigation over real object.

Harsh industrial applications often expose plant equipment to caustic chemical materials, resulting in premature deterioration and failure. Complex systems control requires complete cover of the behaviour of every industrial object and process in all working regimes. This could be achieved using the possibilities of the simulation and modelling. These methods have wide application in industry areas like electric power production, chemical manufacture, machine building and etc. where interruption and accident regimes creation in order to adjust the control equipment are impermissible.

The use of motion transducers has become commonplace and increasingly important to motion control systems designers in all sectors of manufacturing industries. As rapid advances in size, accuracy, resolution, and application sensitive mechanical packaging develops, close loop systems become more attractive to design engineers. The broad range of devices that are currently available can offer design engineers multiple solutions to their motion control needs.

Encoders enable design engineers to control motion by providing reliable feedback within the process loop. Optical rotary encoders are the most widely used method of transforming mechanical rotary motion into electrical output.

Compact macromodels of different devices and in particular, incremental encoders are desired to speedup the simulation without sacrificing any of the required accuracy. One method to decrease simulation time and improve the convergence, without a significant loss of information, is by using behavioural macromodelling technique. Macromodelling is a way of providing macroscopic models of the corresponding devices.

Simulation investigations are of great importance for systems intended for applications in gas and oil production, chemical processing, grain and coal dust, and other hazardous environments.

Macromodels are very useful in education, where the students can investigate and study the basic characteristics of the encoders and the circuits processing their output signals.

Without any doubt macromodels of incremental encoders are necessary for simulating controllable motion systems. However, powerful simulation macromodels have not been available yet.

II. ENCODERS PRINCIPLES

A. Classification

Encoders are mechanical to electrical transducers whose output is derived by “reading” a coded pattern on a rotating disk or a moving scale. Encoders are classified by the:

• method used to read the coded element - contact or non-contact;

• type of output - absolute digital word or series of incremental pulses;

• physical phenomenon employed to produce the output - electrical conduction, magnetic, optical, capacitive.

In comparison to the absolute encoders the incremental ones have some advantages. Generally, incremental encoders provide more resolution at a lower cost than their absolute encoder analogs. They also have a simpler interface because they have fewer output lines. In a simple form, an incremental encoder would have 4 lines: 2 quadrature (A & B) signals, and power and ground lines. A 12 bit absolute encoder, by contrast, would use 12 output wires plus a power and ground line.

B. Theory of operation

The principle of incremental encoder operation is generation of a symmetric, repeating waveform that can be used to monitor the input motion. The basic components of all optical incremental encoders are the light source, light shutter system, light sensor, and signal conditioning electronics.

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These components will be housed and assembled to various mechanical assemblies, either rotary or linear in design depending on how motion will be monitored. The encoder mechanical input operates the light shutter which modulates the intensity of the light at the sensor. The sensors electrical output is a function of the incident light. The encoders electrical output is produced from the sensor output by the signal conditioning electronics and can be either:

- a sine-wave;
- a shaped, square-wave;
- a series of equally spaced pulses produced at regular points on the waveform.

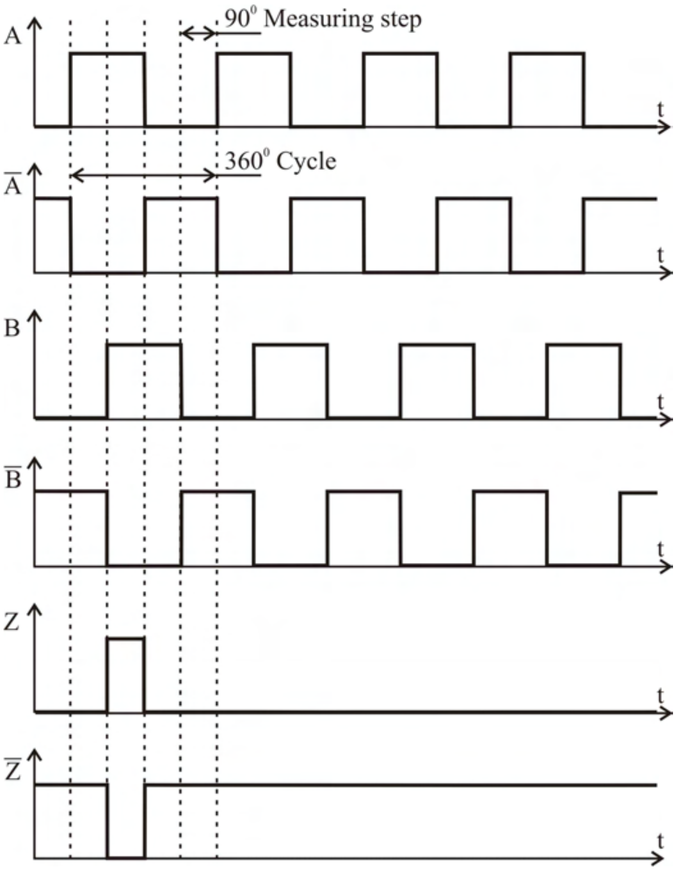

Fig. 1. Output signals in CCW rotation

An incremental encoder produces a series of square waves as it rotates. The number of square wave cycles produced per one turn of the shaft is called the encoder resolution. Incremental encoders work by rotating a code disc in the path of a light source. The code disc acts like a shutter to alternately shut off or transmit the light to a photodetector. The pulse range of an encoder is dictated by the number of tracks of clear and opaque lines located on the disc. Thus, the resolution of the encoder is the same as the number of lines on the code disc. A resolution of 360 means that the encoder code disc will have 360 lines on it and one turn of the encoder shaft will produce 360 complete square wave cycles, each cycle indicating one degree of shaft rotation. Since the resolution is "hard coded" on the code disc, optical encoders are inherently very repeatable and, when well constructed, very accurate. The square wave output is inherently easy for digital signal processing techniques to handle.

Incremental encoders are usually supplied with two channels (A & B) that are offset from one another by 1/4 of a cycle (90 electrical degrees). This signal pattern is referred to as quadrature and allows the user to determine not only the speed of rotation but its direction as well. By examining the phase relationship between the A and B channels can be determined that A leads B for counterclockwise (CCW) rotation of the input shaft as it is shown on Fig. 1.

Generally in addition to the signals A and B, their inverse forms are also available. The complete signals set includes also a “zero” pulse – Z and its inverse form. This signal is generated using another track on the disc that has only one opaque line. Signal Z rises high once per one turn of the shaft.

The relationship of the encoder output signals for turning clockwise (B leads A) is shown on Fig. 2.

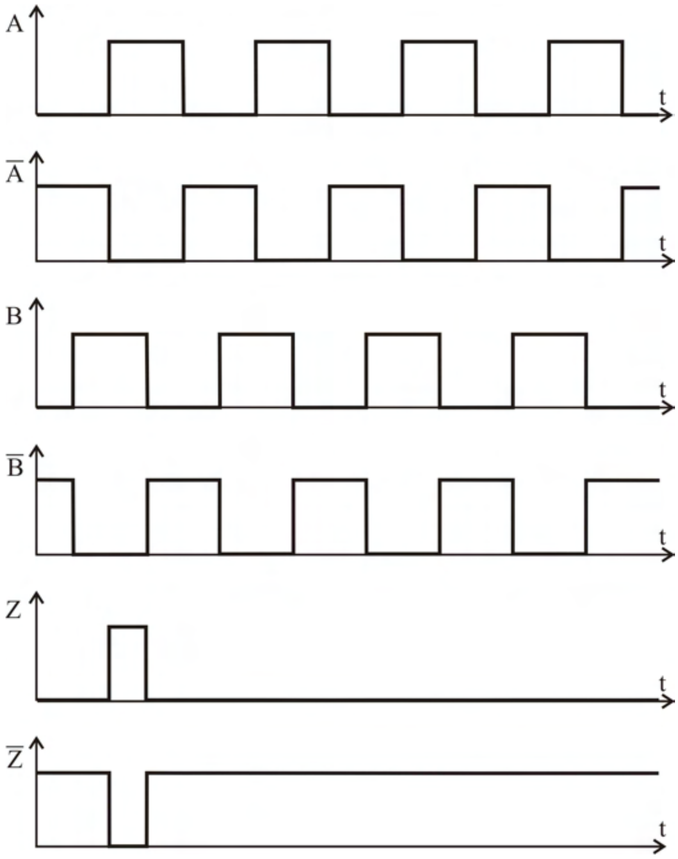

Fig. 2. Output signals in CW rotation

Except for discrimination between direction of movement (CW versus CCW), the quadrature relation allows for error detection in high vibration environments and higher resolution by using edge detection. With quadrature detection the controller can derive 1X, 2X or 4X the basic code disc resolution. 10,000 counts per turn can be generated from a 2500 cycle, two-channel encoder by detecting the Up and Down transitions on both the A and B channels as it is shown on Fig.1. In this case the measuring step is 90 electrical degrees. With a quality disc and properly phased encoder, this 4X signal will be accurate to better than 1/2 count.

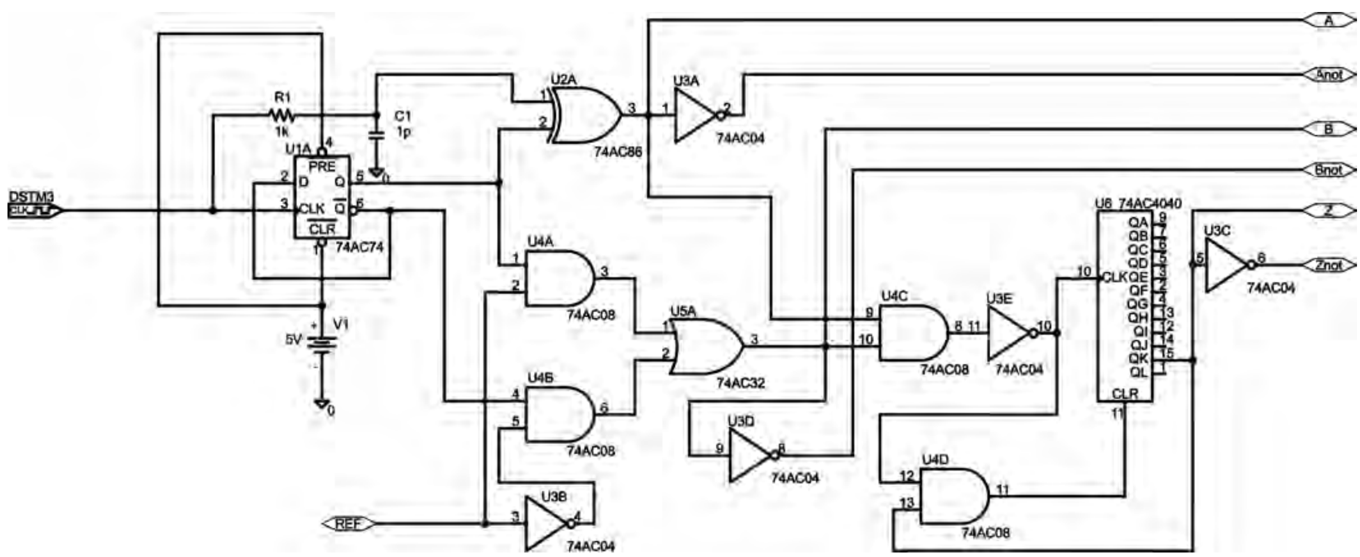

Fig. 3. Macromodel electric circuit

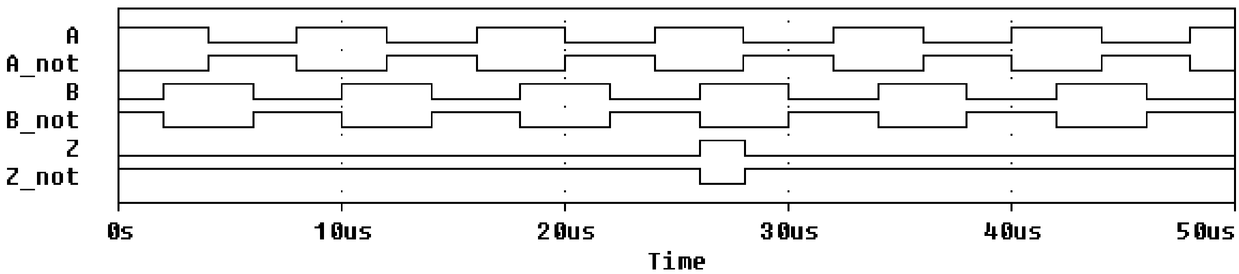

Fig. 4. Simulation results in CCW rotation

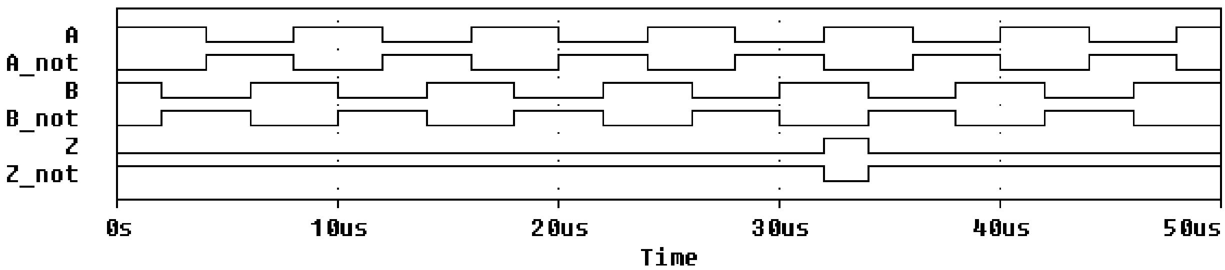

Fig. 5. Simulation results in CW rotation

III. MACROMODEL DEVELOPMENT

The macromodel electric circuit is designed using standard advanced CMOS combinational and sequential logic circuits and is shown on Fig. 3. It simulates the action of a rotary encoder. The frequency of the output signals A and B is set by the digital stimulus DSTM3 and can be adjusted editing its model parameters. This is important for the flexibility of the macromodel because this is the possibility to set the value of the speed of the movement. The main part of the circuit is the generation of the signals with quadrature relation. This is obtained using the D flip-flop (U1A) acting as a frequency divider and the XOR logic gate (U2A). To the inputs of the same gate are applied the signal with the clock frequency and the one with its half value. In this way the signal produced by the XOR gate and the signal produced by the normal output of the flip-flop are with 90 electrical degrees phase shift. If the initial state of the flip-flop is high then the signal from its normal output will lead the signal produced by the XOR gate. In the same time the signal obtained from the inverted output of the flip-flop will lag the output signal of the XOR gate. If it is accepted that the output of the XOR gate produces the signal A, then there must be a part of the circuit that will simulate the signal B and the change of the direction of the rotation. Thus there is a two-input multiplexer realized with the AND gates U4A and U4B, the inverter U3B and the OR gate U5A. The signal B is obtained from the output of the multiplexer. An external logic signal applied to the input REF determines the relation between the signals A and B. When this input is tied low signal B will be produced by the inverted output of the flip-flop and then A will lead B as it is shown on Fig. 4. In contrary when a high level is applied to the REF input the signal B will lead the signal A as it is depicted in Fig. 5.Thus the change of the logic level applied to the REF input simulates the change of the direction of the rotation. In order to have the inverted forms of the signals A and B, two inverters are added. The logic gate U3A produces the inverted form A_not and the logic gate U3D – the inverted form B_not. The complete set of signals of the rotary encoder includes the “index” signal Z. There is another part of the circuit that generates it. The circuit consists of the 12-stage binary ripple counter 74AC4040 (U6) and the logic gates U4C, U4D, U3E and U3C. This circuit must produce a pulse on every previously defined number of pulses on outputs A and B. So this pulse is generated once per one turn of the shaft of the encoder. Because the counter advances on the high-to-low transition of CP input and to simulate correctly the operation of the rotary encoder the clock pulses for the counter are produced by AND function of the signals A and B followed by inversion. The number of cycles of A and B signals per one turn of the encoder shaft is simulated by choosing the output of the counter from which the Z signal will be derived. In the shown example the Z signal is derived from the output QK which means that there will be 1024 cycles per one turn. The biggest number of cycles that can be simulated using this macromodel is 2048 if the signal Z is derived from the output QL. Any less number equal to a power of two can be obtained. In this way the resolution of the encoder is simulated. To shape the Z pulse an additional logic for resetting the counter is used. The width of this pulse must be equal to one quarter of the cycle. To achieve it the AND gate U4D produces the active high level for the master reset input of the counter. Since the chosen output has risen after the falling edge of the clock signal one of the inputs of the AND gate receives logic one. The output of the counter will hold its high level till the clock pulse raises its state. This time interval will continue one quarter of the cycle and after low-to-high transition of the clock pulse logic “1” will be applied to the other input of U4D. At that moment MR input of the counter will receive its active level and all outputs will be cleared. The inverter U3C produces the inverted form of the signal Z_not. So all output signals of the incremental encoder are generated and the simulated timing diagrams are shown on Figs. 4 and 5.

IV. Conclusion

In this paper an incremental rotary encoder macromodel is presented. It simulates the operation of the encoder in both directions of rotation. The full set of output signals is generated. The simulated timing diagrams of the signals correspond to the real ones. This macromodel has been used in the laboratory work of the students at the Technical university of Sofia. The macromodel can be used in design and studying electronic circuits for processing incremental rotary encoder signals.

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