3. THEORY OF OPERATION

GENERAL

1. This section gives an outline of the operation of the Model 257 together with a detailed description of the mechanics, optics and electronics. The outline of operation which follows is written in conjunction with the block diagram (Fig. 3.1).

OUTLINE OF OPERATION

2. The Model 257 Spectrophotometer provides a continuous record of the infrared transmittance of a sample as a function of frequency (expressed in wavenumber units). A chart is driven in synchronism with the monochromator so that a pen moving laterally across the chart records the sample transmittance as a function of wavenumber.

3. As shown in Figure 3.1 the wavenumber scan motor drives both the recorder and the grating monochromator scan mechanism, both of which are directly coupled, thus maintaining an accurate reproducibility of wavenumber setting.

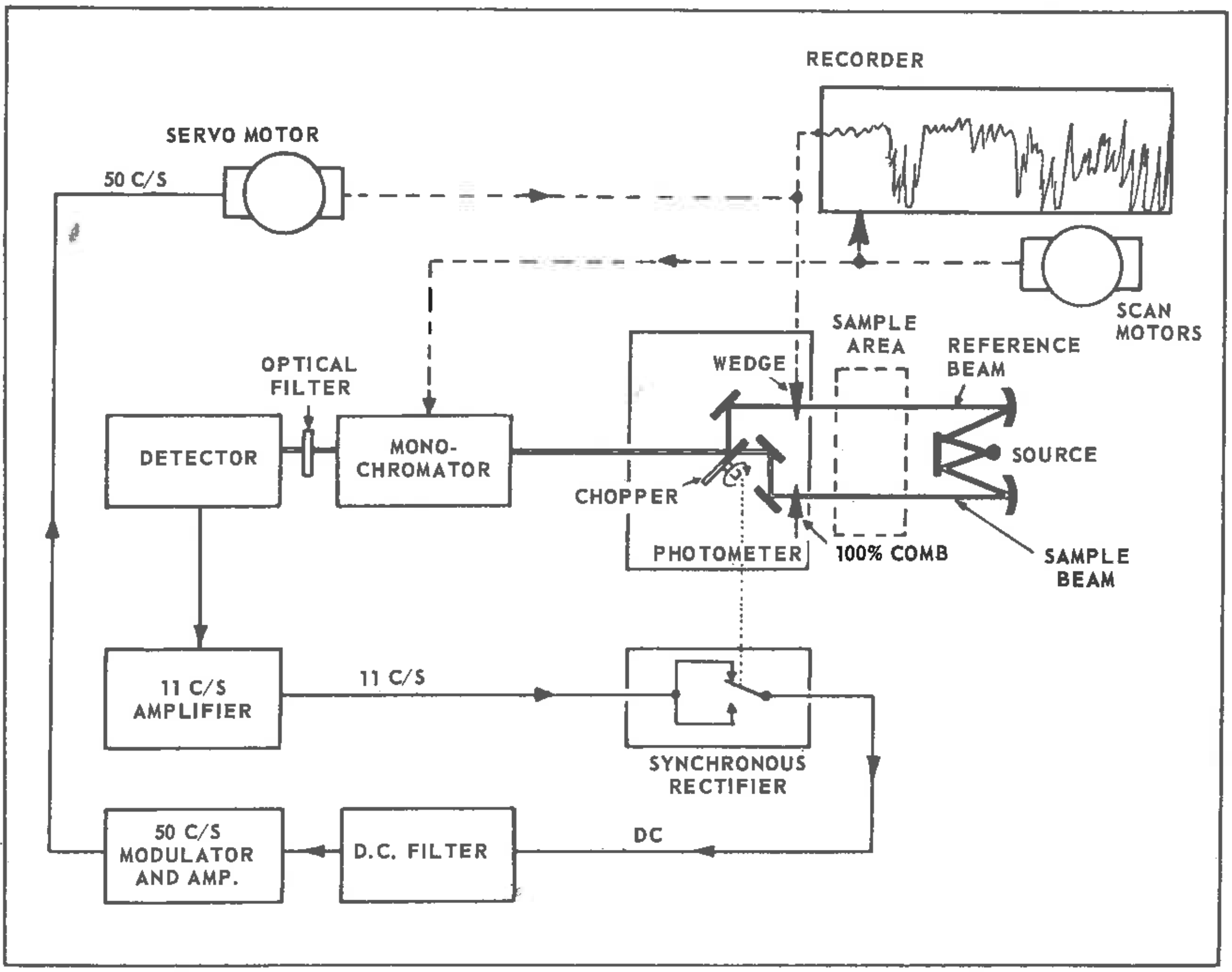


Fig. 3.1 Model 257 Spectrophotometer – Block Diagram

4. The radiation emitted by the source is divided into two beams. One beam passes through the sample which absorbs certain characteristic frequencies whilst the other serves as a reference. In the sample beam there is a wedge-shaped comb attenuator which is mechanically controlled by the 100% knob on the front panel, whilst in the reference beam there is a similar attenuator controlled by a servo motor. In the photometer section the two beams are combined by a rotating semicircular sector mirror to form a single beam consisting of alternate pulses of radiation from the sample and reference beams. This combined beam passes into the monochromator where it is dispersed by the grating into its spectral components. Rotation of the grating results in the dispersed spectrum being scanned across the monochromator exit slit. The mechanical width of the monochromator slit determines the width of the band of frequencies emerging from the monochromator. Thus decreasing the slit width decreases both this bandwidth, (i.e. improves the resolution) and the intensity of the emerging radiation (i.e. decreases the signal to noise ratio). The slit width is adjusted by the slit control on the front panel. After leaving the monochromator the radiation passes through one of a set of optical filters, the correct filter being automatically selected for the spectral region being scanned. This filter absorbs unwanted (higher order) radiation diffracted from the grating at the same angle as the component of the desired wavenumber. Finally the transmitted radiation is focussed onto a thermocouple detector.

5. An alternating signal on the detector is amplified and fed to a servo-motor which moves the reference beam attenuator to equalize the intensity of the sample and reference beams. The alternating signal is thereby reduced to zero, producing a state of equilibrium.

6. When, at the characteristic absorption frequencies of the sample, the intensity of the sample beam changes, the two signals become unequal and the combined beam flickers at 11 c/s (the rotational frequency of the sector mirror). An alternating signal called the ERROR signal is then generated by the detector, the amplitude of this signal being proportional to the error between the true transmittance and the indicated transmittance.

7. The error signal is amplified by the 11 c/s amplifier, rectified by the synchronous rectifier, smoothed and modulated to give a 50 c/s signal the phase of which is dependant on which beam is the more intense. After further amplification by the main amplifier this signal is used to drive the servo motor in a direction depending on the phase of the 50 c/s signal so that the reference beam attenuator is moved to reduce the error signal to zero. Since the recorder pen is mechanically linked to the attenuator, the pen will be displaced by an amount proportional to the change in sample transmittance.

8. The source of radiant energy is a length of ceramic tube heated by an internal metallic heater. The ceramic is heated to about 1200°C and produces a continuous spectrum of electromagnetic energy most of which falls within the infrared region from 4000 to 625 cm^{-1}. The incandescent portion of the tubing is about 15 mm long and 3 mm in diameter. It is largely enclosed by two heat shields to minimize the power required to operate it. The source has a positive temperature coefficient of resistance. No electrical ballasting or water cooling system is needed.

9. So that the instrument will have a uniform response and noise level, the energy available at the detector must be kept relatively constant over the entire spectral range. This is accomplished by cams which control the widths of the monochromator slits. It may be useful to note that an increase in the energy emitted from the source (especially at the higher frequencies) may be obtained by changing the transformer tapping to increase the voltage to the heater coil of the source. The increased temperature of the source will, however, shorten its life.

SOURCE UNIT AND SAMPLE

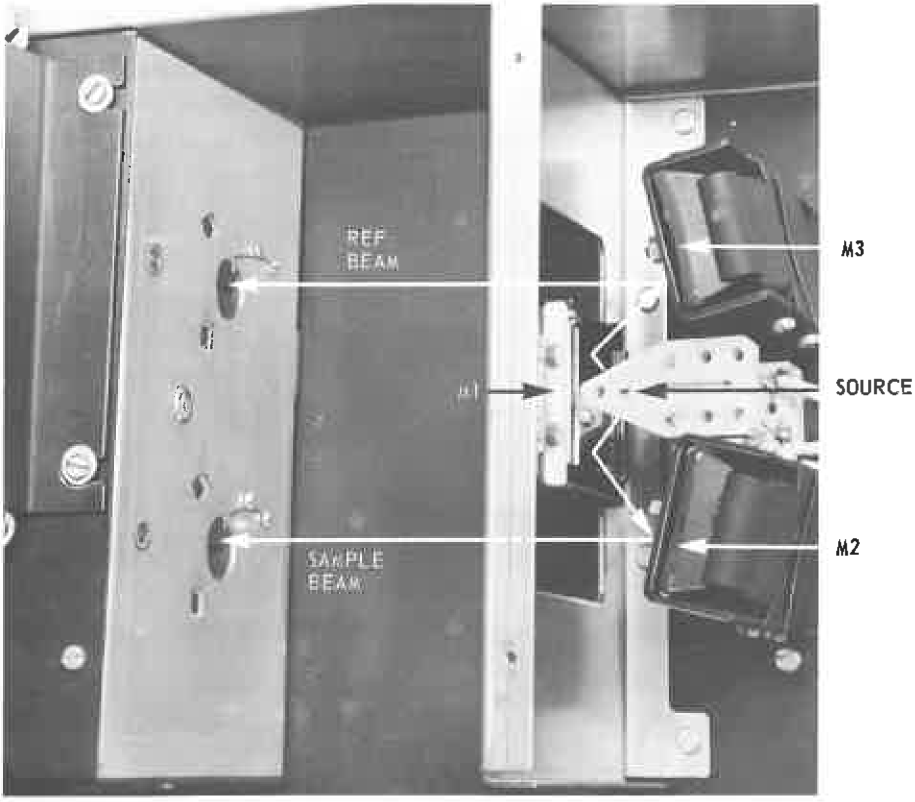


Fig. 3·2 Source Optics

10. As shown in Fig 3.2, the energy radiated by the source is split into the sample and reference beams by the plane mirror M1 and toroidal mirrors M2 and M3. Toroidal mirror M2 focusses the sample beam onto the 100% comb, and M3 focusses the reference beam onto the servo-controlled optical wedge. To ensure that the optical system is filled uniformly, the image of the ceramic tube is double size, i.e. 6 mm wide. The use of toroidal mirrors eliminates astigmatism in the source images of the two beams.

11. The sample is placed in the sample beam where it absorbs some of the radiated energy at its characteristic absorption frequencies.

12. The 100% comb is used to adjust the intensity of the sample beam so that the pen indicates 100% transmittance when no sample is present. Thus, when the comb is moved into or out of the sample beam, the servo motor moves the optical wedge in the reference beam to equalize the beam intensities, its movement being followed by the pen.

NOTE: The 100% comb and optical wedge are constructed from very thin sheet metal in order to improve their optical performance and can be damaged very easily. Do not handle them. Do not poke fingers or objects into the apertures in the sample area.

PHOTOMETER

13. The optical wedge is designed so that, as it is moved into the reference beam, the attenuation of the beam intensity is linearly proportional to the angular rotation of the wedge shaft. The wedge position thus becomes a direct measure of the relative intensities of the sample and reference beams (the transmittance). Since the pen is directly coupled to the wedge, its movements are actually a record of the wedge position, or sample transmittance.

14. The sample and reference beams are combined by the sector mirror, (Fig. 3.3) which rotates at 11 revolutions per second. Plane mirrors M4, M5, and M6 are orientated so that the sector mirror will alternately pass the sample beam and reflect the reference beam through the aperture stop, which is imaged on the grating in the monochromator and ensures that both beams are the same size.

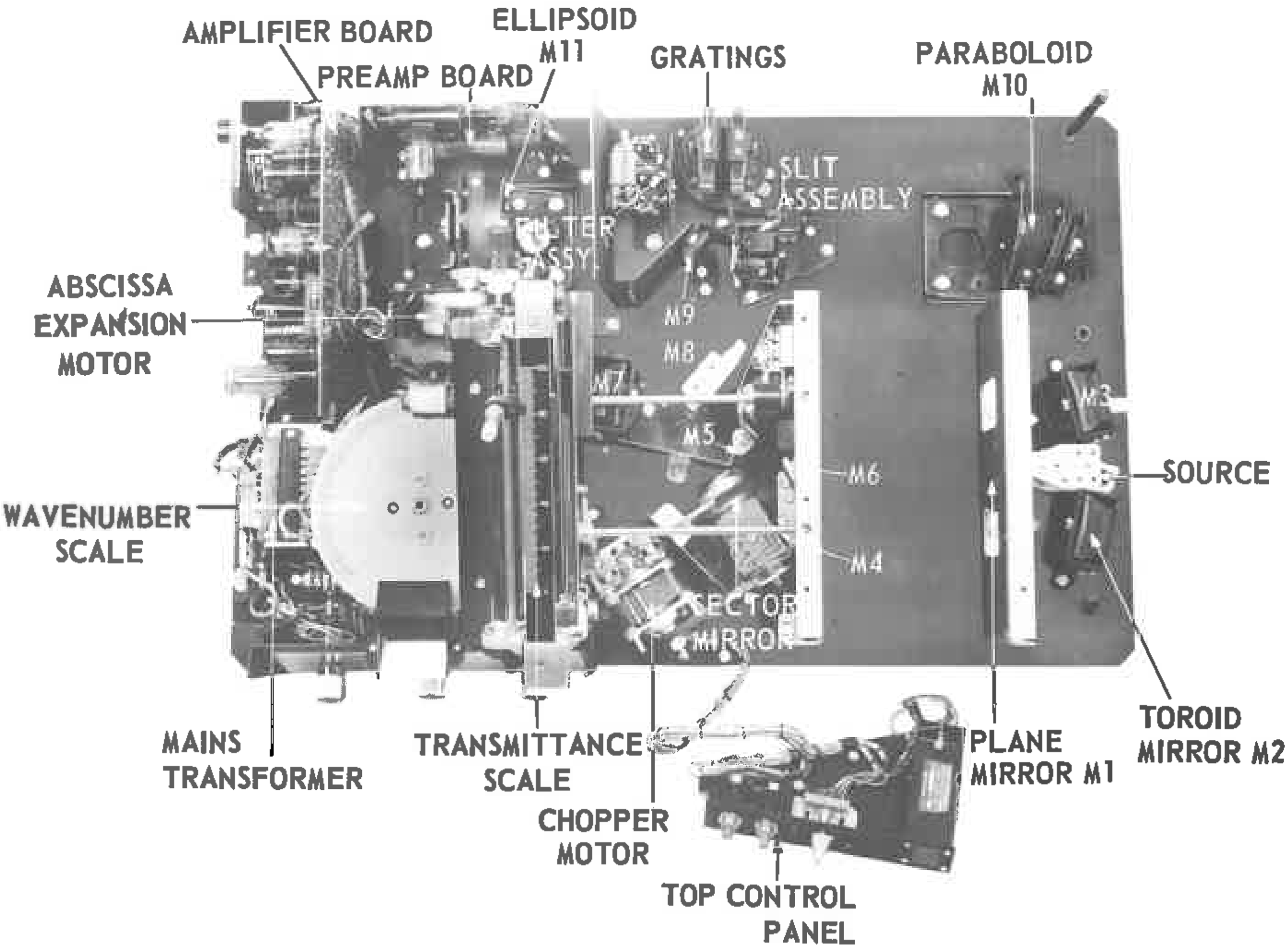


Fig 3-3a Optical System

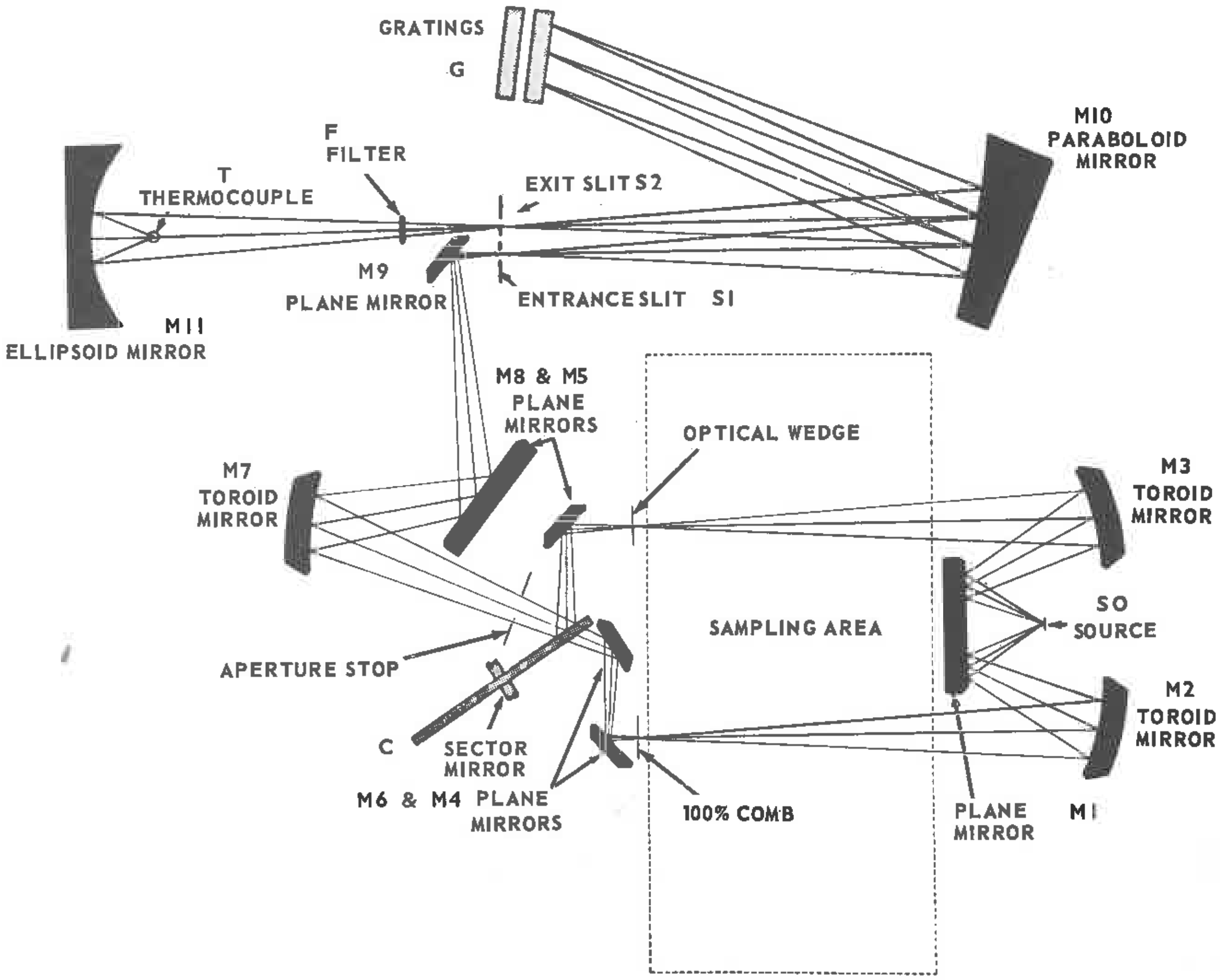


Fig. 3·3b Schematic Diagram of Complete Optical System

15. The toroidal mirror M7 alternately "sees" images of the source at the optical wedge and at the 100% comb. It focusses these images on the entrance slit S1 of the monochromator with no change in image size and no astigamatism.

MONOCHROMATOR

General

16. The monochromator performs three functions which are basic to the operation of the spectrophotometer:

a) It disperses the radiation into its component frequencies.

b) It selects radiation of the desired frequency, this radiation then being transmitted to the detector.

c) It maintains approximately constant energy at the detector when no sample is in the system, regardless of wavenumber setting.

The monochromator consists of the entrance and exit slits S1 and S2 (Fig. 3.3), 19° off-axis paraboloidal mirror M10, two plane replica gratings G, mounted back to back and four optical filters F. The paraboloid M10 has a focal length of 203 mm and the ruled surface of the gratings is 52 mm square. The monochromator is enclosed by a gasketted cover which protects the optical elements and keeps out dust which could cause scattered radiation. Also located under this cover are plane mirrors M9, ellipsoidal mirror M11, the thermocouple detector and preamplifier assembly.

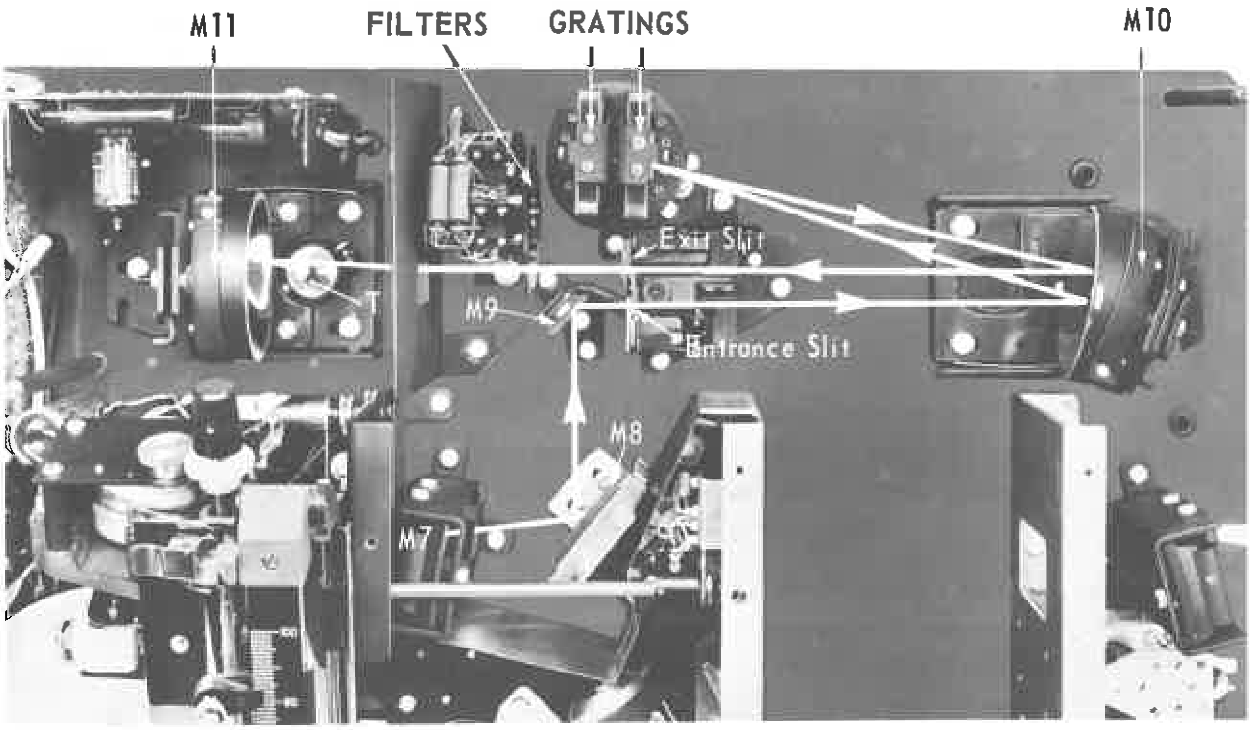


Fig. 3·4 Monochromator Optics

Dispersion of the Radiation

17. Plane mirrors M8 and M9 direct the combined beam onto the entrance slit S1 which is coincident with the focal point of mirror M7. From S1 the beam diverges until the paraboloid M10 reflects it as collimated light (all rays parallel) towards the grating G. At the grating the light is diffracted and returned to the paraboloid which focusses the beam in the plane of the exit slit S2, as a continuous band of dispersed radiation. The frequency, or, more exactly the band of frequencies of the radiation passing through the exit slit is determined by the grating in use and its angular position.

NOTE: Due to the finite non-zero slit widths it is more exact to talk of a band of frequencies emerging from the exit slit instead of a single frequency. The effective bandwidth is termed the spectral slit width and varies with wavenumber setting, the variation being the result of the changes in slit width necessary to keep the energy reaching the detector approximately constant.

Fig. 3·5 Gratings and Mounting

18. To cover a wide spectral range, two gratings mounted back to back are used. In the Model 257 these gratings have 240 and 120 lines per mm, the sectional profile of the lines being shaped, i.e. blazed, to give optimum efficiency at 2666 cm^{-1} and 1333 cm^{-1} respectively. Fig. 3.5 shows the gratings on their rotatable mount. The grating appropriate to the wavenumber setting of the instrument is selected automatically. In full range operation the grating changeover occurs at 2000 cm^{-1} whilst in Range 1 operation the first grating scans continuously from 4000 to 1250 cm^{-1}.

Selection of a Particular Frequency

19. The frequency centred on the exit slit is determined by the angular position of the gratings according to the following simplified equation:–

$$n\lambda = K_1 \sin\theta \quad \text{.......... } 3.1$$

or

$$\nu/n = K_2 \operatorname{cosec}\theta \quad \text{.......... } 3.2$$

where n = an integer, 0, 1, 2, ...representing the order of diffraction from the grating.

ν = frequency

λ = wavelength

θ = angle of rotation of the grating from zero order ($n = o$)

and K_1 and K_2 are proportionality constants. As can be seen from the above equation, any value of θ can give rise to more than one value of ν depending on the value of n. Thus radiation of more than one frequency emerges from the exit slit and impinges on the optical filter assembly F. The purpose of the optical filter is to eliminate all radiation except the component of frequency corresponding to the first order of diffraction from the grating ($n = 1$).

Optical Filters

20. Four transmission filters mounted on a motor driven wheel (Fig. 3.6) are used to cover the full range of the instrument, two filters being used with each grating. Micro-switches S406, S407, and S408 mounted on the filter unit control the filter wheel rotation. The pair of filters appropriate to a particular grating is automatically selected at the grating change-over at 2000 cm^{-1}. The selection of individual filters of each pair is controlled by a microswitch S402 actuated by a cam mounted below the wavenumber scale. Filter changes occur at approximately 2300 and 1150 cm^{-1}.

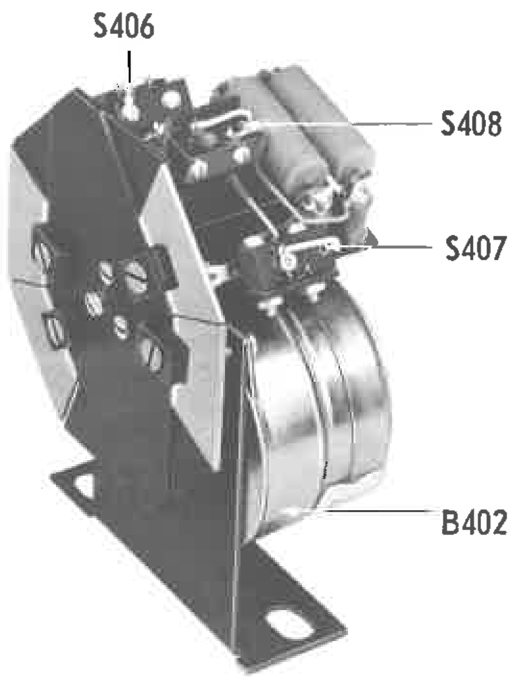


Fig. 3·6 Optical Filter Unit

Grating Drive

21. In order to produce a linear wavenumber presentation, the gratings are driven by a cosecant mechanism (see equation 3.2, paragraph 3.19). A metal tape secured to a pulley on the wavenumber scale shaft (Fig. 3.7) controls the motion of a carriage assembly along two parallel rods. A roller mounted on the carriage bears against a straight cosecant arm, the end of which pivots with the grating table. Rotation of the grating is therefore accurately related to the reading on the wavenumber scale.

22. If θ is the angular displacement of the grating from the position of zero order reflection (n = o) and x is the linear displacement of the axis of rotation of the cosecant drive pulley, point P (Fig. 3.8), from the axis of rotation of the gratings, point 0, then :–

$$x = b \quad \text{cosec}\,\theta \qquad \text{.................... 3.3}$$

where b is a constant equal to the perpendicular distance from P to a line through O parallel to the straight surface of the cosecant arm. Hence from equation 3.2.

$$\nu \propto x$$

In this way a linear wavenumber calibration is obtained.

Entrance and Exit Slits

23. Each slit consists of a pair of accurately machined, straight metal jaws. These are coupled so that both slits have equal width and the motion of the jaws is bilateral, i.e. they move equally in opposite directions, so that the central frequency transmitted by the exit slit and therefore the instrument calibration are independent of slit width. A cam driving through the variable slit mechanism to the slit arm (Fig. 3.10) controls the slit width.

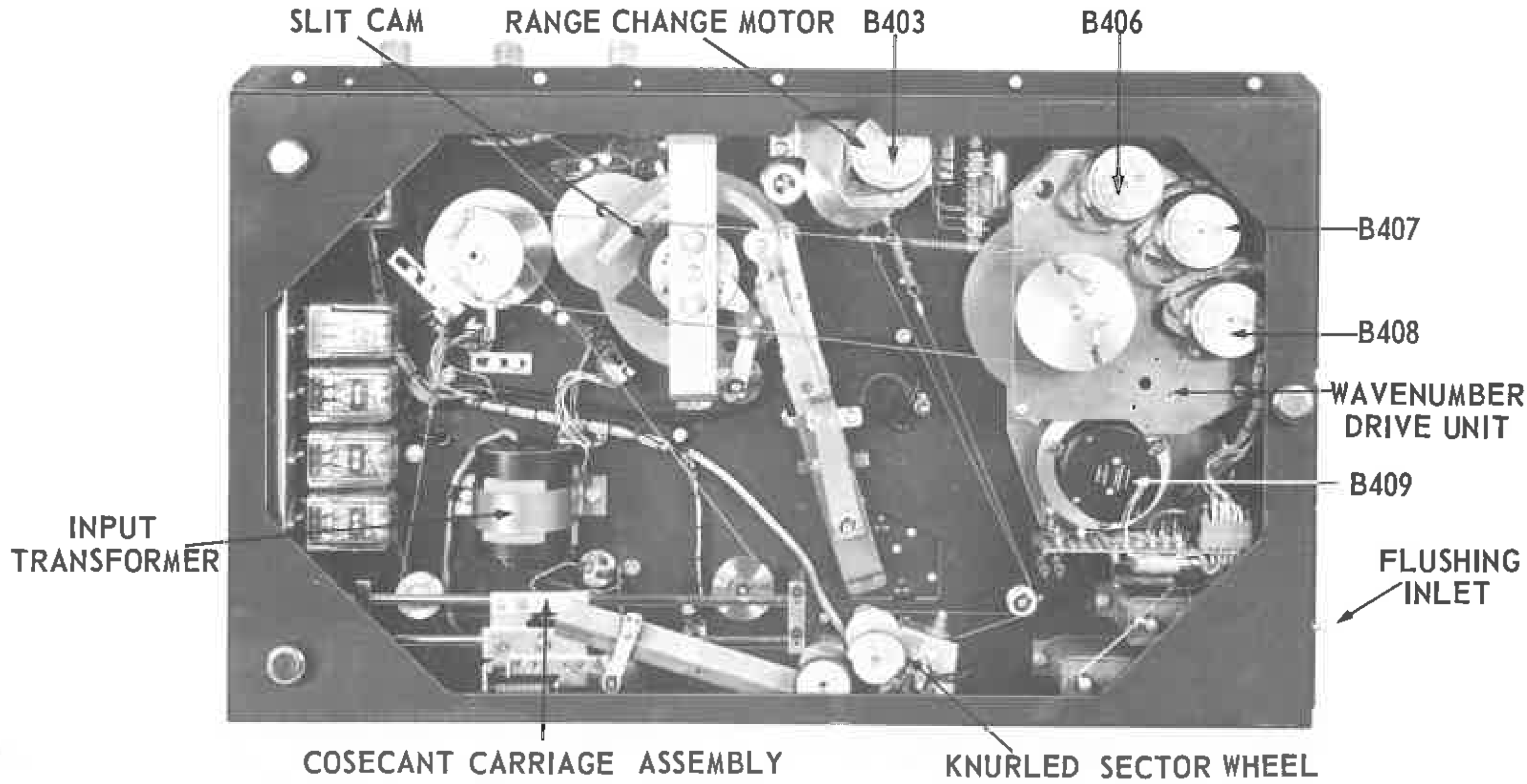


Fig. 3·7 Underside of Instrument, Slit Programme N

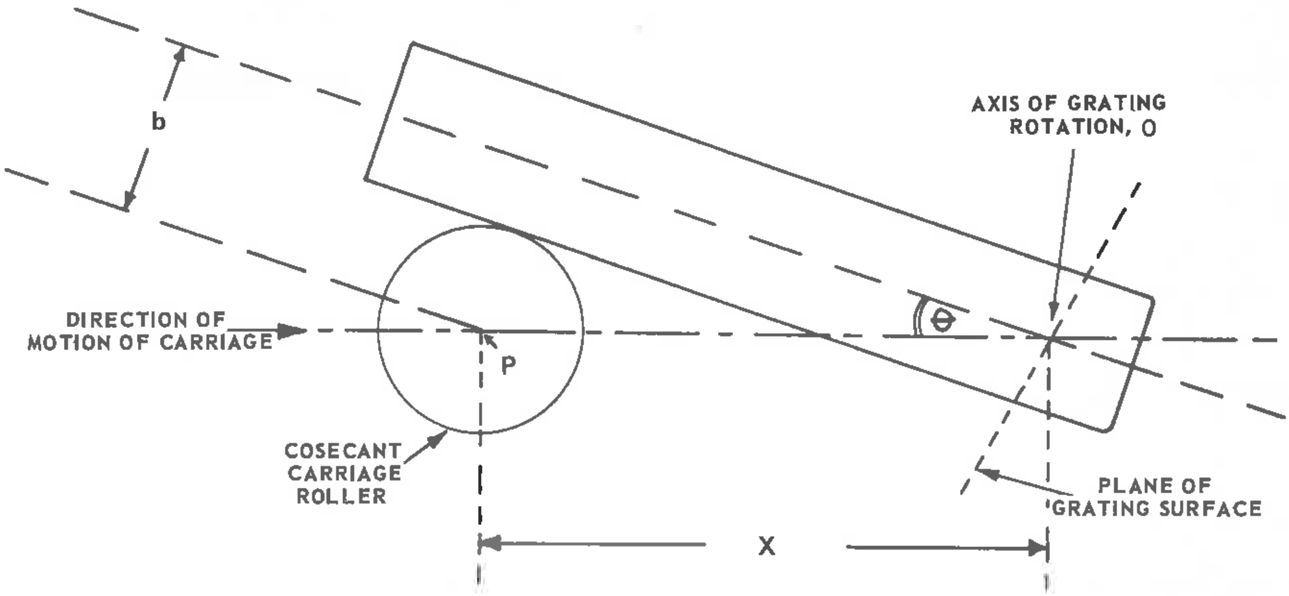


Fig. 3·8 Schematic Diagram of Cosecant Drive Mechanism

Variable Slit Mechanism

24. As already explained (paragraph 3.17) the slits are programmed so that with no sample in the beam, approximately constant energy is received by the detector for all wavenumber settings. There are two programmes on opposite 180 degree sectors of the slit cam, one for each grating. When the grating changeover occurs, the appropriate cam sector is automatically brought into operation by the grating change motor driving through a planetary gear system to which the slit cam is coupled. During normal scanning, the cam is driven through the planetary gears by a gear fixed to the wavenumber scale shaft.

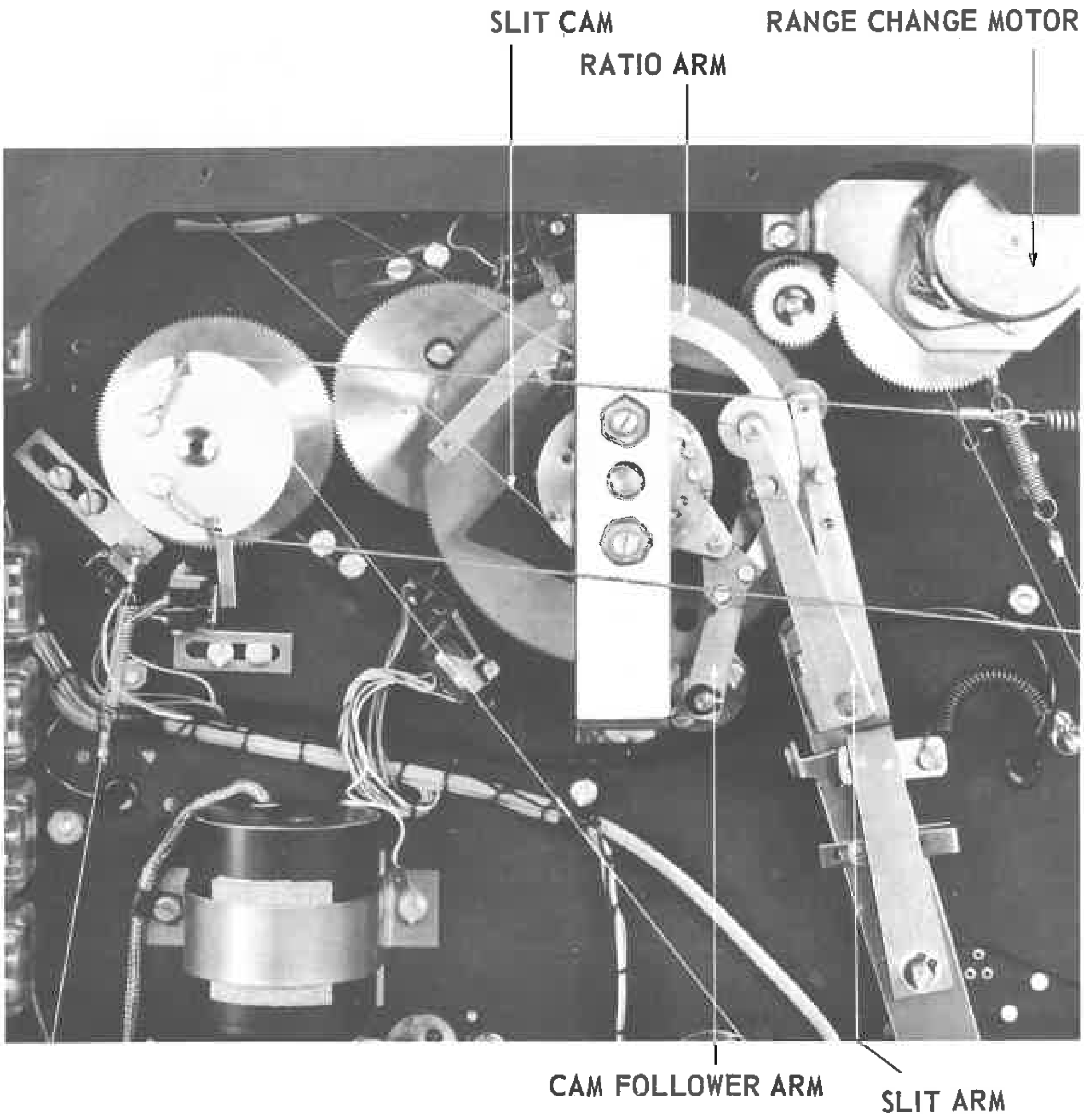


Fig. 3-9 Variable Slit Mechanism (N Slit at 4000 cm^{-1})

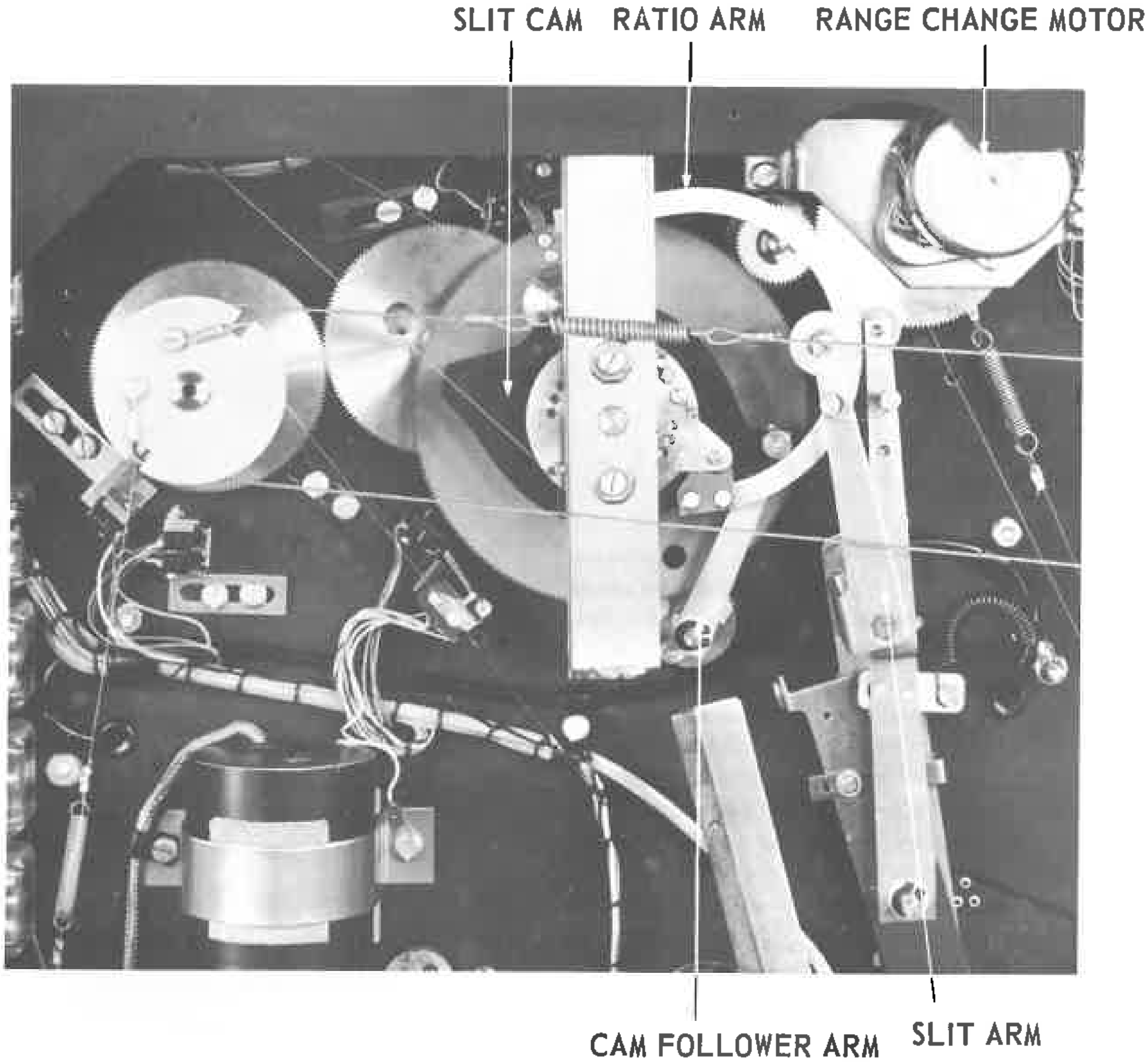


Fig. 3·10 Variable Slit Mechanism (wide slit programme at 1250 cm^{-1}, Range I)

25. Changes in the slit cam profile are communicated through the cam follower to a ratio arm which controls the rise of the slit arm and therefore the slit width. By adjustment of the SLIT control the ratio arm can be located in any one of the seven positions in which the slit width is multiplied or divided by an approximately constant factor throughout the spectral range of the instrument. In this way the slit programme can be varied to give high energy at low resolution or high resolution at the expense of the signal to noise ratio.

DETECTOR

26. The function of the detector is to convert the incident energy into electrical energy that can be used to drive the optical wedge and the pen. The unit consists of the ellipsoidal mirror M11 and the thermocouple T (see Fig. 3.11). The two foci of the ellipsoid are located at the exit slit of the monochromator and the sensitive area of the thermocouple, the ratio of the focal lengths being 6:1. The radiant energy leaving the exit slit is therefore focussed on the thermocouple as an image of the slit reduced in linear dimensions by a factor of six. The signal from the thermocouple for a full-scale error (one beam at full intensity, the other beam zero) is about 0.2 μ V r.m.s. at 11 c/s.

27. The high speed, high sensitivity thermocouple is a delicate unit. The thermocouple target on which the ellipsoid M11 focusses is a 2 x 0.2 mm strip of blackened gold leaf welded to two pins. The gold leaf strongly absorbs the incident radiation which therefore raises its temperature. Temperature differences at the junctions between the gold leaf and the pins set up a thermoelectric potential which becomes the electrical signal. The sensitive element of the thermocouple is enclosed in a steel casing to eliminate pick-up, the casing being evacuated to increase the detector sensitivity. A potassium bromide window, transparent to infrared radiation to approximately 400 cm^{-1} is used to transmit radiation to the sensitive element.

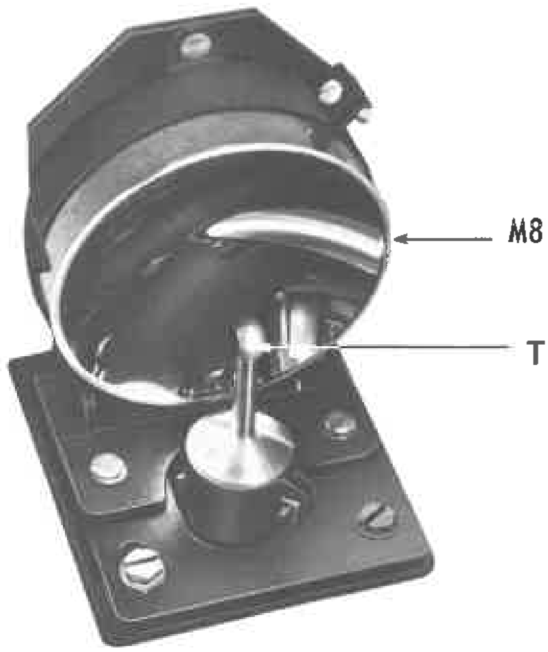


Fig. 3·11 The Detector

CAUTION: Handle the thermocouple carefully. Rough treatment may break the thermocouple junction. The potassium bromide window is very soluble in water and should never be touched or exposed to a damp atmosphere.

PREAMPLIFIER AND ELEVEN C/S AMPLIFIER

28. When the sample and reference beams differ in intensity, the alternating component of the voltage output from the detector is fed to the grid of V101A in the preamplifier via the input transformer, T301 (Fig. 3.13). The secondary winding of this transformer, which has a turns ratio of 1000:1, is tuned to 11 c/s.

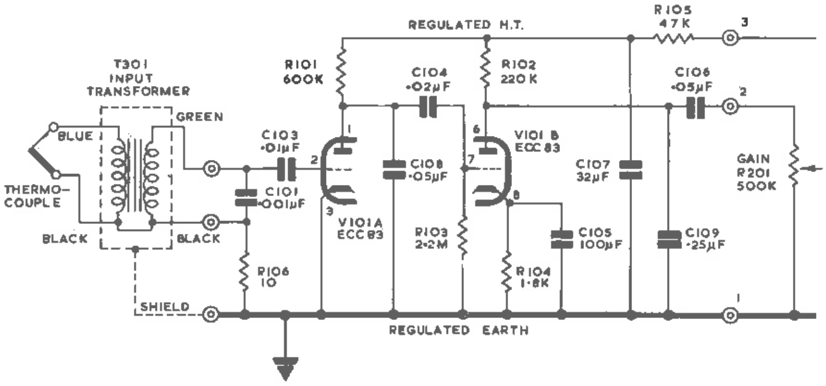


Fig. 3·12 Circuit Diagram of Detector and Preamplifier.

29. The preamplifier has two stages which amplify the error signal by about 800. The "floating" grid of V101A (no grid resistor) establishes a high input impedance to the amplifier to prevent any reduction of the effective voltage step-up in the transformer. The output from the preamplifier is fed to the grid of V201A (Fig. 3.13) in the 11 c/s amplifier through the GAIN control potentiometer R201, and a parallel-T 50 c/s rejection filter. The two halves of V201 provide two stages of gain and amplify the signal by a factor of about 500. Valve V201B is followed by a second 50 c/s rejection filter. The third stage, V202A, is a phase splitter that provides out-of-phase signals to the full-wave synchronous rectifier.

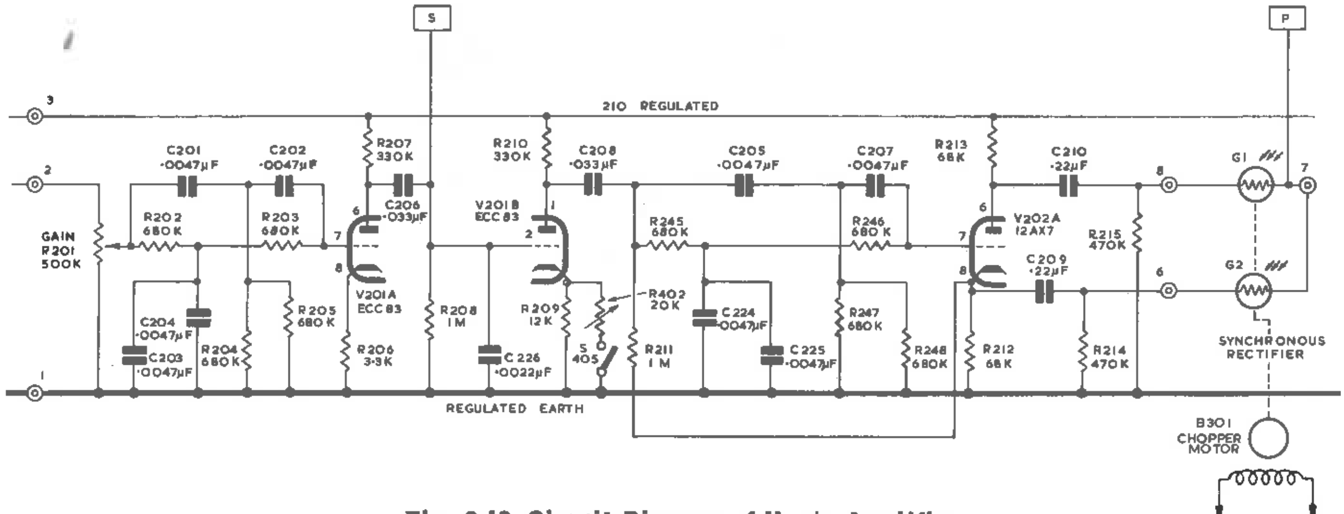


Fig. 3·13 Circuit Diagram of 11 c/s Amplifier

30. The amplifier also amplifies any noise signal and this tends to obscure information when the error signal is very small. This noise is primarily due to Johnson noise in the thermocouple, and to a lesser extent, to flicker noise in the first stage of the preamplifier valve; normally this peak-to-peak noise voltage is of the order of 10^{-9} volts. The significance of this is that any reading on the transmittance scale can vary by about ½% of full scale in the region 4000 to 2000 cm^{-1} or 1% in the region 2000 to 625 cm^{-1}.

31. If the gain is increased excessively (GAIN control turned clockwise), the pen drive system will break into a spontaneous oscillation at about 2 c/s. When the gain is properly adjusted as described earlier, the bandwidth of the pen servo is about 1 c/s.

32. The bandwidth is one of the factors that determines the noise level of the system. It also has further significance. A 1 c/s bandwidth means that all spectral information changing at rates ranging from 0 to 1 c/s is faithfully reproduced. Spectral information at higher frequencies, if present, would not be faithfully reproduced. Scanning speed and spectral slit width in the Model 257 Spectrophotometer, have been selected so that spectral information produced at slow speed with N slit control setting lies within the bandwidth and is faithfully reproduced by the pen. Faster scanning may lead to inaccuracies when substances with very sharp bands are being examined.

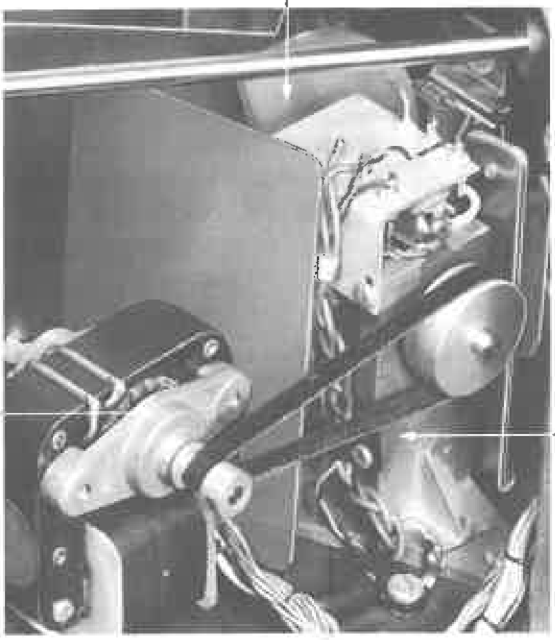


Fig. 3-14 Sector Mirror and Drive

SYNCHRONOUS RECTIFIER

33. The synchronous rectifier changes the 11 c/s signal obtained from V202A into direct voltage whose polarity indicates which beam, sample or reference, is more intense. It consists of two photoconductive cells G1 and G2 which are alternately illuminated (and therefore switched to a conducting state) at the same frequency as the rotational frequency of the sector mirror. Thus during one half cycle of the sector mirror rotation G1 only is conducting and on the succeeding half cycle G2 only is conducting.

34. For the sake of illustration, assume that G1 is conducting only when the sample beam is transmitted by the sector mirror and that negative direct voltage represents less intensity in the sample beam than in the reference beam (increasing absorption). Under the assumed conditions, when the intensity of the sample beam is reduced by absorption and G1 is conducting, the signal at the anode of V202A is in a negative half cycle. A negative signal is applied in turn therefore, to the 50 c/s modulator. During the succeeding half cycle, G2 only is conducting and again a negative signal is applied to the modulator, since G2 is connected to the cathode of V202A. The effect, therefore, is to transmit negative full wave rectified voltage to the modulator whenever the intensity of the sample beam is less than that of the reference beam.

35. The reverse occurs when the intensity of the sample beam becomes greater than that of the reference beam due to decreasing absorption by the sample. The effect here is to transmit positive full wave rectified voltage to the modulator.

NOTE: In practice, a phase shift of about 90 degrees is introduced between the flickering light signal at the thermocouple and the electrical signal at the synchronous rectifier. This shift is due to the effects of the thermocouple and the amplifiers. It is compensated by correctly phasing the illumination of the photoconductive cells with the rotation of the sector mirror. (paragraph 4.24)

FIFTY C/S MODULATOR AND FIFTY C/S AMPLIFIER

36. The 50 c/s modulator (Fig. 3.15) changes the direct voltage from the synchronous rectifier to a 50 c/s alternating voltage which can be used to drive the pen servo motor. It consists of two silicon diodes, V203A and V203B, built into a plug-in unit with a B7G base. A 50 c/s signal from transformer T302 is connected to the diode circuit. The diodes will conduct only during the half cycle signal when the anodes are positive and the cathodes negative.

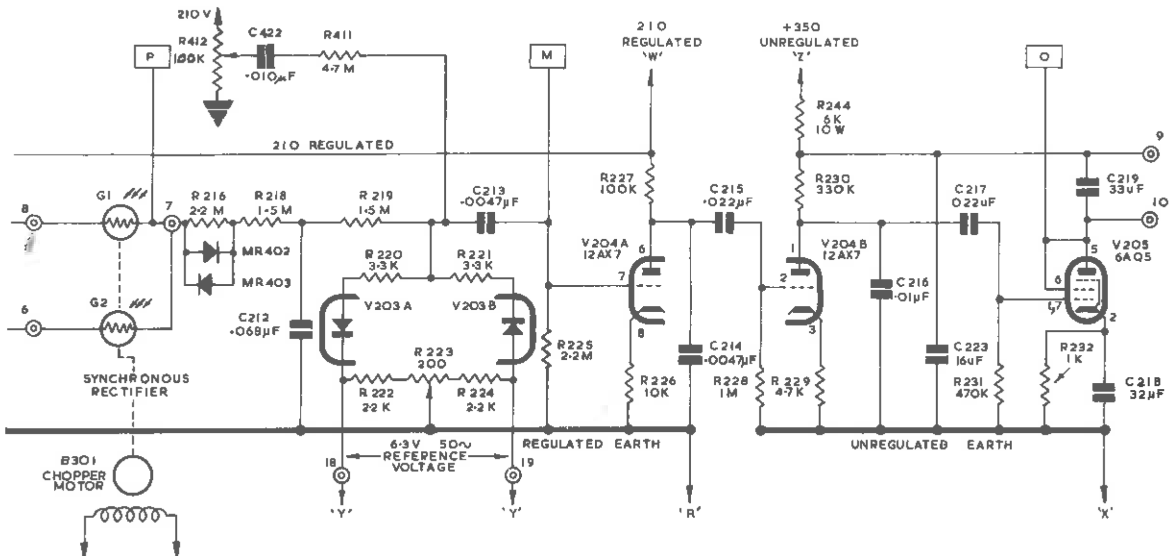


Fig. 3·15 Circuit Diagram of 50 c/s Modulator and Amplifier

37. When the diodes conduct, the direct voltage has a path to earth such that the voltage at capacitor C213 drops almost to zero. When the path is blocked on the next half cycle of the 50 c/s signal the potential at C213 reverts to that of the original direct voltage. The effect is the same as that of a switch operating 50 times a second. As a result, the signal at the output is 50 c/s alternating voltage with a peak-to-peak amplitude equal to the direct voltage. The phase of the 50 c/s voltage is determined by the polarity of the direct voltage.

Balance Control

38. It will be noticed that the modulator is grounded through potentiometer R223, the BALANCE control. By adjusting R223 in one direction, part of the 50 c/s voltage from T302 will add to the signal already present at the output. By adjusting it in the opposite direction, a 50 c/s voltage of opposite phase will tend to cancel the signal already present. This control can therefore be used to balance out any constant undesirable signals which arise in the instrument.

Fifty c/s Amplifier

39. The 50 c/s signal passed by capacitor C213 is amplified by a factor of approximately 600 by the two stages of the 50 c/s amplifier, V204A and V204B. The signal is then fed through the power amplifier V205 to the control winding of the pen servo motor.

AUTOMATIC GAIN CHANGE

40. For a given position of the SLIT control, the slit programme provides comparable resolution for both ranges of the instrument. The black body characteristics of the source are such however, that there is less energy available in the 2000 to 625 cm^{-1} region. To maintain the correct pen response in this range therefore, the gain is automatically increased by a factor of approximately two; hence the change in the signal to noise ratio (from ½% to 1%) at the grating changeover position (2000 cm^{-1}).

41. The change in gain is controlled by micro switch S405 which is automatically closed when the second grating comes into operation. Closing this switch brings potentiometer R402 (connected in parallel with R209, the cathode resistor of V201B) into circuit, thus increasing the gain of this stage of the 11 c/s amplifier. Differences in the pen response between the two ranges can be corrected by adjustment of the potentioneter R402.

THE PEN DRIVE

Mechanics

42. A nylon friction drive wheel (Fig. 3.16) coupled to the servo motor output drives one of two quadrants mounted on a shaft. This quadrant carries the chain connected to the pen carriage; the other carries the optical wedge. Since both the pen quadrant and the wedge quadrant are mounted on the same shaft, the pen must move an amount proportional to the wedge movement, and non-reproducibility due to slippage between pen and wedge is eliminated. The size of the drive wheel is such that the motor shaft rotates at about 100 times the speed of the quadrant shaft. With the servo motor operating at full speed, this gives a response time of about 0.8 seconds in which the pen drives full scale. The driven edge of the pen quadrant is rubber-covered except at its ends to ensure a positive drive. At the ends the nylon drive wheel slips on bare aluminium, thus preventing damage due to the quadrant being driven beyond its limits.

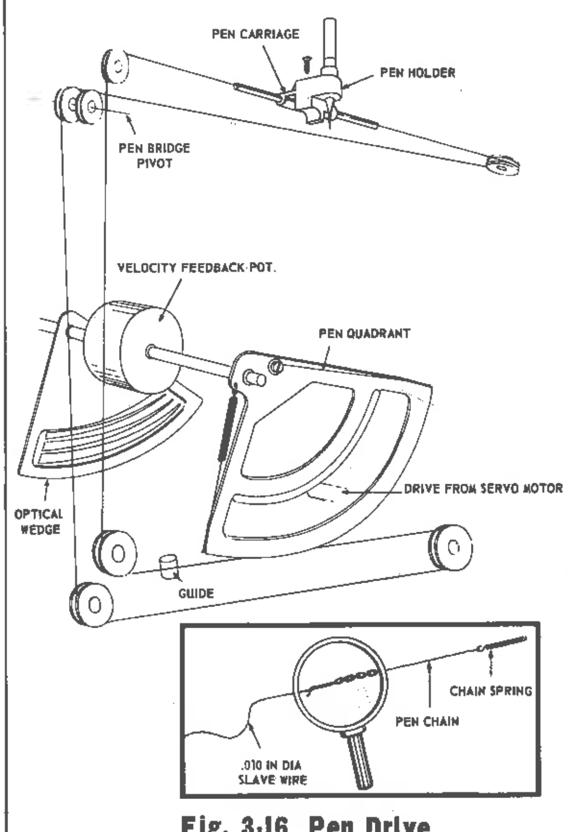


Fig. 3·16 Pen Drive

Electronics

43. The pen servo motor converts the 50 c/s signal from the anode circuit of V205 (Fig. 315) into mechanical rotation and drives the pen and moves the optical wedge to null the signal. The pen servo motor has two windings, a control winding energized by the signal, and a reference winding connected directly to the mains voltage through a phase-shifting capacitor C301. The motor phasing is such that the control winding voltage either leads or lags the reference winding voltage by 90°, depending upon which beam, sample or reference, is more intense. If the signal voltage leads, the motor turns in one direction, if it lags, the motor turns in the opposite direction.

44. A velocity feedback system is employed to tighten the pen servo system and thus retard motion of the pen beyond the optical balance point. The wiper of a potentiometer R412, connected between the 210 volt stabilized supply and earth, is fixed to the shaft carrying the optical wedge. The voltage on the wiper is therefore indicative of the pen position. This voltage is differentiated thus providing a signal proportional to the velocity of the pen, this signal is fed back into the 50 c/s modulator.

POWER SUPPLY

45. The main power supply provides the necessary direct voltages for the instrument. It consists basically of a transformer, a rectifier and a regulator. The alternating voltage, obtained from the high voltage winding of transformer T302 (Fig. 3.17) is converted to a direct voltage using a conventional full wave rectifier. This voltage is smoothed by resistor R233 and capacitor C220.

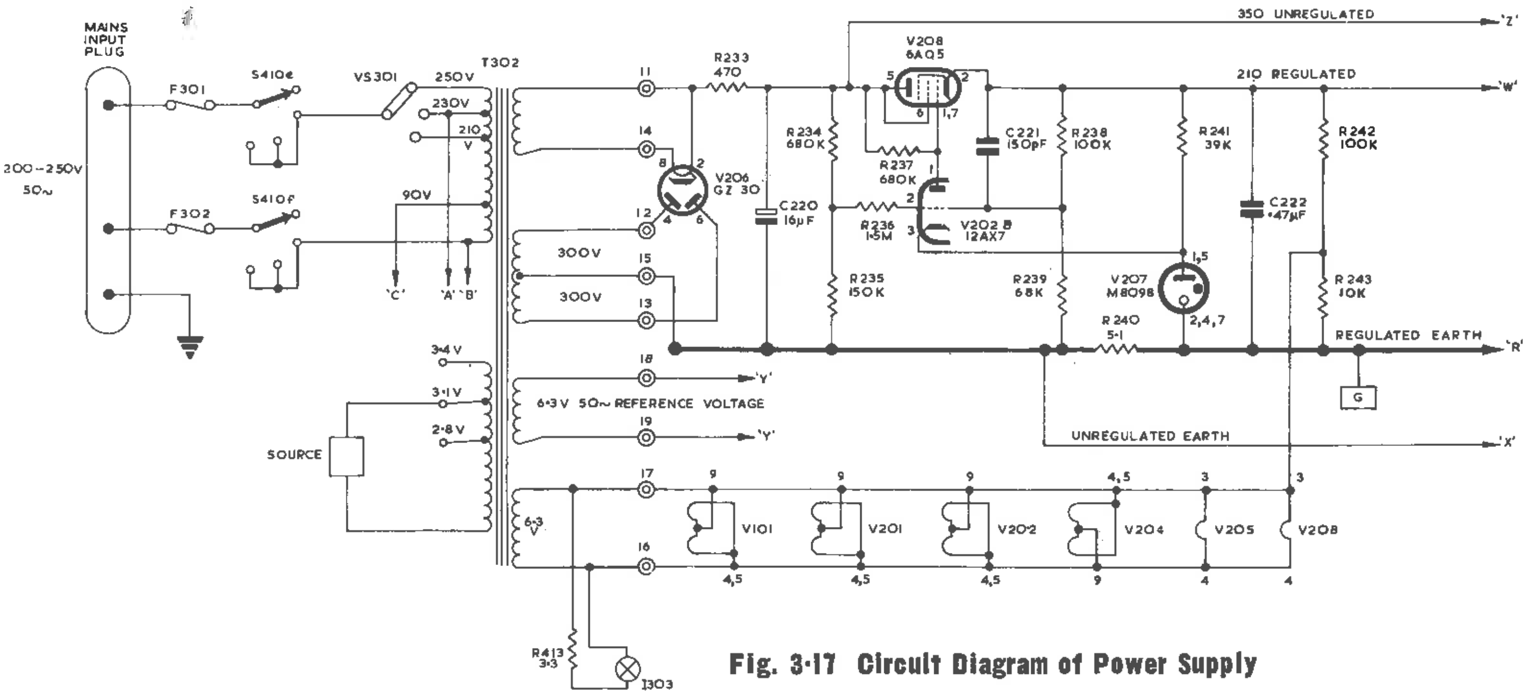


Fig. 3·17 Circuit Diagram of Power Supply

46. The load for the main power supply can be considered in two sections. The major portion of the load is represented by the last amplifier stage V204B and the power amplifier V205 which provides the power to the control winding of the servo motor. Since these stages occur late in the amplifier chain, variations in anode voltage and large amounts of ripple do not affect the performance of the instrument. This being the case, it is not necessary to provide them with regulated power.

47. The gain of the earlier stages of the amplifier is such however, that they do require a regulated power supply, providing constant voltage and low output impedance. The regulator is designed to deliver approximately 210 volts to the early stages of the amplifier regardless of normally encountered variations in line voltage or current load.

ELECTRICAL CONTROL SYSTEM

48. To assist in the explanation of the electrical circuit it is assumed that before switching on, the instrument is in the region defined by the second grating. Constant reference should be made to Fig. 3·18.

Scan Control Circuit, 4000 to 625 cm^{-1}

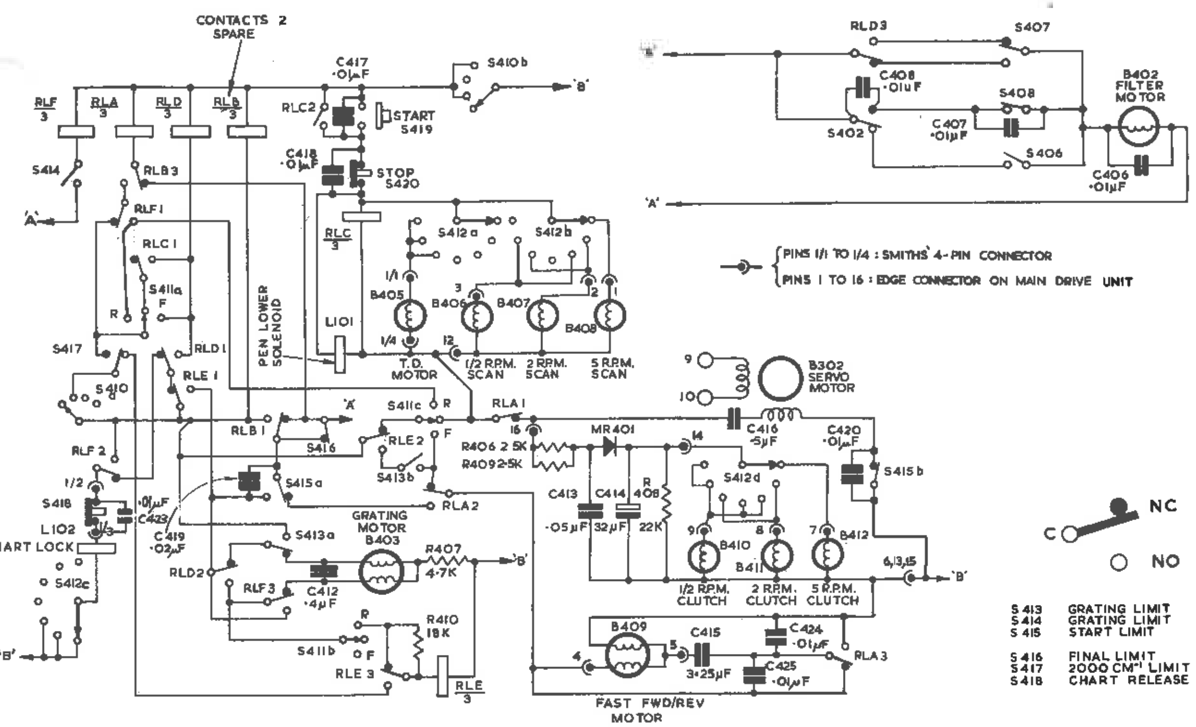
49. On switching the POWER/RANGE switch S410 to the ON position, relay A operates via RLB3. Contact RLA1 de-energizes the pen servo-motor B302, and the scan motor clutch. Contacts RLA2 and RLA3 energize via the start limit switch S415a and RLB1, the fast forward/reverse motor, B409, to drive in the reverse direction.

At the start limit position, S415a de-energizes the fast forward/reverse motor and energizes the grating change motor B403, via RLD2. This motor selects the grating and slit cam programme appropriate to the beginning of the range of the instrument. The correct filter is selected by RLD3 and S402 in conjunction with S406, S407, and S408 on the filter unit. The grating change motor is de-energized by S413a through which relay B is then energized. Relay B holds through RLB1 and the final limit switch, S416. RLB1 energizes the chart lock solenoid via RLE1, RLD1 and S414b. Contact RLB3 releases relay A, re-energizing the scan motor clutch via RLA1 and reconnecting the supply to the pen servo-motor; this is now deadened by start limit switch S415b. The scan relay C can now be energized via RLE2 and S411c by pressing the START button S419. Relay C holds through RLC2. The selected scan motor, B405, B406, B407, or B408 and the pen lower solenoid which are both connected in parallel with relay C are then energized. Immediately the start limit switch S415b is released, the pen servo motor is energized.

At 2000 cm^{-1} (the grating changeover position) the 2000 cm^{-1} limit switch S417 is operated by the cam on the wavenumber scale shaft, energizing relay D via S410a, S417, S411a and RLC1. Relay D then holds via RLD1 and RLE1. Contact RLD1 de-energizes the chart lock solenoid; RLD3 actuates the filter changeover. Relay A operates via the grating limit switch S414a and RLB3, and is held via S411a, RLC1, RLD1, RLE1, RLB1 and S416. RLA1 deadens the pen servo-motor and releases the scan motor clutch. Contacts RLA2 and RLA3 energize the fast reverse drive through S415a. The instrument drive reverses until the start limit switch S415a operates and energizes the grating change motor B403 via RLD2. The grating limit switch S414c operates at the completion of the grating and slit cam changeover, de-energizing the motor; S414b re-energizes the chart lock solenoid and S414a releases relay A. RLA1 re-energizes the servo-motor B302 and the scan motor clutch. The scan restarts, the pen becoming live when the start limit switch S415b is released, and continues until the final limit switch S416 is reached just beyond 625 cm^{-1}. Actuation of S416 de-energizes relays B, C and D, the pen lower solenoid and the chart lock. Relay A now operates via RLB3 and the sequence previously described follows, re-establishing the conditions required for the commencement of a full range scan.

Scan Control Circuit, Range 1,4000 to ~~1250~~ 625 cm^{-1}

50. On switching the POWER/RANGE switch to the RANGE 1 position, relays B, C and D are de-energized, relay A is energized, and the instrument returns to 4000 cm^{-1}. During the scan the action of the 2000 cm^{-1} limit switch is nullified by S410a so that no grating or filter changeover occurs at this position and the scan continues until the final limit switch is actuated beyond 1250 cm^{-1}. The instrument then reverses automatically to 4000 cm^{-1}.



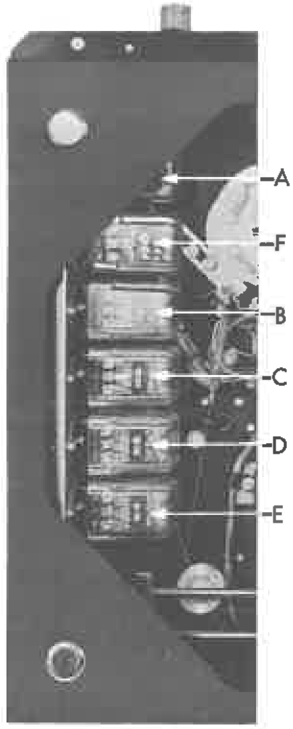


Fig. 3·18 Circuit Diagram of Electrical Control System.

Time Drive and Abscissa Expansion

51. In both modes of operation the chart lock solenoid is de-energized (by the scan mode switch S412c) and the time drive motor B405 geared to the recorder shaft, is energized when the START button is pressed. To lock the wavenumber setting of the instrument, the clutch B410 of the unenergized slow scan motor is engaged during time drive studies. In the abscissa expansion modes the slow or medium scan motor and appropriate clutch are energized.

FAST FORWARD/REVERSE Control, S411

52. Operation of this control energizes the fast forward/reverse motor to drive the instrument rapidly in the appropriate direction. When the FAST FORWARD/REVERSE control is actuated, the relay C is released (therefore the scan motors and pen lower solenoid are de-energized) and the scan motor clutch and the pen servo-motor are de-energized. The START button must therefore be pressed to restart the scan.

a) Fast Forward Drive from the first to the second grating (Relay B energized)

The fast forward/reverse motor is energized via switches RLE2, S411c (F), RLA2 and RLA3 until the 2000 cm^{-1} limit switch S417 is reached. Relays A and D operate via S414a, RLB3 and S411a (F) respectively. Contact RLD1 de-energizes the chart lock solenoid. Contacts RLA2 and RLA3 energize the fast forward/reverse motor in the reverse direction and the nomal grating changeover sequence follows until S414 is operated, de-energizing relay A and re-energizing the chart lock solenoid. The fast forward drive now continues in the region defined by the second grating.

b) Fast Reverse Drive from the second to the first grating (Relays B and D energized).

Relay A operates via RLE2, S411c (R), S414a and RLB3. Contacts RLA2 and RLA3 energize the fast reverse drive until the start limit switch S415 is operated. S415a de-energizes the reverse drive and operates relay E via RLD2 and S411b (R); relay E holds via RLE3 and the 2000 cm^{-1} limit switch S417. Contact RLE1 releases relay D and the chart lock. RLD2 and RLD3 actuate the grating and filter changeover. At the completion of the grating and slit cam changeover, S413 operates, de-energizing the grating change motor B403. The fast forward/reverse motor now drives fast forward via switches RLE2, S413b, RLA2 and RLA3 until the 2000 cm^{-1} limit switch S417 operates, releasing relay E. Contact RLE1 re-energizes the chart lock solenoid and relay A operates via switches RLE2, S411C (R), S411a (R), S414a and RLB3. The fast forward/reverse motor now drives in the reverse direction via switches RLA2 and RLA3, driving the chart in synchronism with the instrument.

Manual Chart Drive Control

53. When the control is pressed, switch S418 operates, interrupting the supply to the chart lock solenoid. If the control is then turned, the chart setting relative to the instrument can be varied.

GRATING CHANGE AND SCAN MECHANISMS

Scan Mechanism

54. The drive unit includes three scan motors B406, B407, B408, and the fast forward/reverse motor B409. The drive from each scan motor is transmitted, through a clutch B410, B411 or B412 (energized from the 90V d.c. supply built into the unit) and a 20:1 gear reduction, to the output pulley. The fast forward/reverse motor drives through a gear reduction of approximately 150:1 to the same output shaft. The scan motor appropriate to the FAST, MEDIUM or SLOW scan rate is energized via the SCAN MODE switch S412, the scan rates being 1000, 400 or 100 cm^{-1} per minute for the first grating and 500, 200 or 50 cm^{-1} per minute for the second grating.

55. The drive unit output is coupled through a wire drive to the wavenumber scale shaft which in turn is coupled to the grating cosecant drive (paragraph 3.21) the slit cam drive (paragraph 3.23) and, by means of a chain and capstan system, to the recorder (paragraph 3.58). The sequence of events occurring during a scan is described in the section dealing with the control circuit (paragraphs 3.48 to 3.50).

Grating Change Mechanism

56. The grating changeover is effected with a reversible motor B403 which also selects the slit cam programme appropriate to the grating in use. The motor drives through a wire cable to a knurled sector wheel which bears against a friction pulley fixed to the grating table shaft. This table rotates through 180 degrees and is then locked in position by one of two magnetic stops. The sector wheel also actuates micro switch S405 (paragraph 3.41) which alters the gain of the 11 c/s amplifier to take into account the different energy programmes for the two gratings.

57. The slit cam is geared to the range change motor through a planetary gear system. When the cam has rotated 180 degrees the motor is de-energized by a trip on one of the drive gears actuating a limit switch (S413a or S414c – depending on the direction of rotation) in series with the motor.

RECORDER AND CHART DRIVE MECHANISM

58. The recorder is driven from the wavenumber scale shaft by a precision chain and capstan drive operating through a solenoid actuated drive pin Fig. 3.19. The driven capstan and attached drive wheel A are free to rotate on the recorder shaft B. Energization of the chart lock solenoid C drives the spring loaded pin D forward through guide E into engagement with A. The drive to the capstan is then transmitted via pin D and guide E to shaft B to which E and the sprocket

drive wheels are fixed. The hinge and latch blocks of the pen bridge incorporate adjustable paper guides which control the feed of the chart over the sprockets.

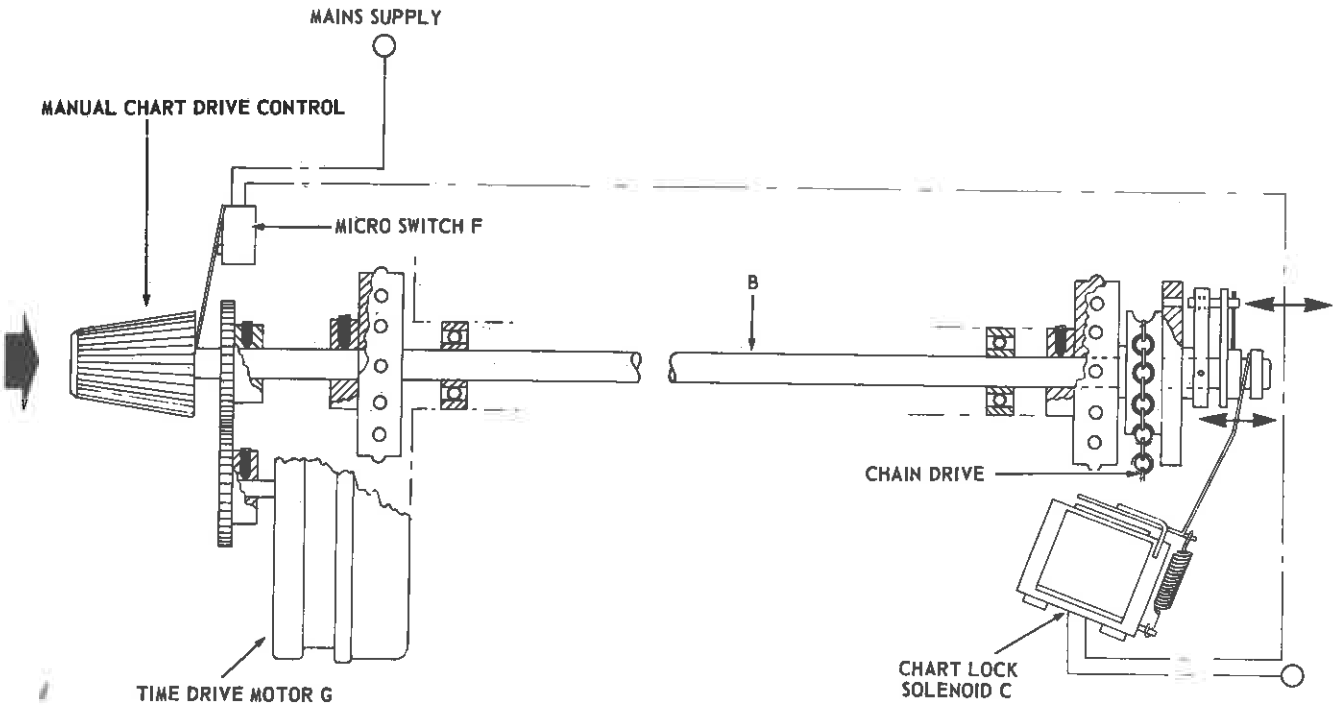


Fig. 3-19 Chart Drive Mechanism

59. In normal operation the drive pin is held in engagement except during the automatic reversal of the cosecant drive at the grating changeover and automatic reversal from the final limit switch. D is also released from A when the MANUAL CHART DRIVE control is pressed resulting in micro switch F interrupting the supply to solenoid C. By pressing and turning this control the chart can be advanced or reversed into the magazine by integral multiples of 4 cm. This corresponds to the angular interval between the three engagement positions in the drive wheel, A. In the time drive and abscissa expansion modes, the drive pin D is automatically disengaged and the chart is driven at a rate of 10 cm/min by a clutch motor G geared to the recorder shaft.

60. When the scan or time drive motors are not energized, the pen is automatically lifted clear of the chart by means of a solenoid and lever system built into the recorder. The pen can be lifted manually by depressing the lever to the left of the pen bridge hinge block. The paper tear-off e is located on the recorder to the left of the pen.

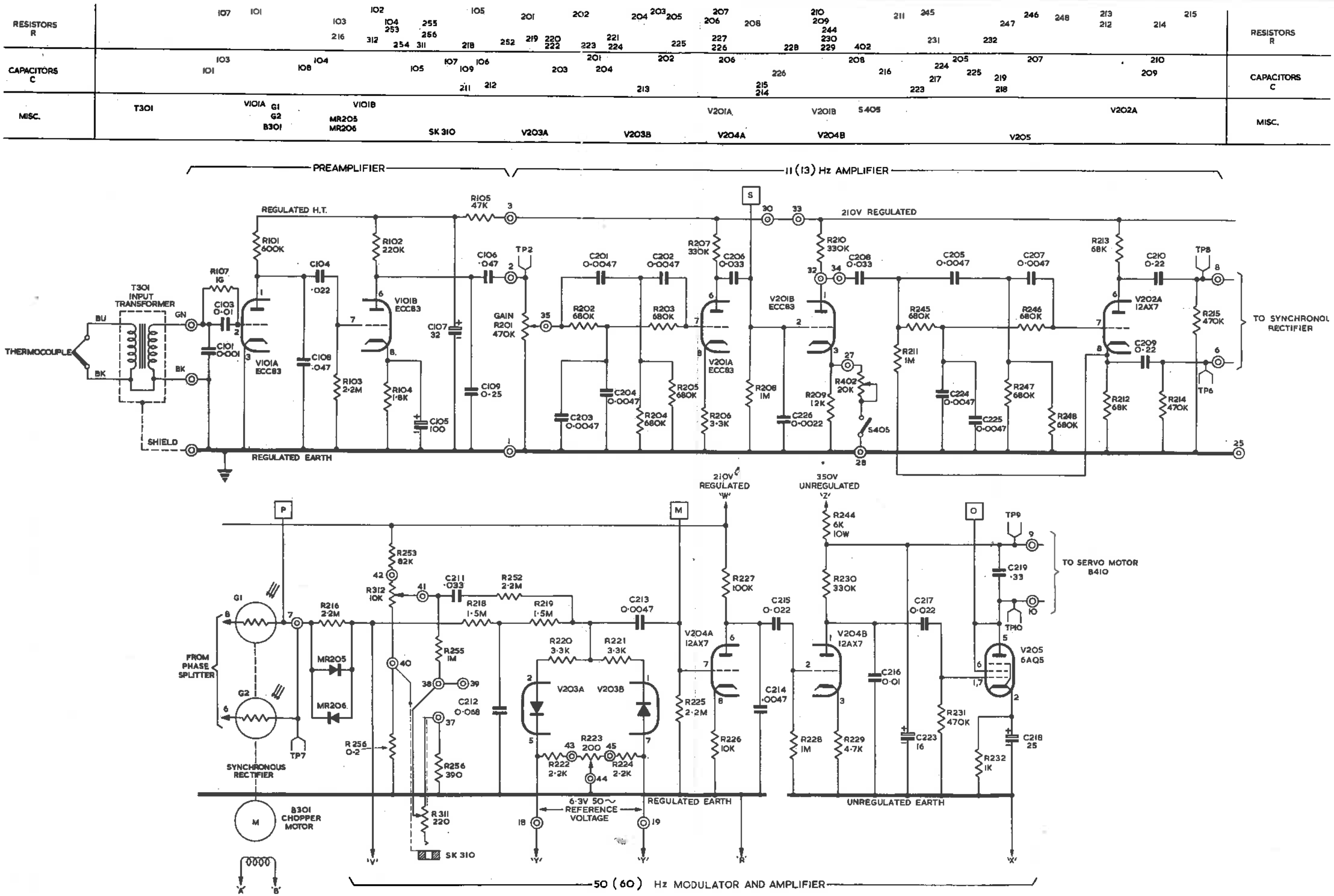


Figure 3.20A Amplifier Circuit

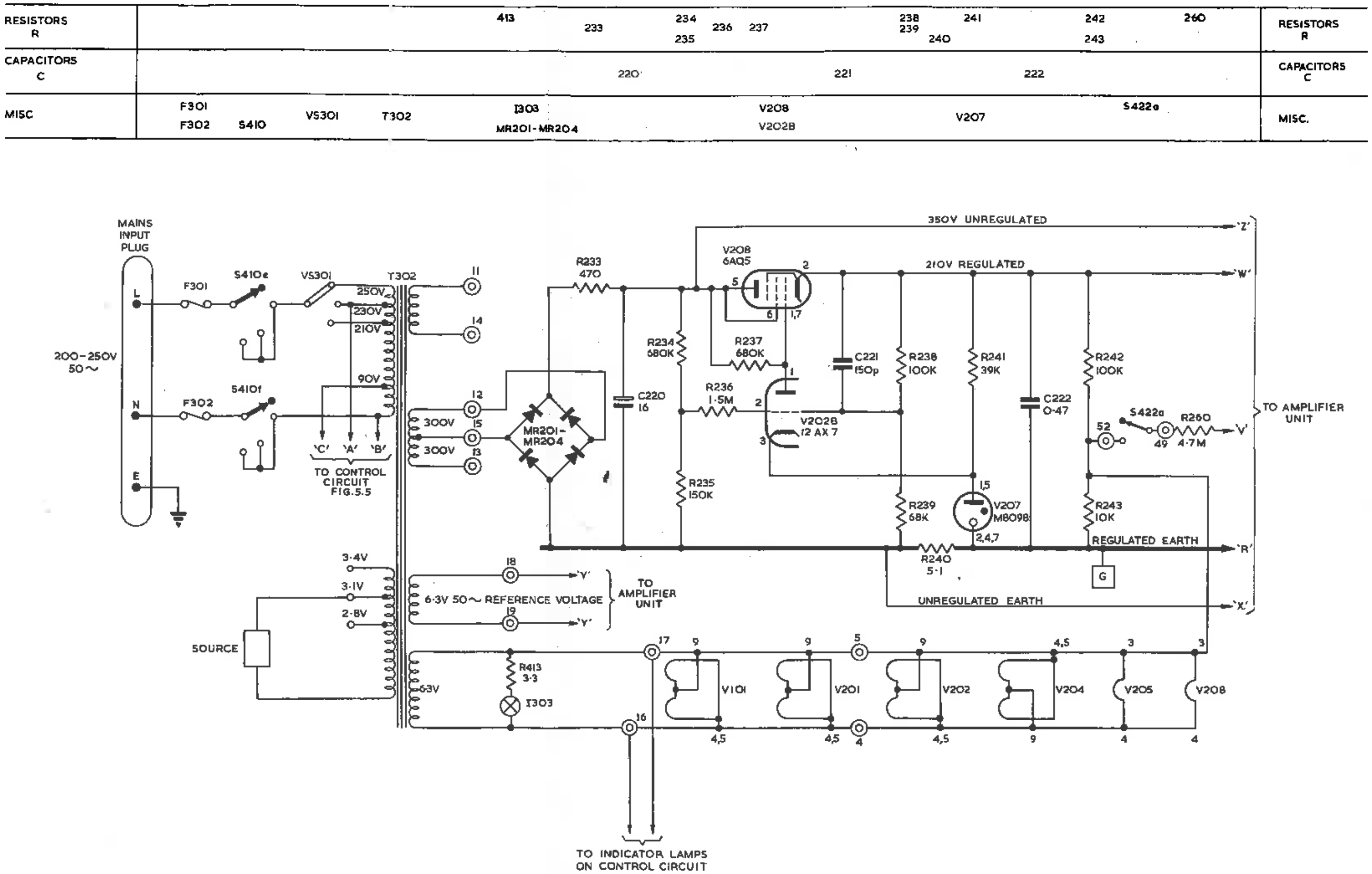


Figure 3.20B Power Supply Circuit

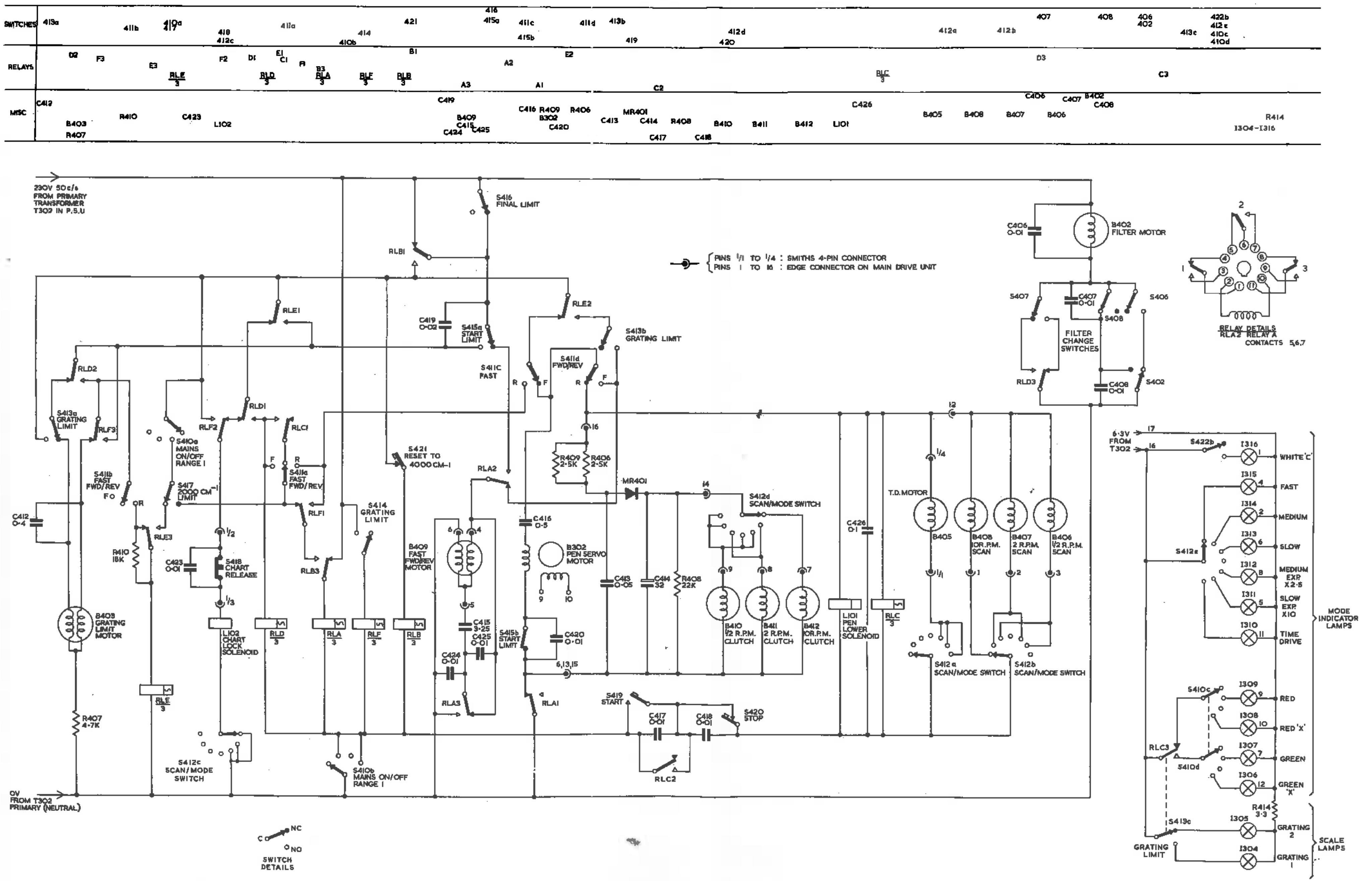


Figure 3.20C Control Circuit