DESIGNING DIGITAL DC SERVO–CONTROLLER USING DISCRETE LOGICS

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1. ABSTRACT

The aim of this paper is to present problems of servicing, redesigning and conditions of replacing the unprocurable electronic parts with easy to buy IC-s and own designed electronic circuits. The following study may help the developers to build own designed digital servo system for home and industrial automation system also for models (airplane, cars and ships) and to reutilize well running electronic or mechanical parts of out of running commercial servos. Because of today's servos are cheap and relative easy procurable the questions of replacing or redesigning of electronic parts of commercial servos has not yet been fully worked out in literature, but alternative methods and the new concept of the structure provide always unquestionable advantage.

2. INTRODUCTION

Whereby a continuous improvement of digital electronic parts, the availability of discrete logics and microcontrollers from around 1970 leading to the development of modern control systems. [3] Control of today's freighters and huge transportation machines require much large forces as the operator actions. Conventional aircrafts having large fuselage and control surfaces (horizontal tails, horizontal and vertical canards, spoilers, all-moving tails, fins, flaps, moving edges, etc.) require enormous forces for action. [4] Control moments and forces capable to affect the angular position of moving parts can be generated using hydraulic differential actuators. While a payload of airplane-models and the capacity of onboard electrical sources are very limited, instead of hydraulic source solely electromechanical actuators and servo systems are widely used. The electromechanical servos are capable to exercise much less forces and moments as hydraulic actuators, but both are controlled using electrical signals. There are several methods to be transmitted the command signals over long distances. In general it is desirable using a wireless communication. The command signal is radiated in space in form of electromagnetic (radio or optical) waves using a carrier and the actuators are signalled electrically using the onboard electric power source, such as batteries or accumulators.

Today's analog and digital remote control systems use the same on-off keying modulation technique. The PDM[1] in other words PWM is one of the modulation technique widely used in remote controlled systems. [5] In analog transmission channel the message is transmitted simply using PWM signals, in digital channel the transmitted message content is described by the code as function of the pulse length. The PWM signal can be processed both by analog and digital hardware, against this the decoding process of serial data require sophisticated hardware based onto microcontrollers or microprocessors. There are considerable differences between analog and digital systems in respect to the immunity against disturbances. The bandwidth restrictions and disturbances due to interference of radio signals and the on-off keying digital signals radiated in space are the primary problems faced by the radio-amateurs and RC[2] modellers.[6] [7]

The next sections are organized as follows. A short presentation of basic structure of electromechanical servo systems will be followed by description of digital servo- electronic using easy procurable standard CMOS[3] logic gates. The worked out electronic board ready for use presented here is a prototype of a new digital servo-electronics. The board ready for use presented here permits direct replacing of the analog electronic circuit of various commercial servos. To fit the board into the chassis of commercial servos the prototype board should redesigned using SMD[4]-s.

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[1] PDM (Pulse Duration Modulation), PWM (Pulse Width Modulation)

[2] RC – Radio Controlled

[3] CMOS – Complementary Metal Oxid Semiconductor

[4] SMD – Surface Mounted Devices

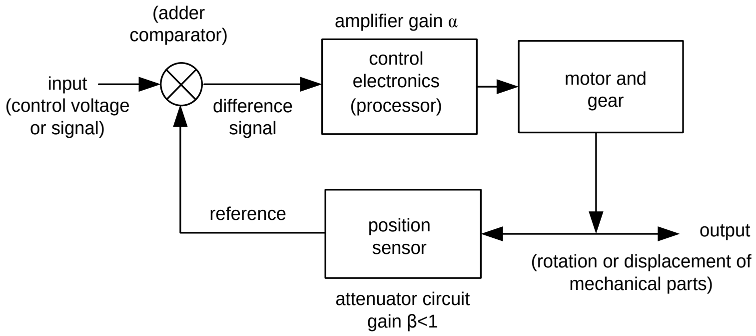

Figure1.
Closed loop feedback system of servos
(designed by author)

3. BASIC STRUCTURE OF ELECTROMECHANICAL SERVO SYSTEMS

In classical structure of remote control system the receiver is followed by “decoder”. The incoming serial signals from receiver in form of rectangle pulse should separated and transformed into sequential signals. The individual signals should transferred to the corresponding output of decoder. The obtained PWM signals, having duration time between 1 and 2,2 ms will be the incoming signals of servo- actuators. The repetition time of pulses is about 20 ms.[8][9] Servos are connected to the output channels via three wire cable (Fig. 2 – right side). If the duration of incoming pulses varies, the angular position of the output shaft of mechanical gear proportionally changes. One of the prevalent names applied to such systems is a “follow-up” system. The detailed description and analysis of closed loop servo systems can be found in the literature. [10][11][12]

The general block diagram of single loop feedback system used in most of servos can be seen on Fig. 1. The blocks represent components having specified function. The essential parts of such control systems are: the controller or “plant” (motor and mechanical gear), the position sensor, or sensors, finally the adder Fig. 1. The key concept in the automatic control systems is that of feedback. Feedback control serves to sustain the equilibrium state or poise of mechanical parts. Any deviation from the equilibrium state of mechanical system due to change of load produces difference signal in output of adder proportional to the angular position error. The difference or error signal provided by the adder (comparator) will be transformed in proper form of signals (current, voltage, etc.) to be processed by the controller. The motor should drives or move the load always in direction corresponding to decrease the position of error signal, and is stopped when the error signal is reduced to zero. This happen, only if the right polarity of electrical source is connected to the DC motor.

The drives of proportional servo systems frequently use position transducers interconnected mechanically with rotating axis or moved mechanical parts. The widely used position transducers are potentiometers (Fig. 2) and incremental encoders. Both provide signals, but contrary to the potentiometers, which generate continuous and variable current or voltage, incremental encoders provides electrical pulses. [13] The generated amplitude of signal or number of pulses is proportional to the angular position of the command elements. The width of an input signals obtained from position sensors are determined by the angular position of command surfaces or rotating axis of the dear with respect to fixed reference or position. The output signal of sensors may also be processed both by analog and digital control circuits.

Manufacturers specialized into the industrial process and control began marketing a wide range of standard electronic components, named control IC-s. Due to the rapid development of electronic components majority of today’s servos use especially MSI and LSI[5] IC-s, diminishing dramatic the number of discrete electronic elements. [2] Electromechanical servos composed by electronic and mechanical parts can be divided into three groups. The first include the direct current servos controlled by linear (analog) electronic circuits, the second group include control systems which contain

[5] MSI – Medium Scale Integrated,
LSI – Large Scale Integrated

beside the analog IC-s also digital components and finally the third group includes the pure digital and programmable servo electronics which are based onto the standard logics or processors.

Because of rapidly spreading of digital systems it has also to be said that today's boundaries between the groups mentioned above can not always clear-cut. The improvement of modern control systems tend to the grown of mixed systems composed by both of analog and digital electronic components.

The Fig. 2 shows the internal structure of MC33030P type servo controller designed especially for micro- servo systems. The specified parts as the "window detector" are frequently used in both of integrated and discrete control systems. Many applications of window detector can be found in literature which uses discrete electronic parts such as comparators, having similar structure and function as the input analog stage of MC33030 servo IC. [14] The MC33030P IC beside the analog window detector and error amplifier includes digital blocks as well as "direction logic" and the "programmable over current detector".

The application of MC330301P servo controller IC may be found in application notes (AN) released by the manufacturers. [2]

4. DESIGNING SERVO-CONTROLLER CIRCUIT BASED ONTO STANDARD LOGIC GATES

In least few years discrete logics and single chip processors become more small and cheaper. The application of digital IC-s and microcontrollers meaningful changes in the configuration of electronic parts. [15]

The block diagram of digital servo controller is presented in Fig. 3. The controller has two identical parts. Each part contains monostables (M1, M2), digital comparators (C1, C2) and bistables (S-R flip-flops: B1, B2). The monostables generates reference pulses, the digital comparators compare the duration of generated pulse with the duration time of incoming signals. The result of comparison is signalled by the flip-flops by the changing the state of its outputs. The B1 flip-flop determines the rotation sense of DC motor, the B2 flip-flop determines the state of K1 and K2 switches. Also, the output state of B2 influences the intermittent rotation and the state of repose of DC motor, which drive the potentiometer having position sensor function. The position of sensor determines the pulse length generated by the M1 monostable. The closed loop feedback system is realized by the M1, C1, and B1 function blocks. The M2, C2 and B2 realizes the digital "window detector" having similar function as the analog window detector mentioned before.

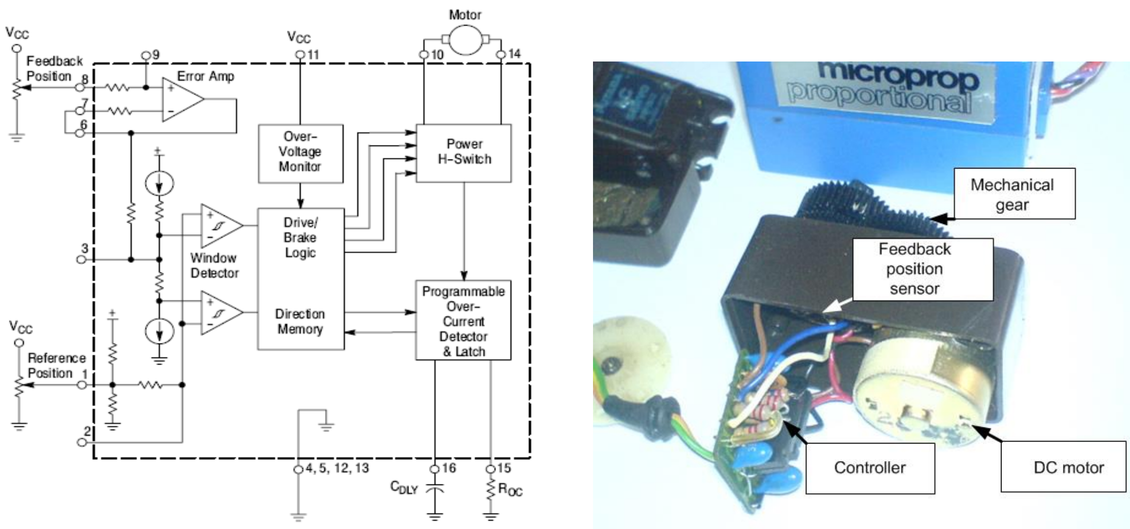

Figure 2.
Left side: Representative block diagram of MC33030P servo IC [1],
Right side: Structure of electro-mechanical servos
(photo made by author)

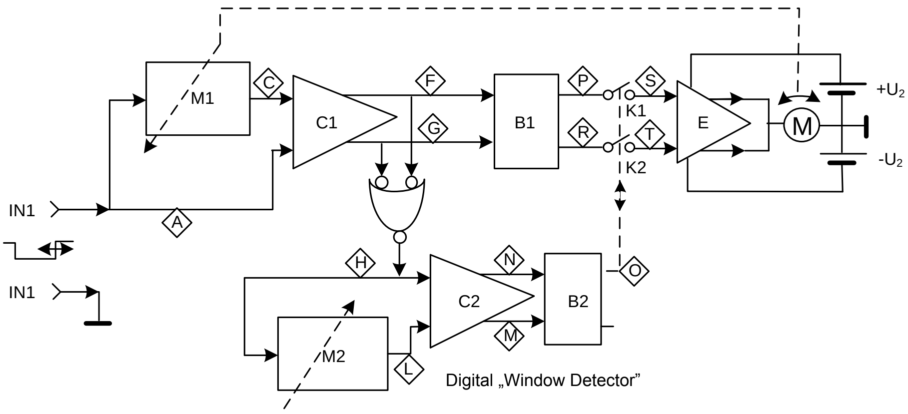

Figure 3.
The block diagram of digital servo
(designed by author)

The length of pulses generated by the M2 monostable, determine the sensibility of the servo-actuator to the variation of pulse length of incoming signals obtained from the decoder. Both parts are interconnected with the gate having logical AND function, represented by its complementary NOR symbol having bubbles also at the inputs. (Fig. 3) The AND gate which serves for synchronizing the two parts is realized using diode-logic (D1, D2) as can seen on Fig. 4. The E stage on Fig. 3 is a current amplifier realized by Q1, Q2, Q3 and Q4 transistors having cascade output, at the end.

The design uses easy to obtain components, mainly NAND gates and inverters as can see on Fig. 4. Because of NAND gates are "universally gates" its combinations permit to obtain the functions of all basic gates. The inverters are obtained using the redundant NAND gates simply by linking its inputs. The M1 and M2 monostable are composed by IC1/2, IC1/3 respectively IC2/2, IC2/3 NAND gates. The S-R flip-flops uses the IC3/1, IC3/2 and IC4/2, IC4/3, the C1 and C2 digital comparators uses the IC1/1, IC1/4 and IC1/2, respectively the IC2/4, IC4/1 and IC4/4 NAND gates. The K1 and K2 switches are realized by the IC3/3 and IC3/4 gates. The outputs of IC3/3 and IC3/4 gates are connected to the current amplifier. The alimentation of DC motor require differential power source, not necessarily separated from power source of IC-s, as can seen on Fig. 4.

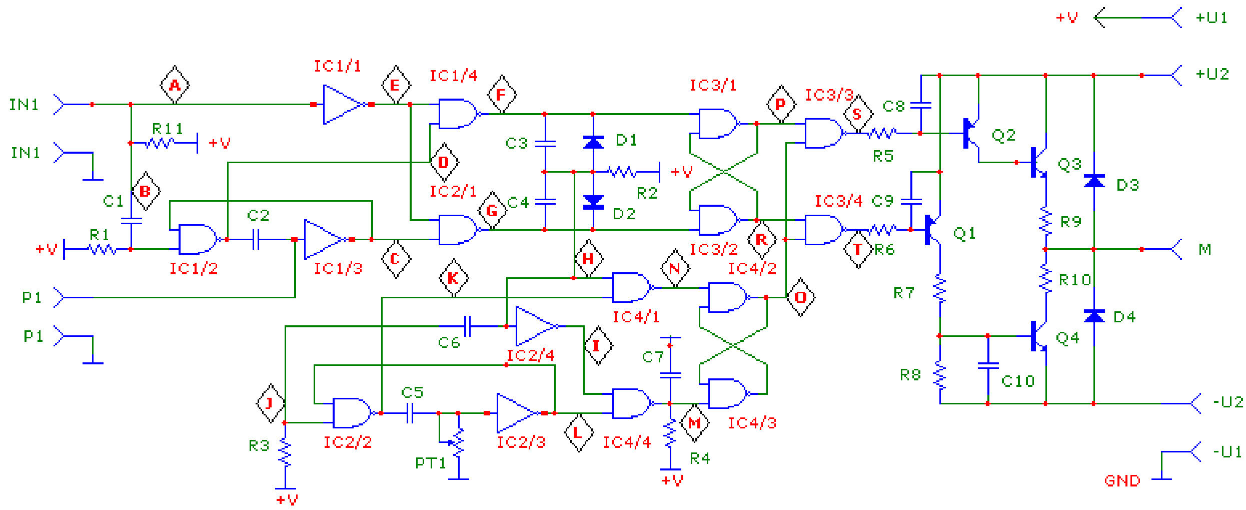

Figure 4.
Complete schematic of circuit using MMC4011 NAND gates [15]
(designed by author)

The detailed timing diagram of complete schematic with the signals varying over a period of 3 time intervals is shown in the Fig. 5. The timing diagram shows the response of gates or group of gates having the specified function presented on the block diagram.

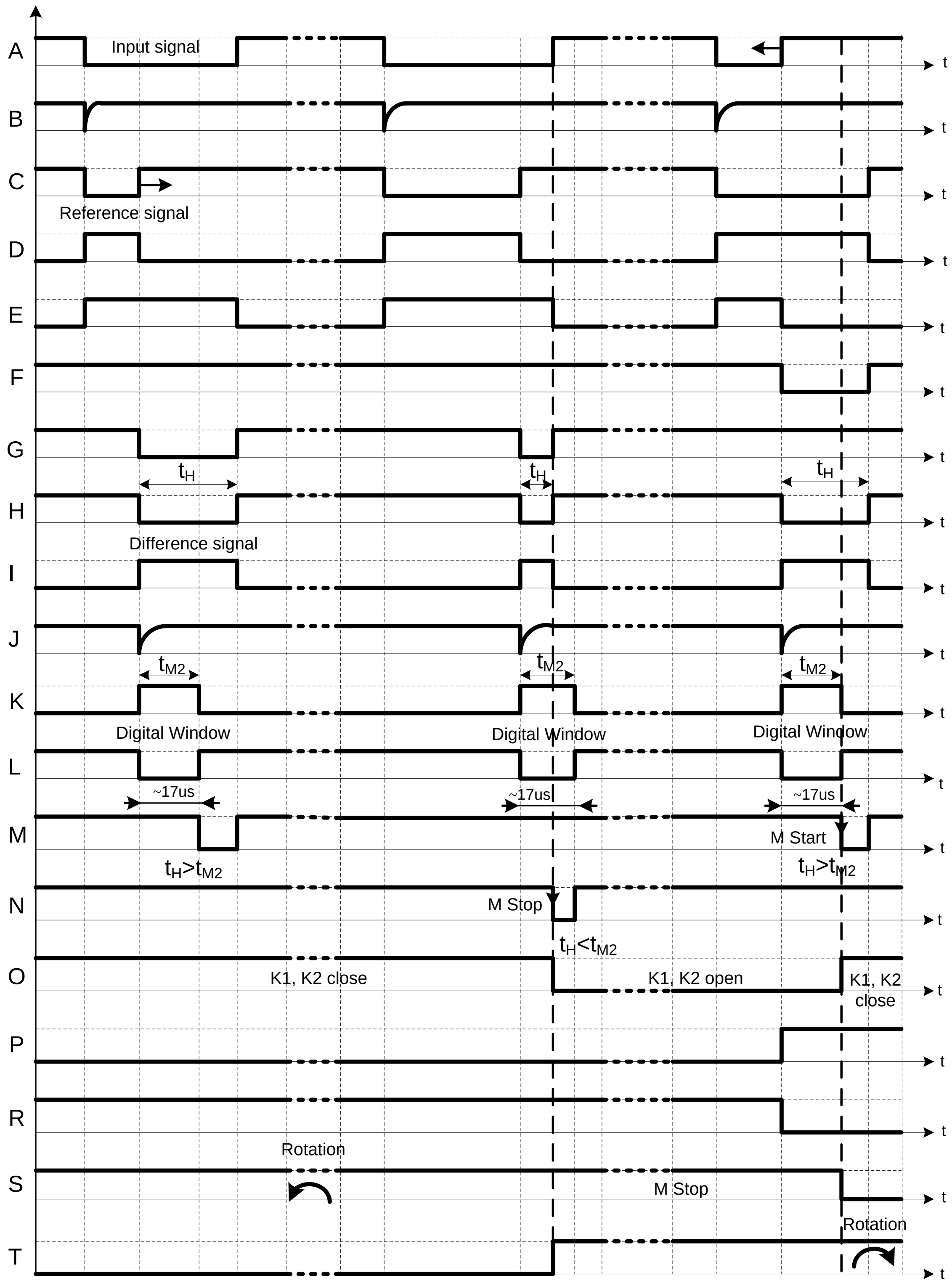

Figure 5.
Time diagram
(designed by author)

The input pulses are inverted signals obtained from decoder (Fig. 5, trace A). The duration of input pulses are constant during the first two time intervals and changed only in a last interval. The first time interval shows the readjusting sequence while the DC motor drive the output axe in the correspondent direction to stabilize the equilibrium of mechanical parts. The second time interval represents the state of equilibrium of gear system, when the pulse length on the H trace (t_H) are shorter then a width of "digital window" pulses when the DC motor stops.

The third time interval represents the pulses, which corresponds to the variation of steering signal. If the variation of input signal exceed the sensitivity of controller, (adjusted by M2 using PT1) (Fig. 5.), and t_H become shorter then t_{M2}, the polarity of voltage on the DC motor is reversed and starts to rotate the gear in opposite sense. The sensitivity of servomechanism to the variation of input signals are determined by the length of pulses, generated by M2 (digital window), which should be adjusted manually during the tests. The complete assembled board of the prototype of controller is presented on the Fig. 6.

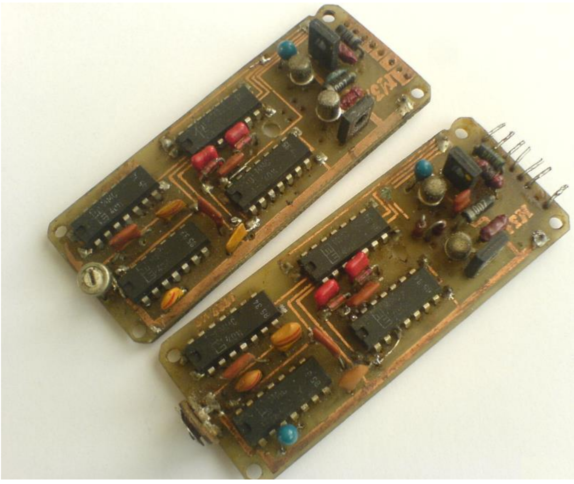

Figure 6.
Prototype boards of digital servo-controller
(photo made by author)

5. SUMMARY

Digital controlled servo systems are widely used in almost every field of our life, from the household appliances to the military and satellite systems. There is a great need of easy-to-use, adaptable intelligent periphery named actuators compatible with today's digital systems. It is well known that analog servo systems are quite instable and has low immunity against rectangle impulse and transients having high repetion rate. Because of operation principle of digital systems based right to the similar signals, can be presumed that high immunity and stability can be obtained using pure digital servo systems instead of analog systems. The new reference hardware proposed by author based onto the basic logic gates provide a comprehensive method for further development of non-programmable simple logic servo systems. The clear and simple operation of hardware presented here permit not only easy to understand the operation of digital hardware as well direct replacement of all type analog systems based onto non-procurable special IC-s.

The author introduces the key concept of sensibility and stability study in order to reduce the power dissipation of electromechanical servos. In order to compare the performance of commercial analog servos and digital servo systems similar reference hardware, further study and measurements are needed.

6. REFERENCES

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