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DESIGN SIMULATION AND HARDWARE OF OPERATIONAL TRANSRESISTANCE AMPLIFIER APPLICATIONS AND ANALYSIS THE PERFOMANCE OF VARIOUS APPLICATONS A dissertation submitted

in partial fulfilment of the requirement for the degree of MASTER OF TECHNOLOGY IN CONTROL AND INSTRUMENTATION by 8

HARDEV MEENA (Roll No. 2K12/C&I/31) Under the guidance of MR. RAM BHAGAT

DEPARTMENT OF ELECTRICAL ENGINEERING DELHI TECHNOLOGICAL UNIVERSITY DELHI Â 110042 MAY 2015 CERTIFICATE This 16

is certified that the thesis work contained in this dissertation entitled "DESIGN SIMULATION AND HARDWARE OF OPERATIONAL TRANSRESISTANCE AMPLIFIER APPLICATIONS AND ANALYSIS THE PERFOMANCE OF VARIOUS APPLICATONS," by Hardev Meena (2K12/C&I/31) has been carried out for

award of the degree of"MASTER OF TECHNOLOGY"in Control and 11

Instrumentation of Delhi Technological University, Delhi - 42 (Sh. Ram Bhagat) Assistant Professor Project Guide ii ACKNOWLEDGEMENT I feel honored in expressing sense of gratitude and indebtedness to my respected guide Mr. Ram Bhagat,

Assistant Professor, Department of Electrical Engineering, Delhi Technological University 17

for their guidance, meticulous efforts, constructive criticism, inspiring encouragement and invaluable co-operation which enabled me to work on thesis entitled "DESIGN SIMULATION AND HARDWARE OF OPERATIONAL TRANSRESISTANCE AMPLIFIER APPLICATIONS AND ANALYSIS THE PERFOMANCE OF VARIOUS APPLICATONS. I would like to extend my gratefulness to Prof. Madushudhan, Head of Electrical Engineering Department, Delhi Technological University, and Delhi for his perpetual encouragement, generous help and inspiring guidance.

I am also very thankful to Dr. Bharat Bhusan and Dr. 11

D. Joshi to enhance my awareness about Mat lab and

entire faculty and staff members of Electrical Engineering Department for their direct or indirect help, cooperation, love and affection, which made my stay at Delhi Technological University memorable. I 7

humbly extend my grateful appreciation to my friends Mr. Ashok Kumawat and Mr.Robi they are help me to know Pspice using Orcad. I thankful to Mr. Karam veer singh and Mr.Rakesh gaushwami for their time to time suggestions and cooperation without which I would not have been able to complete my work. I would like to thanks, Directorate of Training and Technical Education, Pitampura, Delhi, Principal and I/C (Electrical Engg. Deptt.), Pusa Institute of Technology, where I got full Cooperation and guidance to complete my thesis. And greatest thanks to my family and my classmates who bestowed ability and strength in me to complete this work. Hardev Meena (2K12/C&I/31) iii ABSTRACT The major goal of this thesis is to know about Operational Transresistance Amplifier (OTRA), its applications, performance and

practical implementation of OTRA. An introduction to Operational Transresistance Amplifier is presented in Chapter 2. The development and use of operational Transresistance Amplifier model is very important in control and instrumentation engineering. According to application of OTRA we develop a second order low pass filter in Chapter 3. Chapter 4 focuses on the behavior of OTRA based oscillator. Conventional controller such as proportional, integral and derivative individual and combined developed using operational Transresistance amplifier in Chapter 5. In Chapter 2 Â 5 first develop the mathematical model of each application of OTRA. Derived transfer function of filter, oscillator and controllers. Operational Transresistance Amplifier and its application such as filter, oscillator and controllers are design and simulated with help of Proteus ISIS Professional simulation software. Their transient, frequency, phase and noise responses derived using Proteus. Some electronic part analysis using Orcad capture, Pspice A/D. The performance of controllers evaluated using Mat lab simulink. Hardware implementation of OTRA may be possible due to AD844AN current feedback amplifier. The Chapter focuses on the software tools, particular control problem and results. iv CONTENTS LIST OF FIGURES

PD Â Controller 43 (Kp=10, Kd=6) Table 5.7

Performance comparison of closed loop with 6

P I- Controller 44 (Kp=10,Ki=1) Table 5.8

Performance comparison of closed loop with 6

PID Â Controller (Kp=10,Ki=1,Kd=6) 45 ix x CHAPTER - 1 INTRODUCTION This thesis is serves as study and analysis about Operational Transresistance Amplifier (OTRA) and its various instrumental applications like oscillator, filter and conventional controllers (Proportional, Integral and Derivative). This work done is analysis with Electrical and Electronic simulator Proteus ISIS Professional, Electronic simulator Orcad Pspice capture and Mat Â lab. Implementation of OTRA is based on AD844AN (CFOA). 1.1 INTRODUCTION TO OTRA The OTRA

is a high gain current input voltage output device. Both input and output terminals of the OTRA are characterized by low impedance 3

resulting in

circuits that are insensitive to stray 1

capacitance making OTRA appropriate for high frequency application.

To maintain compatibility with existing voltage processing circuits, it is necessary to convert the input and output signals of current mode circuits to voltage, using Transresistance. This has the disadvantages of increasing both the chip area and power dissipation. 1

OTRA as the active element benefits

from the current processing capabilities at the input terminals and can directly drive the 4

existing voltage mode signal processing circuits eliminating the requirement of additional circuitry and associated power consumption at the output. 1.1.1 OVERVEIW OF FILTER OTRA based second order filter could be design with help of AD844AP (CFOA), and its performance can be analysis using Proteus ISIS Professional simulation software. Simulation verified by practically also. 1.1.2 OVERVEIW OF OSCILLATOR Generating signals carrier for test signals, clock pulses for control and time. These signals have various shapes such as sinusoidal, triangle etc. Wave generated by signal generator describe by shape, amplitude, frequency and duty cycle. In continuation we will learn about sinusoidal oscillator using single OTRA. 1.1.3 OVERVEIW OF CONTROLLERS 1 Controller action depends on the difference between measured output variables and set point, it called error. Controller tries to minimize the error value by adjusting the process control inputs. 1.2 LITERATURE SURVEY Srinivasulu Avireni, Chandra Shaker Pittala [1] have describe the operational transresistance amplifier based five sinusoidal oscillator controlled by ground resistance and capacitance, it is important for integration point of view, performance of said circuit is examined with pspice models.

K.N. Salama, A.M. soliman 1

[2] have introduce

the operational transresistance amplifier (OTRA) based novel active 1

RC oscillators, which is generated minimum component oscillator, two OTRA based four new oscillator are reported. Hung Â Chun Chein [3] have study and proposed operational transresistance amplifier based three new sinusoidal oscillators, said OTRA based sinusoidal oscillator use to minimum RC oscillator and discuss nonideal effect, sensitivity and frequency stability of said circuit. Rajeshwari Pandy, Neeta Pandy, Sajal K. Paul [4] have describe electronic tunable circuit OTRA based applications and design of Transimpedance instrument amplifier. Rajeshwari Pandy, Saurabh Chitransi, Neeta Pandy, Chander Shekhar [5] describe the design of OTRA based analog controller proportional (P), proportional Â integral and derivate (PID) controller with control application of operational transresistace amplifier. Mayank Bothra, Rajeshwari Pandey, Neeta Pandey, Sajal Paul [6] have present operational transresistance amplifier based flexible and modular wave active filter structure, to overcome the effect of parasitic capacitor they have suggested the doubly terminated butterworth filter. V.Zeman, K. Vebra [7] are shown the solution design high order synthetic elemens with the type D admittance and maximum possible use of elements in higher order filter. Ashish Ranjan, Vivek Bhatt and Manoj Joshi [8] have present single Â input single Â output (SISO) butterworth, Chebyshev and Bessel operational transresistance amplifier based voltage mode low pass filters.

Khaled N. Salama, Ahmed M. Soliman 1

[9] have introduced Operational Transresistance Amplifier new CMOS realization, OTRA properties

are shown be for VLSI application , imploying MOS transistors operating in the ohmic 4

resign, proposed circuits are present with

both passive compensation and self compensation. 1

Rajeshwari pandey, Neeta Pandey, Mayank Bhotra, Sajal K. Paul [10] are utilized operational transresistance amplifier for multipurpose sinusoidal amplifier as the active element, described circuits are simple to realize. Cevat Erdal [11] have implemented a PID controller using commercial available active component AD844, this is based on current 2 feedback amplifier (CFOA), by use of parameter sensitivity optimized the PID controller circuit parameters. Vijaylaxmi Kalyani, Aayushi Arya [12] have introduced CFA by considering the advantages high slew rate due to architecture of current feedback, in this paper they present the comparison of maximum frequency range of differentiator and integrator for both CFA and VFA. A Budak[13

],A.M. Soliman, M.H. Al-Shamaa, M. 22

Dakalbab[14], A.M. Soliman[15], in the literature sinusoidal oscillator proposed using operational amplifier, bandwidth and slew rate are limitation of operational amplifier, these conditions affect the frequency of oscillator. C.M.Chang[15], A. Srinivasulu[16], A.M. Soliman[17], D.R. Bhaskar[18] are study to overcome these said drawback many oscillator based on current feedback amplifier (CFOA) and current conveyor are used as active element in above literature, these oscillators are known to for their wider bandwidth, large frequency range. 1.3 PROTEUS ISIS PROFESSIONAL SIMULATION SOFTWARE This is the software by using this we can design and simulate the electrical and electronic circuit, and analysis concern result as Orcad Pspice. 1.4 MAT Â LAB 3 1.5 ORCAD PSPICE 1.6 AD844 The AD844 is fabricated using the analog device. It is high speed monolithic operational amplifier. Its current feedback results are better. AD844 is free from slew rate limitation . AD844 operated from Â±4.5V to Â±18V biasing supply. AD844 have low noise, low distortion, and low drift with wide band width. 4 Figure 1.1 AD844AN 5 CHAPTER - 2 DESIGN SIMULATION AND HARDWARE OF OPERATIONAL TRANSRESISTANCE AMPLIFIER (OTRA) 2.1 INTRODUCTION The OTRA is three terminal current mode analog devices with

two low impedance input terminals and one low impedance output 21

terminal.

The input terminal of OTRA are virtually grounded. 23

Figure 2.1 OTRA Symbol and equal anent circuit The OTRA

is a high gain current input voltage output device. Both input and output terminals of the OTRA are characterized by low impedance 3

resulting in

circuits that are insensitive to stray 1 capacitance making OTRA appropriate for high frequency application.

To maintain compatibility with existing voltage processing circuits, it is necessary to convert the input and output signals of current mode circuits to voltage, using Transresistance. This has the disadvantages of increasing both the chip area and power dissipation. 1

OTRA as the active element

benefit from the current processing capabilities at the input terminals and can directly drive the 4

existing voltage mode signal processing circuits eliminating the requirement of additional circuitry and associated power consumption at the output. An ideal OTRA senses the difference of the currents at its two input terminals, namely `p' and `n', amplifies it and provides a resulting voltage at the output terminal Fig. 2.1. For ideal operation the input terminal voltages should be zero. The output voltage should be 6 independent of the current that may be drawn from the output terminal by the load impedance. Where Rm

is Transresistance gain of OTRA. For ideal operations the Rm approaches infinity and force the input current to be equal. 5

0 0 0 []=[0 0 0] [] (1) - 0 OTRA can be used in an open loop configuration. Its gain being infinity the output voltage saturates either at +ve or Âve saturation level.

Thus OTRA must be used in a negative feedback configuration where the output is 5

not driven into saturation and the circuit behaves linearly.

The OTRA is a current input and voltage output, 19

a shunt- shunt feedback is used which places the feedback network and amplifier in parallel. A parallel configuration is suitable for low voltage operations as it minimizes stacking of transistors thereby providing more head room for signal swing. OTRA bandwidth independent of closed loop gain by using current feedback. 2.2 OTRA IMPLEMENTATION The OTRA implementation based on the following 1. Using commercially available AD844AN (current feedback operational amplifier). 2. Using integrating circuit implementation Current feedback operational amplifiers commercially available as IC AD844AN. The OTRA can be realizied using two AD844AP CFOA ICs. Figure 1.2. Figure 2.2 OTRA implementation using of two AD844AP (CFOA) 7 Current calculated according to given circuit diagram in Figure 2.2 1= (2) 2= -1 (3) 2=2 (4) The current through Z2 terminal can be computed as 2= - (5) The voltage at various ports my be written as = 1-= 1+= 0 (6) = 2-= 2+= 0 (7) = 2 = -22 = (-)2 (8) =(-)2 (9) Where Rz2 is transresistance gain of the

OTRA. Figure 2.3 Transresistance Amplifier internal circuit If Rin Rs then Iin = Is If Rout RL than Vout = Rin*Iin = Rin*Is An ideal Transresistance amplifier should have input and output resistance zero. 8 2.3 SIMULATION AND HARDWARE RESULTS Performance of Operational Transresistance Amplifier study and analysis with the help of Proteus ISIS Professional simulation software. Simulation and hardware circuit design by following elements mentions in table 2.1. Quantity Part Â Name Value Specification Resistance 2 R1, R2 10K 1 R3 3M Integrated Circuits 2 U1,U2 AD844AP Miscellaneous 2 B1,B2 15V Batteries 1 Function Generator 0 Â 1MHz 1 CRO Table 2.1 Used elements list OTRA simulation and hardware designing Figure 2.4 Simulation circuit of OTRA using AD844 9 Figure 2.5 Practical circuit of OTRA Figure 2.6 Input Â Output response 10 Figure 2.7 Frequency and Phase response of OTRA Figure 2.8 Practical output of OTRA 11 CHAPTER - 3 DESIGN SIMULATION AND HARDWARE OF OTRA BASED SECOND ORDER LOW PASS FILTER 3.1 INTRODUCTION Analog designer got new boost in form of Operational Transresistance Amplifier because it is replace the current mode analog building block. Parasitic capacitance eliminated which are internally generated at input terminals. High slew rate and bandwidth are major strength of OTRA. In this chapter we will introduce single OTRA based analog filter. 3.2 PROPOSED CIRCUIT Generalized structure of filter using admittance term shown in figure 3.1 Figure 3.1 Generalized circuit of OTRA based filter Transfer function of proposed circuit is derived as Current at positive terminal ip calculated with help of figure 3.1 as ip = VinYa + VoYd (1) Current at negative terminal in calculated with help of figure 3.1 as in = VinYb + VoYc (2) 12 Let's assuming that in ideal condition of OTRA, the amplifier voltage gain can by calculate by equating the current of positive (p) and negative (n) terminal, that is ip = in (3) VinYa + VoYd = VinYb + VoYc (4) Transfer function of OTRA based filter given by Vo(s) Ya - Yb T(s) = = (5) Vin(s) Yc - Yd There is Ya, Yb, Yc and Yd are admittance function of passive elements. Figure 3.2 Proposed filter circuit By using equation (5) we derived transfer function of circuit given in figure 3.2 1 Ya = (6) R3 sC1 Yb = (7) 1 + sC1R1 1 + sR2C2 Yc = (8) R2 Yd = 0 (9) 1 + sC1R1R2 - sC1R2R3 T(s) = (9) s 2 C1C2R1R2 + s(C1R1R3 + C2R2R3) + R3 Rearranged equation after putting R1=R2=R3=R and C1=C2=C 1 T(s) = R2 C2 (10) 2s 1 s2 + CR + 2 2 RC 13 3.3 SIMULATION AND HARDWARE RESULTS OTRA based second order filter could be design with help of AD844AP (CFOA), and its performance can be analysis using Proteus ISIS Professional simulation software. Simulation verified by practically also. Details of used element in hardware and simulation given in table 3.1. Quantity Part Â Name Value Specification Resistance 3 R4 - R6 2K 1 R7 1M Capacitor 2 C1, C2 1uF Integrated Circuits 2 U1,U2 AD844AP Miscellaneous 2 B1,B2 15V Batteries 1 Function Generator 0 Â 1MHz 1 CRO Table 3.1 List of used elements for OTRA based filter designing 14 Figure 3.3 Simulation circuit of OTRA based second order filter Figure 3.4 Input Â Output response of OTRA based filter Figure 3.5 Frequency and Phase response of OTRA based filter 15 Figure 3.6 Input Â Output response Figure 3.7 Practical circuit of OTRA based second order filter Figure 3.8 experimental result 16 CHAPTER - 4 DESIGN SIMULATION AND HARDWARE OF OTRA BASED OSCILLATOR 4.1 INTRODUCTION In communication, instrumentation, control system and measurement application signal generators have an important role. Generating signals carrier for test signals, clock pulses for control and time. These signals have various shapes such as sinusoidal, triangle etc. Wave generated by signal generator describe by shape, amplitude, frequency and duty cycle. In continuation we will learn about sinusoidal oscillator using single OTRA. Other waveform can be explained as a Fourier combination of sine waves. Sinusoidal waveform can be generated by shaping of triangular wave, or consisting positive feedback loop of an amplifier shown in figure 4.1. Figure 4.1 Functional block of a sinusoidal oscillator All the circuits utilize the positive feedback approach and Barkhuasen criterion; it is satisfied for a single frequency only. 4.2 GENERALIZED CIRCUIT OF OTRA BASED OSCILLATOR Single OTRA based generalized configuration shown in figure 4.2. 17 Figure 4.2 Generalize circuit of OTRA base Oscillator Generalised characteristics equation of single OTRA based oscillator can be expressed as =3+2 (1) =4+5 (2) 1+3+4+6+7=0 (3) = (4) 3+2=4+5 (5) 3+2-4-5=0 (6) By comparing equations (5) and (6) we get 1+3+4+6+73-4 = (7) 1+6 5-2 12 + 23 + 24 + 26 + 27 + 13 + 36 - 14 - 15 - 46 - 35 - 45 - 56 - 57 = 0 (8) Equation (8) is general characteristics equation of OTRA based oscillator. There Y1 to Y7 are the admittance of the passive elements. The condition of frequency and oscillation given table 4.1. The proposed single OTRA based oscillator could be controlled by a grounded resistor said circuit could be controlled if resistor replaced by grounded capacitor. 18

Design Y1 Y2 Y3 Y4 Y5 Y6 Y7 **18**

A 0 sC2 G3 sC4 G5 0 G7 B sC1 0 G3 sC4 G5 0 sC7 C G1 0 G3 0 sC5 sC6 G7 D 0 G2 G3 sC4 G5 sC6 G7 E 0 G2 sC3 G4 0 sC6 G7 Table 4.1 Condition of oscillation frequency generation 4.3 SIMULATION AND HARDWARE SESULT A second order oscillator can be design with help of characteristics equation (8) is shown in figure 4.3. Figure 4.3 Simulation circuit of second order OTRA based Oscillator Characteristics equation of figure 4.3 according to equation (8) calculated as Where Y1 = sC2 = 10uF, Y2 = 0, Y3 = 1/R2 = 1/100, Y4 = sC1 = 0.01uF, Y5 = 1/R3 = 1/1K, Y6 = 0, Y7 = 1/R4 = 1/10K, 19 Then 2 12 + (12 - 22) + 23 + 34 = 0 3(2 + 4) = = 10.045 12 Figure 4.3 and hardware components used in analysis of second order oscillator are stored in table 4.1. Quantity Part Â Name Value Specification Resistance 1 R1 15K 1 R2 100 1 R3 1K 1 R4 10K Capacitor 1 C1 0.01uF 1 C2 10Uf Integrated Circuits 2 U1,U2 AD844AP Miscellaneous 2 B1,B2 5V Batteries 1 Function Generator 0 Â 1MHz 1 CRO Table 4.1 List of used element in design of OTRA based oscillator Figure 4.4 Practical circuit of OTRA based oscillator 20 Figure 4.5 Experimental result of OTRA based oscillator Figure 4.6 Simulation output result Figure 4.7 Simulation output frequency 21 Figure 4.8 Output noise in OTRA based oscillator 22 CHAPTER Â 5 DESIGN SIMULATION OF OTRA BASED CONVENTIONAL CONTROLLERS 5.1 INTRODUCTION The operational condition of any system and dynamical system could observe and rectify by using a controller. Operational condition of any system related to as measured output variables and can be change by adjusting certain input variables. Controller action depends on the difference between measured output variables and set point, it called error. Controller tries to minimize the error value by adjusting the process control inputs. Controller classified as:- 1. Conventional controller Example of conventional controller

are Proportional (P), Proportional derivative (PD), Proportional integral (PI), Proportional derivative and integral (PID) controllers. **14**

2. Non conventional controller Example of Non conventional controller are Neuro, Fuzzy controllers. The conventional controllers are mostly used in the process industries. PID controller algorithm are popularly used, proper tuning of controller parameters. The proportional,

derivative and integral of the error signal E(s) are **13**

summed up

to calculate the output actuating signal U(s) of **13**

the controller. 23 Figure 5.1 Basic architecture of PID - Controller The transfer function of

PID controller can be written as U(s) 20

Ki Gpid(s) = = Kp + + Kds E(s) s Where Kp, Kd, and Ki are the proportional, derivative and integral constants respectively. Case-1

The transfer function of proportional controller 15

given by U(s) Gp(s) = = Kp E(s) 24

The transfer function of proportional controller 15

in control system given by Kpn2 Tp(s) = 2 s + 2ns + Kpn2 Case- II Gpi(s)

transfer function of the PI controller 12

given by

U(s) Ki Gpi(s) = = Kp + E(s) s 12

Closed loop transfer given by (Ki + sKp)n2 Tp(s) = s 3 + 2ns2 + (Ki + sKp)n2 Case Â III Gpd(s) transfer function of the PD controller in control system given by U(s) Gpd(s) = = Kp + sKd E(s) Closed loop transfer given by (Kp + sKd)n2 Tp(s) = s2 + (2n+Kdn2)s1 + Kpn2 25 5.2 OTRA BASED PROPORTIONAL CONTOLLER The OTRA based (using CFOA ICs AD844AN) P-Controller is shown in Figure 5.2.Its transfer function derived as OTRA Vin R1 p Vo n R2 Figure 5.2 OTRA based P - Controller The current at positive terminal (p) derived as Vin ip = (1) R1 The current at negative terminal (n) derived as Vo in = (2) R2 Let's assuming that in ideal condition of OTRA, the amplifier voltage gain can by calculate by equating the current of positive (p) and negative (n) terminal, that is ip = in (3) Vin Vo = (4) R1 R2 Vo R2 = = constant = Kp (5) Vin R1 Transfer function of OTRA based P controller is 26 () 2 () = = (6) () 1 The controller parameter Kp can be tuned by changing either R1 or R2 or both. 5.2.1 SIMULATION RESULTS Simulation circuit of OTRA based P Â controller design with reference of table 5. The simulation of P ÂContoller shown in figure 5.3, by choosen value of passive component as R1=10K and R2 = 20K. For resulting parameter of controller Kp=2. Quantity Part Â Name Value Specification Resistance 1 R2 10K 1 R3 3M Variable resistor 1 RVP 100K Integrated Circuits 2 U1,U2 AD844AP Miscellaneous 2 B1,B2 15V Batteries 1 Function Generator 0 Â 1MHz 1 CRO Table 5.1 List of used element in design of OTRA based P - Controller 27 Figure 5.3 Simulation circuit of OTRA based P - Controller Figure 5.4 Input Â Output response 28 Figure 5.5 Frequency and Phase response of P Â Controller The time domain and frequency domain responses shown in figures 5.4 and 5.5 respectivly. For electronic tunability feature we get transfer characterstics by keeping R1 constant and R2 varied. 5.3 OTRA BASED PROPORTIONAL, INTEGRAL CONTROLLER The OTRA based (using CFOA ICs AD844AN) PI-Controller is shown in Figure 5.6.Its transfer function derived as C OTRA 1nF R1 p Vin Vo n CF Figure 5.6 OTRA based PI - Controller The current at positive terminal (p) derived as 29 Vin ip = (1 + R1Cs) (7) R1 The current at positive terminal (p) derived as in = VoCfs (8) Let's assuming that in ideal condition of OTRA, the amplifier voltage gain can by calculate by equating the current of positive (p) and negative (n) terminal, that is ip = in (9) Vin (1 + R1Cs) = VoCfs (10) R1 Vo 1 + R1Cs C 1 = =+ (11) Vin R1Cfs Cf sCfR1 Derived transfer function of OTRA based PI Â controller is given by Vo(s) 1 + R1Cs C 1 Gpi(s) = = =+ (12) Vin(s) R1Cfs Cf sCfR1 There is C 1 Kp = Cf , Ki = R1Cf Kp and Ki values may adjuste independently by varying C and R respectively. 30 5.4.1 SIMULATION RESULTS The passive component values for simulation of proposed PI Â Contoller shown in figure 5.7 as R1=10K Â 1M, R2 = 50K, R4 = 50K, C1=10uF and C3 = 5uF to comput the parameter Kp and Ki. Figure 5.7 Simulation circuit of PI Â Controller 31 Quantity Part Â Name Value Specification Resistance 1 R3 20K Variable Resistor 1 RV1 100K 1 RV2 1K Capacitor 1 C1 0.1uF 1 C2 0.5uF Integrated Circuits 2 U1,U2 AD844AP Miscellaneous 2 B1,B2 15V Batteries 1 Function Generator 0 Â 1MHz 1 CRO Table 5.2 List of used element in design of OTRA based PI - Controller Figure 5.8 Input Â Output response 32 Figure 5.9 Frequency and Phase response PI - Controller The simulated frequency response shown in figure 5.9 and transient response depicted in figure 5.8. 5.4 OTRA BASED PROPORTIONAL, DERIVATIVE CONTROLLER The OTRA based (using CFOA ICs AD844AN) PD-Controller circuit diagram is shown in Figure. Transfer function of given circuit is derived as C1 1nF OTRA R1 p Vin Vo n RF Figure 5.10 OTRA based PD - Controller 33 The current at positive terminal (p) derived as Vin ip = (1 + R1Cs) (13) R1 The current at negative terminal (n) derived as Vo in = (14) Rf Let's assuming that in ideal condition of OTRA, the amplifier voltage gain can by calculate by equating the current of positive (p) and negative (n) terminal, that is ip = in (15) Vin Vo (1 + R1Cs) = (16) R1 Rf 1 + R1Cs Vo Rf = (17) R1 Vin Vo Rf = + RfCs (18) Vin R1 Derived transfer function of OTRA based PI Â controller is given by Vo(s) Rf Gpd(s) = = + RfCs (19) Vin(s) R1 There is Rf Kp = , Kd = CRf R1 By varying values of R1 and Rf, parameter Kp and Kd tuned respectively. 34 5.4.1 PROTEUS SIMULATION RESULT PD Â CONTROLLER Passive component values and requirement to design simulated circuit of PID Â Controller are stored in table 5. Quantity Part Â Name Value Specification Variable Resistance 1 RVP 100K 1 RVD 100K Capacitor 1 C1 0.05uf Integrated Circuits 2 U1,U2 AD844AP Miscellaneous 2 B1,B2 12V Batteries 1 Function Generator 0 Â 1MHz 1 CRO Table 5.3 List of used element in design of OTRA based PD - Controller 35 Figure 5.11 Simulation circuit of PD - Controller Figure 5.12 Input Â Output response Figure 5.13 Frequency and Phase response of PD Â Controller The transient and frequency response of PD Â Controller depicted in figure 5.12 and 5.13. 36 5.9 OTRA BASED PROPORTIONAL INTEGRAL AND DERIVATIVE CONTROLLER (PID Â Controller) Figure 3.4 shown the circuit diagram of OTRA based PID Â Controller.The transfer function of said circuit diagram expressed as C1 OTRA R1 p V1 n C3 Vin 1nF C2 R3 OTRA R2 p Vo n R4 Figure 5.14 OTRA based PID - Controller The current at positive terminal (p1) at Fig. Vin ip1 = (1 + R1C1s) (20) R1 The current at negative terminal (n1) at Fig. 3.4 in1 = V1C3s (21) The current at positive terminal (p2) at Fig.3.4 37 ip2 = i2 - i10 (22) Vin V1 ip2 = (1 + R2C2s) + (23) R2 R3 The current at negative terminal (n2) at Fig.3.4 Vo in2 = (24) R4 In ideal case of OTRA, we find voltage gain of amplifier by equating the ip=in so ip1 = in1 (25) Vin (1 + R1C1s) = sC3V1 (26) R1 Vin V1 = (1 + R1C1s) (27) sC3R1 And Vin V1 Vo (1 + R2C2s) + = (28) R2 R3 R4 V1 Vo Vin = - (1 + R2C2s) (29) R3 R4 R2 R3Vo Vin V1 = - R3 (1 + R2C2s) (30) R4 R2 By using equation Vin R3Vo Vin (1 + R1C1s) = V1 = - R3 (1 + R2C2s) (31) sC3R1 R4 R2 Transfer function of PID Â Controller is 38 Vo(s) R4 R4C1 R4 Gpid(s) = =+ + + sC2R4 (32) Vin(s) R2 R3C3 sC3R1R3 There is R4 R4C1 Kp = + R2 R3C3 Ki = R4/sC3R1R2 Kd = sC4C2 5.10 PROTEUS SIMULATION RESULT OF PID Â CONTROLLER Quantity Part Â Name Value Specification Resistance 1 R1 50K 1 R2 625 1 R3 5K 1 R4 1.8M 1 R5 1M 1 R6 3M Variable Resistor 1 RV1 1K 1 RVI 1M 1 RVP 100K 1 RVD 1M 39 Capacitor 1 C1 0.1Uf 1 C2 1uF 1 C3 0.5uF Integrated Circuits 2 U1,U2 AD844AP Miscellaneous 2 B1,B2 12V Batteries 1 Function Generator 0 Â 1MHz 1 CRO 1 Switch SW Â SPDT Table 5.4 List of used element in design of OTRA based PID - Controller Figure 5.15

Simulation circuit of PID - Controller 40 Figure 5.16 Input Â Output response Figure 5.17 Frequency and Phase of PID - Controller 41 6.10 PERFORMANCE EVALUATION OF OTRA BASED CONTROLLERS The performance of controllers and their effect on third order plant (turbine) is analyzed by using

closed loop system. The transfer function of the **24**

turbine is given by Figure 5.18 Closed Â loop system 1 () = (+ 1)(+ 5) The

step response of the open loop third order system study and calculate the **10**

effect of various controller by realising the a closed loop system figure 6.16. Figure 5.19 Closed loop response of system For time domain analysis a step signal and simulate the response shown in figure 6.17. 42

To evaluate the performance of P Â controller **9**

with third order system . Step response of the system, choosing Kp=10

of the closed loop system shown in figure 6.18. Figure 5.20 Closed loop step response of **9**

system with P Â Controller and Frequency and Phase response The value of Kp are drived by putting value . To study the performance of P Â controller, the concern values of overshoot, peak response, settling time and rise time recorded in table SYS NAME OVERSHOOT PEAK O/P RISE TIME (Sec.) SETTLING TIME(Sec.) CLOSED LOOP 0 0.999 8.33 15 SYS SYS WITH P- 48.5% 1.49 0.943 12.7 CONTROLLER Table 5.5 Performance comparision of closed loop with P Â Controller (Kp = 10) The step response of PD Â controller with closed loop with Kp =10 and Kd=6. 43 Figure 5.21 Closed loop

step response of system with PD Â Controller and Frequency and Phase response Effect of **2**

parameter of PD Â controller observed by system parameter improvement, this effect is recorded in table . SYS NAME OVERSHOOT PEAK O/P RISE TIME(Sec.) SETTLING TIME(Sec.) CLOSED LOOP 0 0.999 8.33 15 SYS SYS WITH P- 11.9% 1.12 0.838 3.25 CONTROLLER Table 5.6 Performance comparison of closed loop with PD Â Controller (Kp=10, Kd=6) Observed that the PD Â controller improve the parameter in terms of rise time ,maximuim overshoot and settling time are increased. Step responce for varying value of Ki while keeping Kp = 10 constant. 44 Figure 5.22 Closed loop

step response of system with PI Â Controller and Frequency and Phase response The **2** performance parameter of PI Â controller recorded in table. SYS NAME OVERSHOOT PEAK O/P RISE SETTLING TIME(Sec.) TIME(Sec.) CLOSED LOOP 0 0.999 8.33 15 SYS SYS WITH P- 60.6 1.61 0.906 17.7 CONTROLLER Table 5.7 Performance comparison of closed loop with P I- Controller(Kp=10,Ki=1) Observed that the PI Â controller improve the performance in terms of rise time ,maximuim overshoot and settling time are increased. 45 Figure 5.23 Closed loop

step response of system with PID Â Controller and Frequency and Phase response The 2

step responce

of the closed loop system with PID Â controller 2

for Kp = 10, Ki =1 and Kd=6.The performance of parameters are recorded in table SYS NAME OVERSHOOT PEAK O/P RISE TIME(Sec.) SETTLING TIME(Sec.) CLOSED LOOP 0 0.999 8.33 15 SYS SYS WITH P- 16.7% 1.17 0.816 10.2 CONTROLLER Table 5.8 Performance comparison of closed loop with PID Â Controller (Kp=10,Ki=1,Kd=6) 46 SYS NAME OVERSHOOT PEAK O/P RISE TIME SETTLING TIME CLOSED LOOP SYS SYS WITH P- CONTROLLER Figure 5.24 Tune response of PID - Controller 47 CONCLUDING THESIS REMARK AND FUTURE SCOPE OF OTRA Realization, terminal characteristics and practical realised of OTRA taken into consideration to evaluation of OTRA and OTRA based circuit. By using OTRA we make circuits fully integrable and electronically tuneable. An operational Transresistance amplifier voltage mode, single input single output based second order low pass filters theoretical practical and simulation based result verified. 48 49