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APPENDIX A

VOLTAGE DIVIDER AND RECTIFIER CIRCUIT

A signal directly proportional to the output voltage (see Fig. 3.1) is fed into the voltage divider shown in Fig. A1.

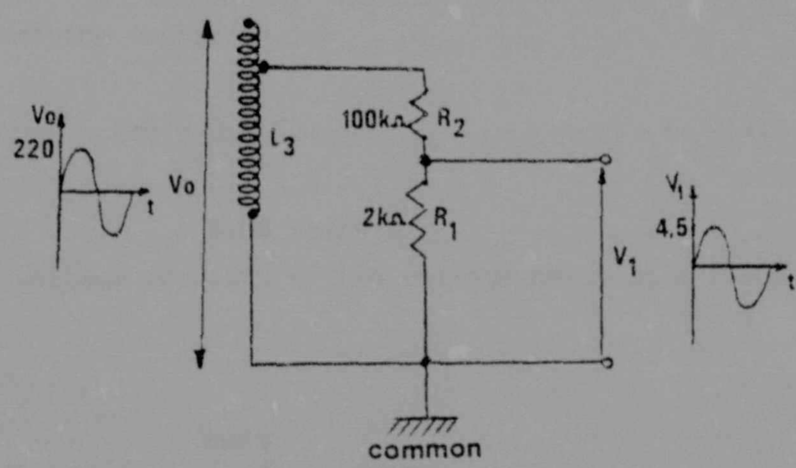

Figure A1 The Voltage divider

R_1 = 2K

R_2 = 100K

Note : All resistors in the circuit are 1/2 watt except when specified.

$$V_1 = \frac{R_1}{R_1 + R_2} V_0 \qquad \text{------------} \qquad (a1)$$

An output voltage of 220 volts RMS at 50 Hz gives a voltage V_1 = 4,5 Volts RMS. Although the output voltage varies as the input parameters to the C.V.T. change, this condition shall be carried through from APPENDIX A to APPENDIX F.

The signal voltage is then rectified using a full-wave bridge rectifier. Four diodes configured as a full-wave bridge rectifier may be used, otherwise an integrated full-wave precision rectifier provides excellent rectification. The former requires only diodes whilst the latter consists of two operational amplifiers with resistors (12,14).

Assuming a sinusoidal 4,5 volts rms ac voltage the dc voltage at the output of the rectifier is:

$$
\begin{aligned}
E_{dc} &= 0{,}9\ E_{rms} \qquad \text{------------(a2)} \\
&= 0{,}9 \times 4.5 \\
&= 4{,}05 \text{ volts dc}
\end{aligned}
$$

The dc voltage consists of two voltage peaks at a frequency of 100Hz.

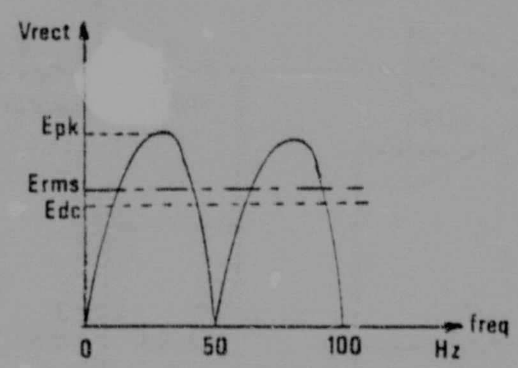

Figure A2 Output voltage waveshape of the full wave bridge rectifier

where

$$
\begin{aligned}
E\ peak &= 1{,}57\ E_{dc} \qquad \text{--------(a3)} \\
&= 1{,}57 \times 4{,}05 \\
&= 6{,}34 \text{ volts}
\end{aligned}
$$

APPENDIX B

FILTER AND INVERTER CIRCUIT

The dc voltage is filtered through a second order low-pass Butterworth filter with a cut-off frequency of less than 5Hz. The low cut-off frequency prevents unwanted ripple on the varying dc signal from passing into the integrator stage of the circuit.

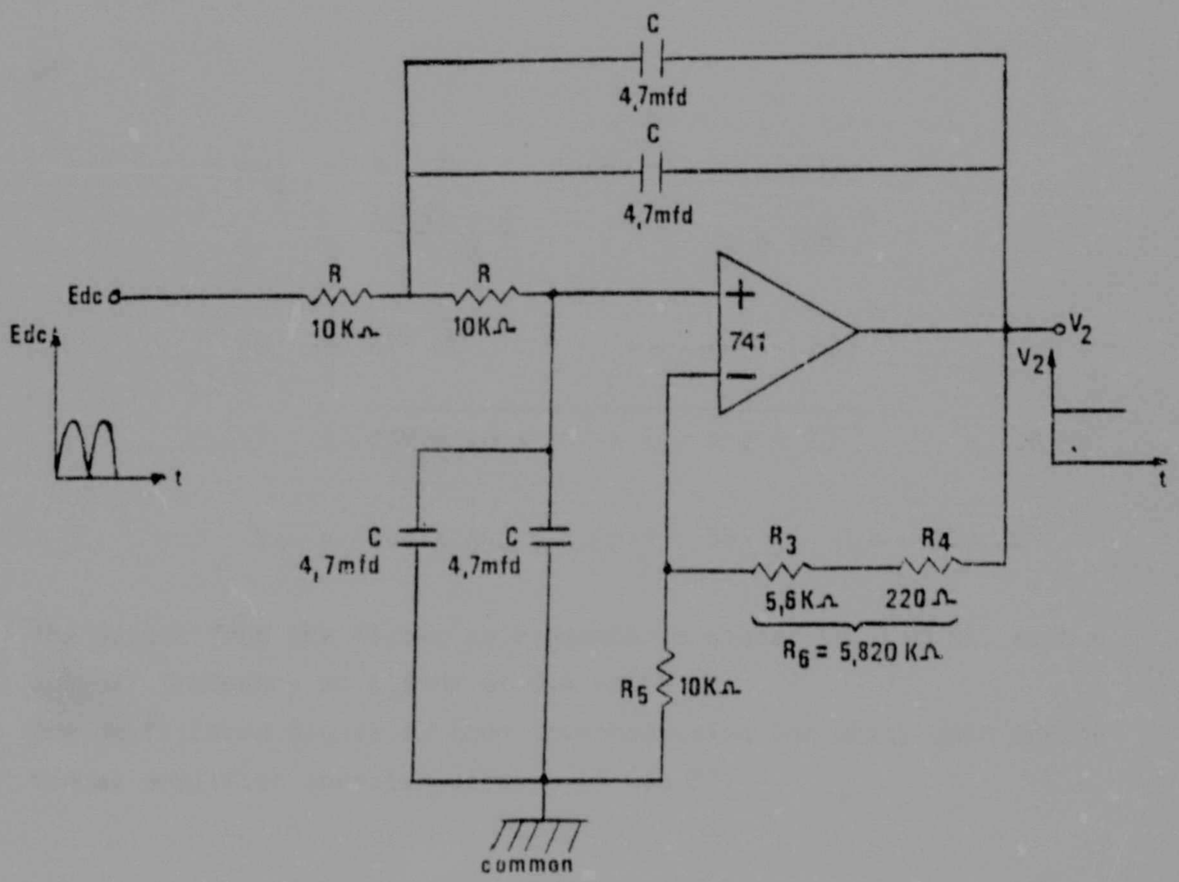

Figure B1 Second order low-pass Butterworth filter

The following equations are taken directly from Millman-Halkias (15) page 551.

Define Gain of the system of Fig. B1 as Av_2.

$$Av_2 = \frac{V_2}{Edc} \qquad \text{----------(b1)}$$

$$= \frac{R_6 + R_5}{R_5}$$

$$= \frac{5,820 + 10}{10}$$

$$= 1,582$$

OR

$$Av_2 = 3 - 2k \qquad \text{----------(b2)}$$

$$k = \frac{1,582 - 3}{-2} \qquad = 0,709$$

$$fo = \frac{1}{2\pi\ RC} \qquad \text{-------(b3)}$$

$$= \frac{1}{2\pi \times 10 \times 10^3 \times 4,7 \times 2 \times 10^{-6}} \qquad = 1,69\text{Hz}$$

$$V_2 = Edc \times Av_2 = 4,05 \times 1,582 = 6,4 \text{ volts dc}$$

The output from the filter is a smooth dc signal (V_2 Fig. B1) with a cut off frequency at 1,69Hz at 6,4 volts dc.

The dc filtered signal is then inverted using the unity gain operational amplifier inverter circuit of Fig. B2.

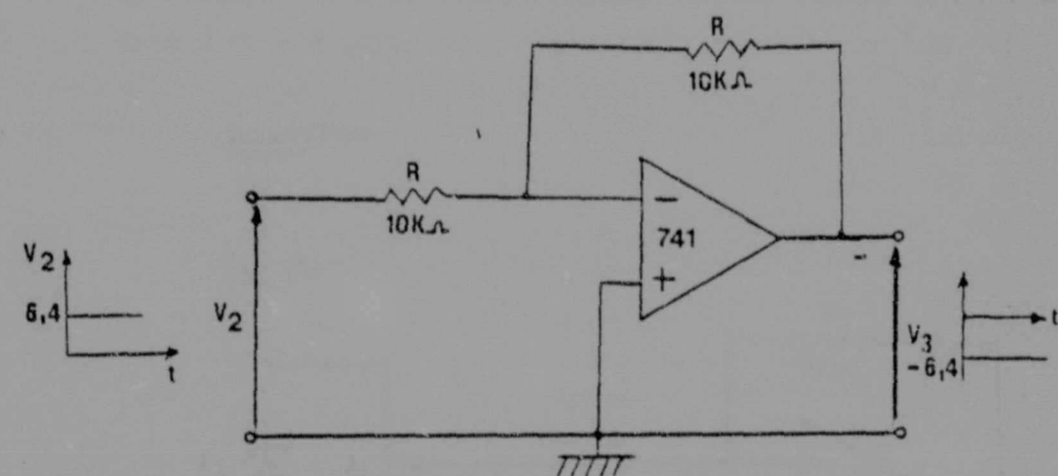

Figure B2 Unity gain inverter circuit

$$\frac{V_3}{V_2} = -\frac{R}{R} = -1 \qquad \text{---- (b4)}$$

$$V_3 = -V_2$$

$$V_3 = -6{,}4 \text{ volts dc}$$

APPENDIX C

REFERENCE VOLTAGE AND THE ADDER

The positive reference dc voltage is added to the negative varying dc voltage. The reference voltage may be varied to give any voltage from 0 to 6.8 volts dc. The circuit is shown in Fig. Cl.

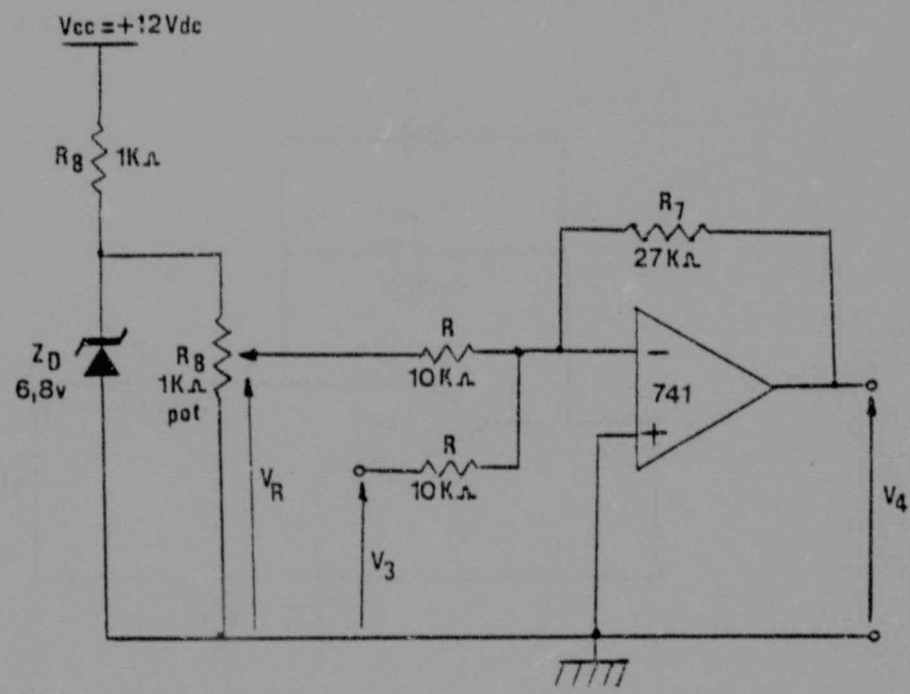

Figure Cl   Summing circuit showing the positive reference and negative varying dc signal

$$V_4 = -\frac{R_7}{R}(V_3 + V_R) \quad \text{-------------} \quad (c1)$$

For V_3 = 6,4 volts dc and V_R = 6,3 volts dc then from equation cl

$$V_4 = -\frac{27 \times 10^3}{10 \times 10^3}(-6{,}4 + 6{,}3) = 0{,}27 \text{ volts}$$

APPENDIX D

THE INTEGRATOR

An integrator is the next stage of the circuit which is followed by the voltage to current converter circuit and the current amplifying transistor configuration.

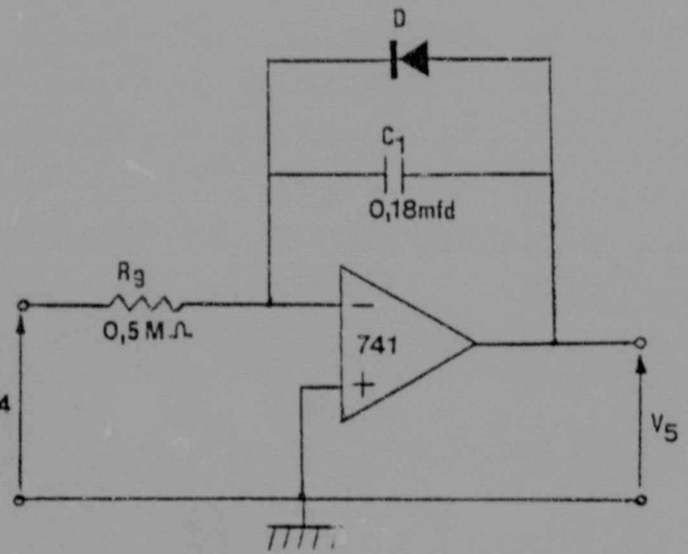

Figure D1 Integrator circuit

$$V_5 = -\frac{1}{RC}\int_0^t V_4 \, dt \qquad \text{----------(d1)}$$

Integrator gain is $\frac{1}{RC} = \frac{1}{0,5 \times 10^6 \times 0,18 \times 10^{-6}} = -11,11$ and the time constant is RC = 90 msec. The full swing of the ramp output is limited from 0 to 12 Vdc. The diode clamps the voltage at zero and does not allow for a negative swing. A long time constant is desirable as this allows the C.V.T. to start up under normal operating conditions before the control circuit is activated.

The function of the integrator of Fig. dl is to reduce the small error signal to zero. The voltage to current converter requires a positive input voltage to drive the transistor amplifier circuit. The varying voltage must be negative and its magnitude must be less than that of the reference voltage. The negative output voltage V_4 (dl) is inverted by the integrator to give a slowly rising positive voltage at the output of the integrator. The positive voltage then drives the converter circuit described in Appendix E.

APPENDIX E

THE VOLTAGE TO CURRENT CONVERTER CIRCUIT

The voltage V_5 supplies the voltage to the voltage to current converter given in Fig. E2. The basic operation of the voltage to current converter is described below. From Fig. E1 the load that the converter circuit sees is the control winding impedance in series with a low value resistance to ground. The voltage source V_5 has a high internal impedance. No current flows into the operational amplifi[illegible] terminal so there is no drop across resistance R_5 and the full voltage appears between the positive terminal and ground.

Therefore, the current $I_1 = \frac{V_5}{R_1}$ ----(e1)

Since no current flows into the operational amplifier, the current I_1, must be supplied by the feedback current I_L.

Therefore $I_L = I_1 = \frac{V_5}{R_1}$ ---------(e2)

and the source voltage has been converted into a load current (15).

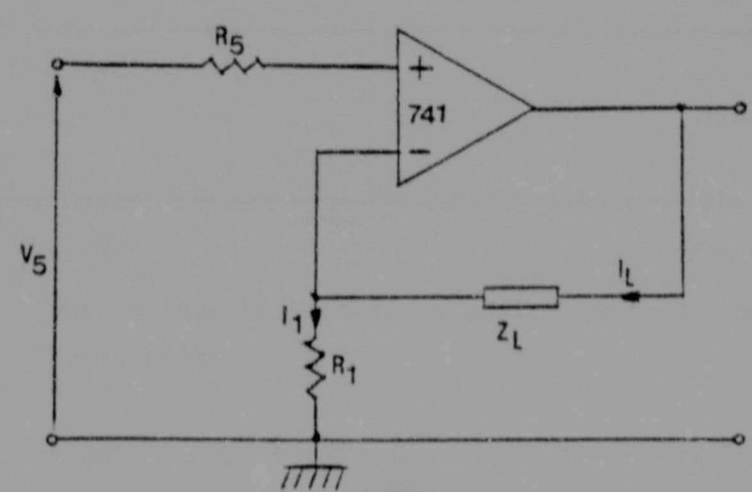

Figure E1 Basic voltage to current converter circuit

- V_5 = source voltage
- R_5 = source resistance
- R_1 = load resistance
- Z_L = load impedance
- $I_L = I_1$ = load current

The load that the actual control circuit sees is the coil impedance of winding L_8 in series with winding L_9 and the 1,6 Ω resistance to ground.

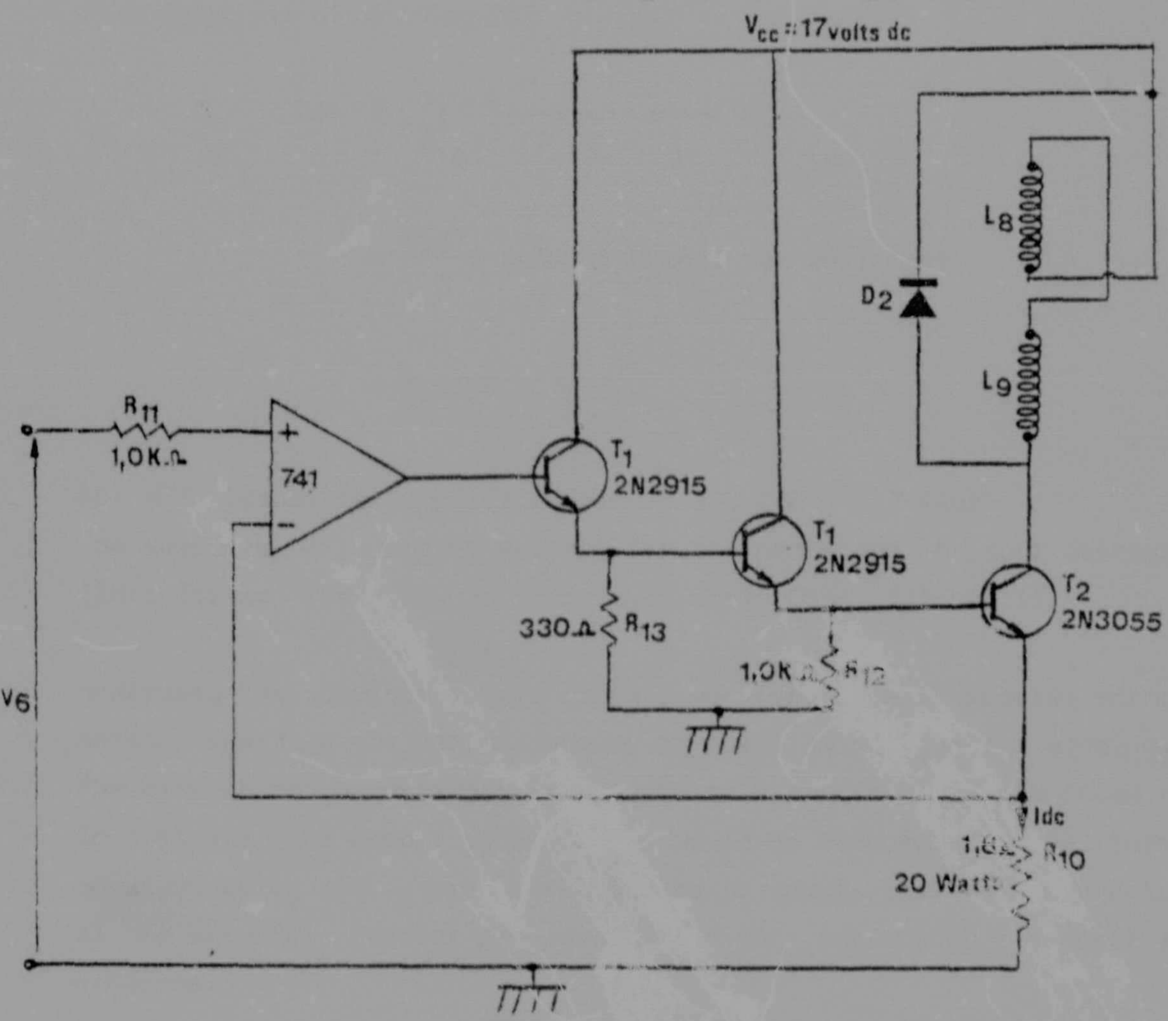

Figure E2 The voltage to current converter with current amplying transistors

A maximum of 3 amps dc is required to enable the control circuit to operate over the full range of frequencies. The current of equation e2 .

is therefore amplified using a Darlington transistor configuration which drives the power transistor. Although no ac from the fundamental exists across the coils L_8 and L_9, harmonics induced in these windings may cause damage to the converter circuit. The diode D_2 prevents negative voltage spikes from destroying the power transistor.

From equation e2 and Fig. E2

$$Idc = \frac{V_6}{R_{10}} \quad \text{---------}(e3)$$

$$= \frac{0,27}{1,6} \times \text{gain of transistor amplifier}$$

$$= 0,1688 \times g_t$$

For a dc transistor amplifier gain of 10, Idc = 1,7 Amps.
The measured dc injection current for the condition of input voltage 220 volts ac, frequency 50 Hz is 1,82 amps (Chap. 3, Table 1).

Analysing the complete C.V.T. circuit accurately, will provide information regarding the nominal number of turns on the control windings. The circuit can be designed to operate only within a pre-specified range. In this way, the copper requirements would be reduced. The 600 turns on windings L_8 and L_9 has been selected to ensure that the ampere-turns of the saturable reactor provides sufficient current to the control windings.

The complete circuit is shown overleaf in Fig. E3.

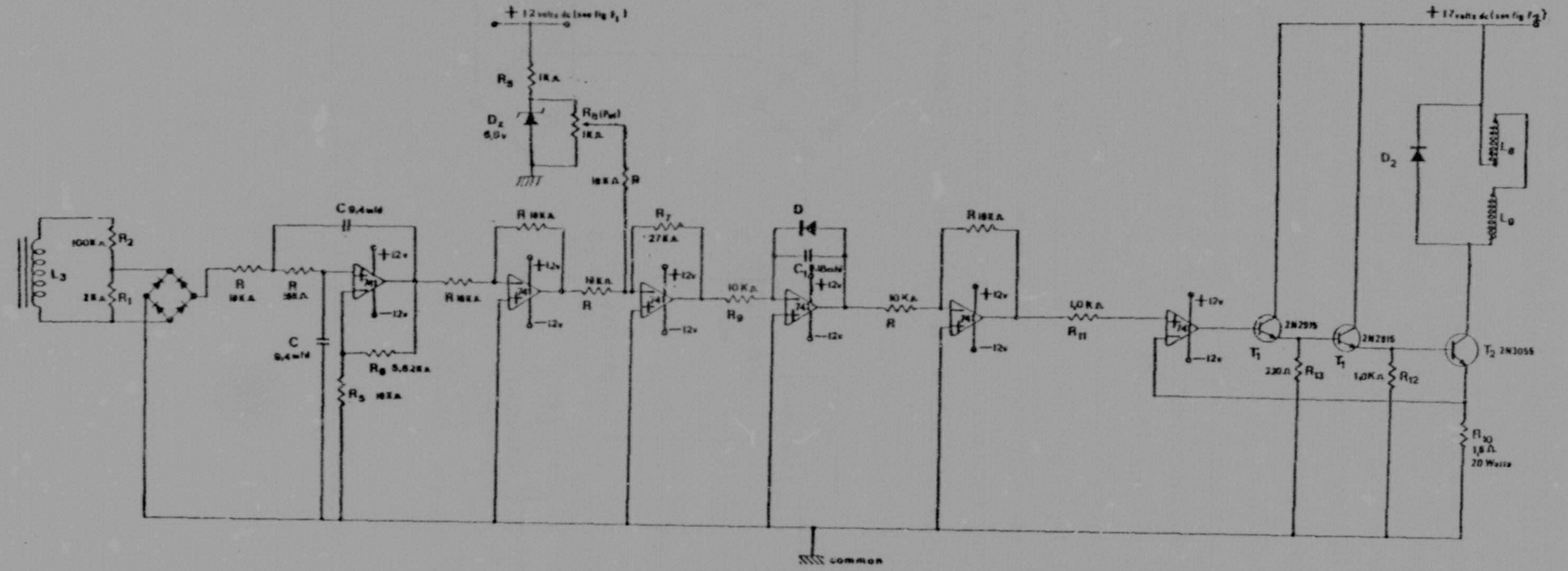

Figure E.3 The complete control circuit excluding power supply windings

APPENDIX F

THE REGULATED POWER SUPPLIES

A requirement for this design is that the device be independent of auxilliary power supplies. The circuit consists of 741 operational amplifiers which work off ± 12 Volts dc. Winding L_7 in Fig. 3.1 consists of three windings, two of which have an equal number of turns. With 0,85 volts per turn on the secondary winding (7) and 20 turns on each coil 0,85 x 20 = 17 volts ac is produced across each coil. The ac voltages are each rectified through a full wave bridge rectifier as shown in Fig. F1. The rectified voltages are regulated using positive and negative sold state voltage regulators to provide +12 volts dc and -12 volts dc respectively. The negative rail of the positive regulator and the positive rail of the negative regulator are connected as a neutral or common point. The volts per turn vary slightly when the C.V.T.'s input parameters are changed but the regulators hold the power supply voltages constant under all conditions.

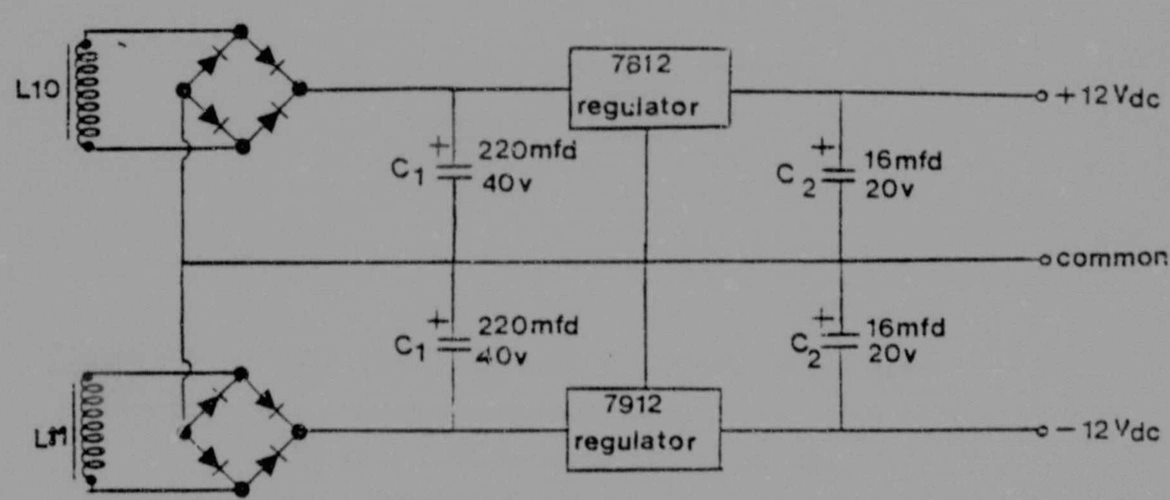

Figure F1 ± 12 Volt dc power supply for control circuit

The third winding L_{12} supplies current to the transistor amplifier stage and the control windings. The position of this winding in relation to C-core C_2 and the split C-core C_3 and C_3' is shown in Fig. 3.1.

The induced ac voltage across the winding L_{12} is full-wave rectified and filtered via a large dc capacitor as shown in Fig. F2. The winding has 20 turns and gives 20 x 0,85 = 17 volts ac.

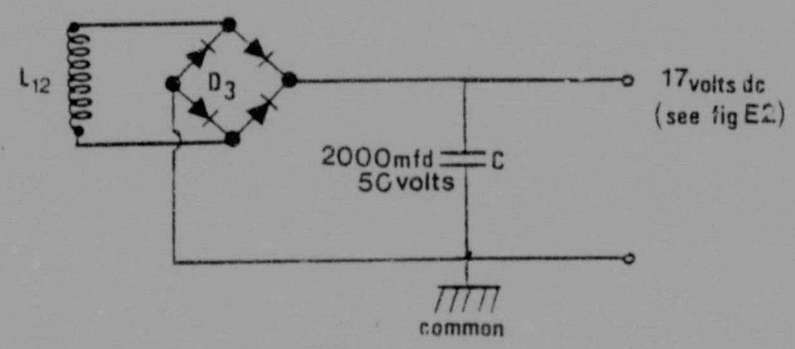

Figure F2 Power supply to supply current to the load
- L_{12} is the supply winding
- D_3 is a full-wave rectifier bridge
- C_2 = 20000 mFd, 50 V