SAULT COLLEGE
of Applied Arts and Technology
Sault Ste. Marie

COURSE OUTLINE

CONTROL SYSTEMS I

ELN 214-6

revised May 1980 by Norm Barker

COURSE OUTLINE

TOPIC	Periods		Topic Description
	Lec	Lab	
1	3	3	<u>Introduction to Control Systems</u> Principles and applications of electronic control systems. A closed loop system providing angular position control.
2	3	0	<u>Precision Potentiometers</u> Construction. Mathematical relations. Non-linear functions in servo loops. System adjustments. Polar to rectangular coordinate conversion.
3	6	9	<u>Synchros</u> Theory of operation - receiver, transmitter, control transformer, differential synchros. Zeroing and system adjustment. System trouble shooting.
4	6	3	<u>Resolvers</u> Theory of operation. Data transmission - angular addition/subtraction. Coordinate conversions. Rotation of coordinate axes. Zeroing and system adjustments.
5	3		<u>Mathematics of Block Diagrams</u>
6	6	9	<u>Analysis of Servo Motors and Generators</u> AC servo motors. DC serv motors. Tachometer. Amplidyne. Stepper motor and control techniques.
7	4	3	<u>Amplifiers</u> Characteristics of servo amplifiers. Performance testing. Modulation. Demodulators. Magnetic amplifiers.
8			<u>Sensors/Transducers</u>
9	15	15	<u>Servo - System Stability</u> System response. Damping. Modes of control

EVAULTION PROCEDURES

Course: ELN 214-6 Control Systems I

1. Specific Objectives:
   Specific Objectives (S.O. 's) will be assigned to the class.

2. Tests & Evaluation:

   Theory
   a) Students will be informed of the date about one week in advance of a test. Material from previous blocks may be included.
   b) Periodic quizzes may be conducted without notice. These quizzes will be of about five minutes duration and will normally cover assigned studies from the previous week.

   Practical
   a) Students will be subject to continuous evaluation in the laboratory, with emphasis on skill in the care and use of test equipment, work habits, and co-operation.
   b) Each student will maintain a lab-logbook, which will be available for evaluation at any time during lab periods. Reference to lab-logbooks will be permitted in some tests.
   c) Students are reminded that all lab periods are compulsory.

3. Grading
   Students will be graded A, B, C or Incomplete (I) as follows:

   A - 76 - 100%
   B - 66 - 75%
   C - 56 - 65%
   I - Below 55%

   The grading weight will be: Theory 60 %
   Practical 40%

   Attendance at all scheduled classes will be a factor in determining final grade.

4. Incomplete
   a) At the discretion of the instructor students with an I in any block will have an opportunity to upgrade, provided they complete a special assignment. The highest grade for the rewrite test will be a C (56%). Further upgrading tests will be conducted as required during the special make-up period at the end of the semester.
   b) If a student presents a valid reason for missing a lab or if it is necessary to repeat a lab assignment, special lab time will be arranged if scheduling permits. Otherwise the lab activity will be graded incomplete and must be completed during the make-up period at the end of the semester.

CONTROL SYSTEMS I

General Objectives:

1. To provide a sound understanding of the physical operation of automatic control systems with a limited use of mathematical analysis.

2. To provide a sound understanding of the principles of operation and typical applications of:
   a) Precision potentiometers
   b) Voltage and power amplifiers
   c) Synchros and resolvers
   d) Stabilization techniques
   e) Position control systems
   f) Transducers

3. To be able to troubleshoot and measure the performance of simple automatic control systems.

TEXT A. Servo Mechanisms, Devices and Fundamentals
R. W. Miller

REF. A. Servomechanism Fundamentals and Experiements
Philco

B. Introduction to Control System Technology

Specific Objectives

BLOCK I - INTRODUCTION TO AUTOMATIC CONTROL

1. Recall that automatic control is used in many applications such as:
   - the control of industrial processes
   - the launching and maneuvering of space vehicles
   - temperature control
   - control of a stable platform sometimes required in a moving vehicle such as a ship
   - antenna position control.

2a. Draw a simplified block diagram of a closed loop system providing angular position control.

b. Describe the operation of such a system at the block diagram level

3. Recall that a servomechanism (slaved mechanism) is part of a system used to control the mechanical position of the controlled device.
   Examples are: - the angular position of an antenna
   - the positioning of an industrial X-Ray camera

4. Explain the terms open loop and closed loop as they apply to automatic control systems and recall the advantages and disadvantages of each.

5. Given a simplified block (layout) diagram of a steel rolling mill, explain in general terms how the operation is automatically controlled.

6. Define the following terms as they apply to control systems:

- transducer	- deadtime	- the error
- transfer function	- time constant	- control action
- setpoint	- controlled variable	- measured variable

7. Given the circuit diagram of the speed-O-max self-balancing recording potentiometer:
   a) describe circuit operation
   b) draw a block diagram, label the blocks and signals and indicate signal direction
   c) given the symptoms of a malfunction, diagnose the probable cause.

8. The main advantage of a closed loop control system is that more accurate control of the process is achieved. The main disadvantages are:
   a) It is more expensive than open loop control.
   b) The feedback feature makes it possible for the system to become unstable.

9. The main benefits of closed loop automatic control are:
   a) Increased productivity
   b) Greater accuracy and quality
   c) Higher efficiency
   d) Powered assistance eg. servo-hydraulic systems
   e) Greater personnel and equipment safety
   f) Comfort and convenience

10. The control mode is the way in which a controller acts on an error signal to produce a control action. The most commonly used control modes are, on-off, floating, proportional, integral, and derivative.

11. The modes used in a particular controller depend upon:
    a) How difficult the process is to control
    b) How accurately the process must be controlled
    c) How quickly the controller must respond to a disturbance

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Specific Objectives

BLOCK 2 - PRECISION POTENTIOMETERS

1. Given an "exploded" diagram discuss the construction of precision potentiometers employed in servo-systems.

2. Develop the relationship between angular position and R for linear potentiometers.

3. Evaluate errors in output voltage caused by loading currents.

4. Explain and illustrate voltage resolution and travel resolution.

5. Calculate the theoretical resolution of a given potentiometer.

6. Illustrate and discuss the linearity and conformity characters of polentiometers and explain how improvements can be accomplished by "end-trimming" resistors.

7. Explain how and why potentiometers must be dented under high ambient temperature conditons.

8. Draw the circuit diagram and sketch the standard functions for the following types of potentiometers:

   Sin 360° Sin 180° Sin 90° Cos 360°

   Cos 180° Sin - Cos 360° $Y = x^2$ $Y = \pm x^2$

   Cos 90°

9. Analyse/design servo loops employing potentiometers to provide
   a) a reference input
   b) feedback
   c) coordinate conversion (Polar Rectangular)

10. Develop procedures for zero - adjustment of the servo loops outlined in # 9 above.

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BLOCK 3 - SYNCHROS

1. With the aid of diagrams and waveforms, describe the operation of the following synchro devices:
   - transmitter
   - receiver
   - differential transmitter
   - differential receiver
   - control transformer

2. Given the outline requirement of a synchro system employing the devices above, draw the system diagram showing how they would be connected, and develop a procedure for correct alignment of the system.

3. Given the necessary information with regard to a synchro system:
   a) diagnose the cause of failure
   b) predict the symptoms that will result from a component failure.

4. Demonstrate the ability to trouble shoot synchro systems and adjust (zero) the devices.

5. With the aid of diagrams, describe how the accuracy of an angular-position indicating system can be improved by use of a dual speed system.

6. Explain the need for sychronizing the high speed components of the dual speed system.

7. With the aid of sketches, describe how the addition of stick-off voltage to the coarse CT output allows correlation of coarse and fine nulls.

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BLOCK 4 - RESOLVERS

1. With the aid of diagrams recalled from memory describe the theory of operation of a four winding resolver.

2. Given the voltage inputs to the slator windings together with the angular position of the shaft, calculate the voltages induced in the rotor.

3. Develop a resolver circuit which will convert polar coordinate date, range elevation and bearing, into rectangular coordinate data, height Eastings and northings.

4. With the aid of diagrams describe how a resolver circuit may be used to rotate rectangular coordinates from one set of axes to a second set of axes (given the angle between the two sets of axes.

5. With the aid of diagrams describe how angular addition or subtraction may be accomplished by resolvers.

6. With the aid of simple diagrams describe the principle of the Hall generator.

7. With the aid of a diagram describe the operation of the Hall-effect resolver.

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Specific Objectives

BLOCK 5 - MATHEMATICS OF BLOCK DIAGRAMS

1. Draw the block diagram for a closed loop system with negative feedback (a. $e_f = c_o$ b. variable) and develop the expressions for system gain:

   a. $\frac{e^\circ}{e\ in} = \frac{G}{1 + G}$ b. $\frac{e^\circ}{e\ in} = \frac{G}{1 + HG}$

2. Recall the characteristics of a system with negative feedback.
   a. gain is reduced
   b. stability is increased
   c. response time is slowed down
   d. bandwidth is increased

3. Recall that if the feedback is positive the sign in 1a and 1b is negative and as 1 - G approaches zero the system becomes unstable.

4. Recall that positive feedback has the following characteristics:
   a. Very high gain (up to infinity)
   b. Very unstable
   c. Extremely fast response
   d. Very narrow bandwith

5. Simplify system block diagrams and determine the transfer function.

CONTROL SYSTEMS I

Specific Objectives

BLOCK 6 - SERVOMETERS AND GENERATORS

1. List and explain the advantages and disadvantages DC motors and two-phase AC motors when employed in servomechanisms.

2. Recall the fundamental equation for servomotors,
   $Ts = \frac{1352Pr}{SO}$ where Ts = stall torque in oz - ins

   So = no load speed in RPM and Pr = stall power to rotor in watts.

3. Illustrate and explain the development of a revolving magnetic field in a two-phase AC motor.

4. Sketch a typical "Power-Torque/Speed" curve and explain why the speed of a servo motor, when driving the rated load, should be more than one half of the free speed.

5. With the aid of a typical Torque-Speed curve explain that the total torque available consists of two components, one to accelerate the rotor (load) inertia and one to accelerate the inherant damping (viscous friction) of the machine.

6. Sketch a typical family of Speed-Torque curves for a two-phase AC servomotor and discuss the difficulty of achieving system stability at the operating point which is usually at or near zero control voltage.

7. Define the term Time-constant as applied to a servomotor.

8. Recall that the instantaneous speed of all the motor may be calculated using the expression:
   $$\text{speed} = \frac{dO}{dt} = K_s\, V_c(1 - E^{\frac{-T}{rm}})$$
   where K_s = speed per volt applied.

9. Explain and compare the control of a split-series field motor using:
   a. Armature control
   b. Field control

11. Define and measure the "Dead Band" of a servo system.

12. Recall that the Torque Constant $K_T = \frac{Ts}{Vc}$

    where T_s is the stall torque
    V_c is the control voltage

13. Recall that the velocity constant is the ratio of motor speed and control voltage and represents the speed in radians per second that the motor can develop for every one volt that is impressed upon it. The velocity constant is expressed as
    $Kv = \frac{S}{Vc}$ where S is in radians/sec
    and Vc is the control voltage

14. Recall that the motor transfer function is the ration between motor output in terms of angular motor and the input control voltage and may be inserted into a system block diagram as shown below:

$$V_c \quad \frac{Kv}{S(1+Ts)} \quad O_o$$

T = time constant
S = laplace operator

15. With the aid of a diagram describe the theory of operation of:
    a. an AC tacho-generator
    b. a DC tacho-generator

BLOCK 7 - SERVO-AMPLIFIERS

Specific Objectives

1. Recall that a servo amplifier is usually comprised of a signal (error) voltage amplifier together with a power amplifier to drive a motor or to supply the control field on an amplidyne.

2. Draw a block diagram of each of the following servo-systems and describe the operation. (Fig. 1)

3. Describe the main characteristics of AC and DC amplifiers.

4. Define the term drift as applied to amplifiers and state the causes of this disadvantage.

5. Explain why drift introduced in early stages of amplification is troublesome whereas in later stages may be counteracted by negative feedback.

6. Explain the term negative feedback and state the improvements it provides in the amplifier and/or system characteristics.

7. Recall that AC amplifiers employ capacitor coupling and that the value of the capacitor should be chosen to satisfy the following expression at the lowest frequency to be amplified.

$$X_C \quad \frac{R}{10}$$

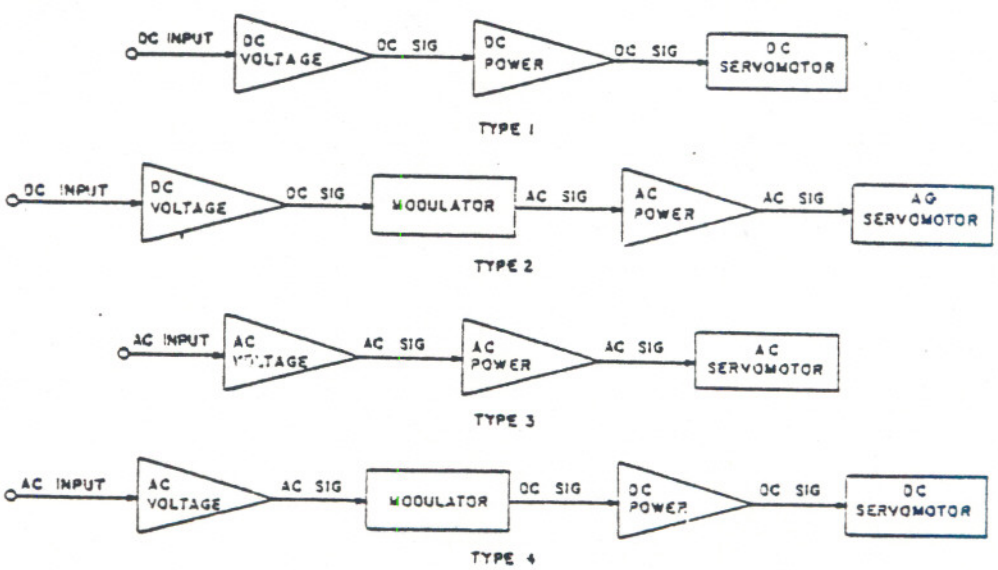


FIG. 1.

BLOCK 8 - SENSORS AND TRANSDUCERS

Specific Objectives:

1. To be able to recall that a transducer is a device used for converting a signal or physical quantity of one kind into a corresponding physical quantity of another kind.

2. To be able to recall the principle of operation, characteristics, limitations, advantages and simple applications of the following sensors and transducers.

   a) Motion sensors
      1) Linear motion
         a) Linear motion potentiometers
         b) Linear motion variable inductors
         c) Linear motion variable capacitors
         d) Linear variable differential transformers

      2) Angular motion
         a) Angular motion potentiometer
         b) Angular motion variable capacitor
         c) Rotary variable differential transformer
         d) Variable reluctance angular position transducer

3. a) Speed Rotational
      a) DC tachogenerator
      b) AC tachogenerator
      c) Magnetic pick up

   b) Force Sensors
      1) Compression
         a) Bonded wire strain gauge
         b) Unbonded wire strain gage
         c) Piezoelectric crystal sensor
         d) Linear variable differential transformer

      2) Tension
         a) Bonded wire strain gauge
         b) Unbonded wire strain gauge

3) Torque
    a) Bonded wire strain gauge
    b) Linear variable differential transformer

4) Acceleration
    a) Piezoelectric crystal acceleromoter
    b) Inductive vibration sensor
    c) Capacitive vibration sensor
    d) Linear variable differential transformer vibration sensor

c) <u>Fluid Sensors</u>
1) Fluid pressure
    a) Bellows
    b) Bellows and variable resistance sensors
    c) Bellows and variable inductance sensors
    d) Bourdon tubes
    e) Diaphragms
    f) Capicitor diaphragm sensors
    g) Bonded strain gauge pressure sensor
    h) Linear variable transformer differential pressure sensor

2) Fluid flow sensors
    a) Turbine flowmeters
    b) Electromagnetic flowmeters

3) Liquid level sensors
    a) Float operated rheostats
    b) Capacitive liquid level sensors
    c) Gamma ray liquid level sensors

4) Level limit sensors
    a) Float switch sensors
    b) Gamma ray sensors
    c) Ultransonic sensors

d) <u>Temperature Sensors</u>
1. Bimetallic sensors
2. Fluid pressure sensors
    a) Liquid filled
    b) Vapour filled
3. Resistive sensors
    a) Resistance temperature detectors
    b) Thermistors
4. Thermocouple sensors
5. Radiation pyrometers

e) Radiation Sensors
   1) Light sensors
      a) Photoemissive sensors
      b) Photoconductive sensors
      c) Photovoltaic sensors
   2) X-ray sensors
   3) Nuclear radiation sensors
      a) Geiger-Mueller tube
      b) Ionization chamber
      c) Scintillation counter

f) Thickness Sensors
   1) Inductive sensors
   2) Ultrasonic sensors
   3) X-ray sensors

g) Proximity Sensors
   1) Magnetic
   2) Inductive
   3) Capacitive

h) Density Sensors
   1) Photoelectric
   2) Linear differential transformer

i) Moisture Sensors
   1) Hair hygrometer
   2) Lithium chloride

BLOCK 9 - STABILIZATION TECHNIQUES AND POSITIONAL CONTROL SYSTEMS

Specific Objectives:

1) To be able to recall that the requirements of a stable system with rapid response are conflicting since:
   a) The system gain must be high
   b) Damping must be adequate

2) To be able to recall that no practical system is linear because
   a) Inertia of moving parts causes time lag
   b) Non linearity of amplifiers
   c) Hysteresis
   d) Friction
   e) Inductance
   f) Resilience
   g) Backlash

3) To be able to define what is meant by
   a) A step input function
   b) A ramp function

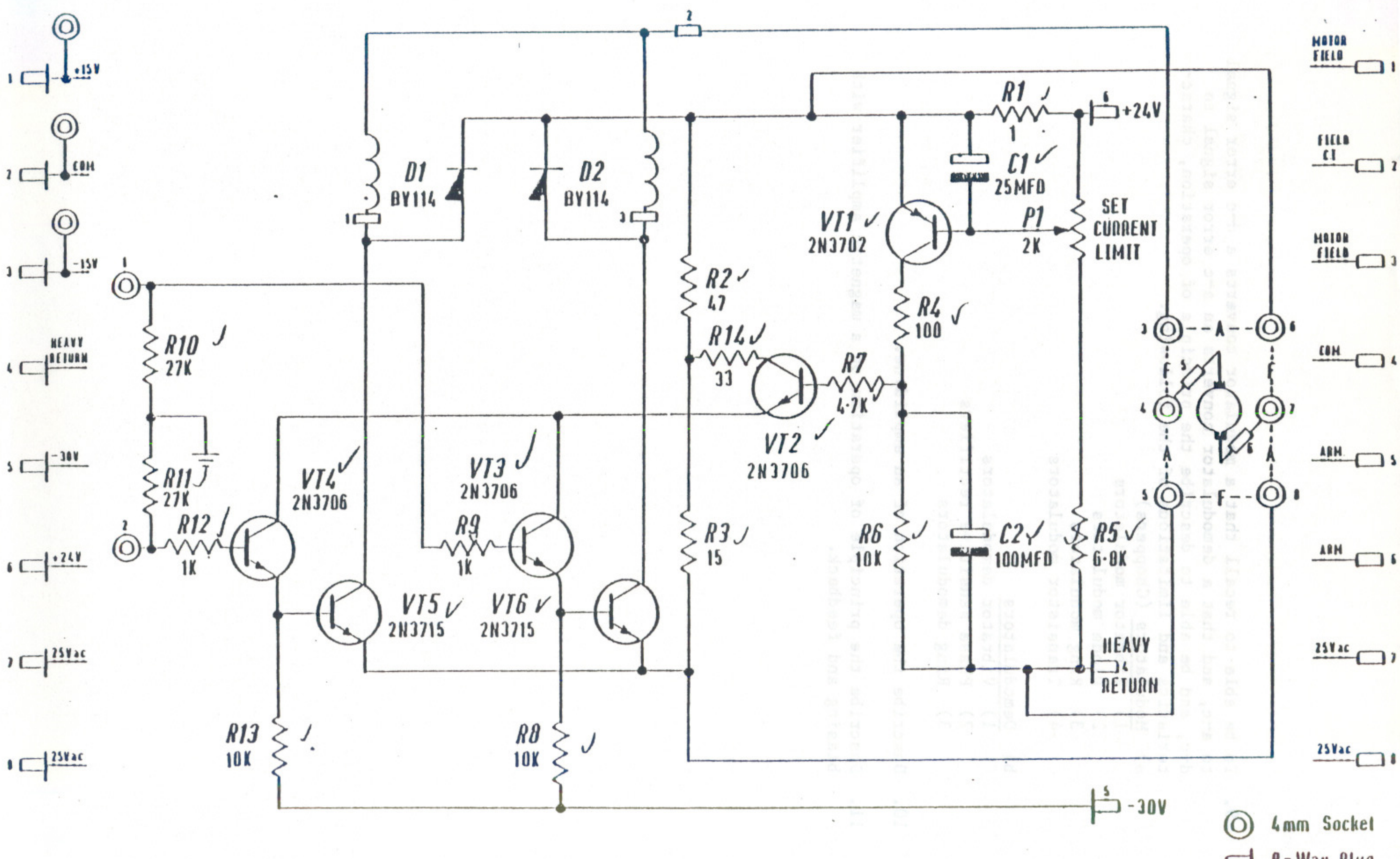
4) To be able to recall the effects of step input and ramp functions on the following types of damped servo systems:
   a) Undamped
   b) Critically damped
   c) Overdamped

5) To be able to recall the advantages, limitations and applications of the following types of stabilization:
   a) Mechanical
      1) Inertia
      2) Electromagnetic
   b) Electrical
      1. Error-rate
         a) D.C. lead networks
         b) A.C. lead networks
      2. Output rate
         a) Tachometer
      3. Integral
         a) D.C. lag networks
         b) A.C. lag networks

6) To be able to recall the principles of operation, characteristics, limitations and advantages of the following representative position control systems
   a) Proportional control
   b) Proportional plus derivative
   c) Proportional plus derivative plus integral

   as applied to d-c, a-c and hybrid positioning systems.

CIRCUIT DIAGRAM



SERVO AMPLIFIER UNIT SA150D

FEEDBACK LTD

9. To be able to recall that a modulator converts a d-c error signal to a-c, and that a demodulator converts an a-c error signal to d-c, and be able to describe the principle of operation, characteristics and limitations of the following:
   a) <u>Modulators</u> (Choppers)
      1) Vibrator modulators
      2) Diode modulators
      3) Ring modulators
      4) Transistor modulators

   b) <u>Demodulators</u>
      1) Vibrator demodulators
      2) Phase sensitive rectifiers
      3) Ring demodulators

10. Describe the operation of an amplidyne.

11. Describe the principle of operation of a magnetic amplifier with biasing and feedback.