2. EXPERIMENTAL TECHNIQUE

2.1 Principle of Operation of a Single Channel Recorder.

The recorder can be devided into two main parts namely; a display unit and an electronic control unit. The principle of operation is roughly the same as the operation of the display unit of a navigation aid radar except that the cathode ray screen is replaced by a metal coated paper and the angular sweep is represented by a linear paper displacement. Fig. 1 and Fig. 5b show general layout of the display unit. Details of its construction and mechanical principle are given in section 2.3-1

The paper is fed along the paper carrier plate by the paper driving drum. The stylus track assembly is mounted above the paper carrier plate at one end. This stylus track assembly serves as a guide rail for a fast moving stylus belt, driven by a constant speed motor, and also as a trolley for conveying marking pulse to a moving stylus. The stylus rectilinear motion is kept constant by a constant speed motor (approximately 600 cm/sec in this experiment). At the moment, the marking end of the stylus touches lower recording area of the paper (the line y = 0), a light triggering unit is interupted which in turn emits a pulse to the electronic control unit which then actuates a ramp-function generator. From the circuit arrangement as shown in Fig. 2a and Fig. 2b, the distance from the stylus marking end to the line, y = 0, varies directly as the voltage level from the output of the ramp-function generator; therefore the travelling distance of the stylus (the y-amplitude) varies directly as the sweep voltage. In order to record an input signal, the signal after being amplified or attenuated to the proper level, is compared with a signal from the ramp-function generator by a sensitive comparator. When the amplitudes of both signals are equal, the voltage at the comparator output terminal shifts to another voltage level. This output step voltage is differentiated and fed to a pulse generator. The pulse generator generates a single pulse (approximately 200 volts by 200 μ sec) only when the comparator output voltage jump to another voltage level. The output pulse is fed into the stylus trolley and the paper carrier plate. During the transition period of the comparator, the output pulse is transmitted to the stylus trolley, stulus body and marks the paper. Therefore, the distance between recorded point and the line y = 0 is always kept proportional to an input voltage level. The relation between the recorded point and the input voltage level is shown below:-

At the starting position $y = 0,\quad t = 0,\quad v_{ramp} = 0$

At the maximum sweep position $y = Y,\quad t = T,\quad v_{ramp} = V$

where y = swept distance of the stylus from line $y = 0$ to line y

t = travelling time of the stylus from line $y = 0$ to line y

v_{ramp} = output voltage from ramp-function generator

v_{in} = input signal to be recorded

since, $v_{ramp} = \frac{V}{T} t$ and $y = \frac{Y}{T} t$,

therefore $v_{ramp} = \frac{V}{Y} y$.

When both signals are equal

$$v_{ramp} = v_{in} ,$$

and $y = y_t$ = swept distance between line $y = 0$ to the position of the stylus when the marking pulse is emitted.

$$v_{ramp} = v_{in} = \frac{V}{Y} y_t$$

or $$v_{in} = K y_t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

2.2 Principle of Operation of a Multi-channel Recorder

Application of the afore mentioned recording method to a vacuum-tube characteristics plotter is made by using electronic selector switches and an electronic digital pulse counter circuit. The functional diagram is shown in Fig. 3a and Fig. 3b. Plate current of the vacuum tube is detected by inserting a dropping resistor between the cathode and the negative return of a power supply whose output voltage varies directly as the chart displacement. This voltage drop is recorded by a basic recorder circuit described in the operation of a single channel recorder. The electronic switches and digital counter are arranged so that at the beginning of the sweep (stylus position is at y = 0), reset pulse from a light triggering circuit sets the grid voltage to the minumum pre-set negative value (-1 volt). At the same time, the output voltage from the ramp-function generator starts its sweeping. When voltage drop across the cathode resistor and the sweep voltage are equal the first marking pulse is transmitted to mark the paper at position (1) Fig. 3a and Fig. 3b). The digital counter, at the same time, also receives the first pulse from the pulse generator. It then changes its state so that the electronic switch unit switches to the next pre-set grid voltage (-2 volt) which in turn, decreasing the plate current to the next lower level. Output voltage from the ramp-function generator resumes its sweeping and as soon as the ramp-voltage level and the ralative voltage drop across Rk are again equal, the second pulse is generated. The switching operation is repeated until the corresponding plate current of the grid voltage of -3 volt and -4 volt has been plotted. This switching operation will be restarted at the beginning of the next stylus sweep.

During this repetition plotting of the plate current, the paper is also travelling in the x-direction by means of the friction rubber roller and chart driving drum. Opposite to the driving end of the drum a control potentiometer is coupled directly to the drum axis. A linear chart travelling distance is then converted into a relative change in resistance which is used to control plate supply voltage so that it is kept proportional to the paper travelling distance.

2.3 Operating Description of Individual Unit

The basic block diagram shown in Fig. 2a and Fig. 3a are not clear enough to described details function of the circuit. Block dbagrams in Fig. 4a shows actual circuit function and expecting waveform at various points. The general view of each circuit board is shown in Fig. 6a to Fig. 6h.

2.3-1 Display Unit Assembly (Fig. 4 block No. 15)

A general view of the display unit assembly is shown in Fig. 5a to Fig. 5i and the detail drawings for mechanical construction are shown in Fig. 21a to Fig. 21d. The dimensions of the display unit are 44 x 32 x 13 cm. It consists of three sub-units:-

(1) The paper driving unit (Fig. 5b and Fig. 5c)

The paper spool (1) is held in the paper compartment (2). The paper travels on top of the paper carrier plate, through a slot (3) formed between the carrier plate and the stylus track unit mounted on top of the plate. A guide block (4) is provided at each side of the platen to prevent transverse movement of the paper. The paper is driven as it travels between the driving drum (5) and the pressure rollers (6). The pressure rollers are spring loaded against the drum to ensure non slip. The angular displacement of the drum is then converted into a linear displacement of the paper.

In order to detect linear chart displacement, a potentiometer (7) was mounted on the opposite side of the paper driving motor (8) and coupled directly to the shaft of the paper driving drum. The paper driving drum is made from a 5.85 cm diameter (D = 18.20 cm) P.V.C. tube. The construction of the potentiometer is such that the effective angular displacement is less than 360 degree. Therefore, the effective chart length is shortened down to 16.25 cm.

(2) Stylus driving unit. (Fig. 5c)

The stylus driving unit is mounted above the paper carrier plate near the paper compartment. It consists of:

a) A belt driving mechanism. In this experiment a two pole , shaded pole motor was used instead of a synchronous motor because of inavailability of the latter. A driving pulley (10) of 4.5 cm. diameter was mounted directly on the motor extended shaft. An idling pulley (11) was put in a brass sleeve (12) and then screwed on top of the paper carrier plate. For the sake of simplicity, a conventional ball bearing of 4.6 cm. outside diameter and 4.2 cm. inside diameter was used as the idling pulley.

b) A stylus carriage. Between the driving and idling pulleys, a stylus carriage was mounted above the paper carrier plate. It consists of:

b1) A stylus belt (14). A flat belt driven by the pulleys was used for transporting the stylus. In order to keep the belt on the flat pulleys, two plexiglass guide blocks (13) with grooves were provided between the pulleys. These guide blocks also help reducing transvese vibration of the belt.

b2) A stylus trolley (15). The output signal is conveyed to the moving stylus (20) by means of a stylus trolley installed on top of one of the guide block. It was made from a brass sheet of 0.3 mm. thickness.

b3) A stylus guide plate. This plate was installed to reduce the effect of belt transverse vibration to a minimum. The stylus body was arranged in such a way that during sweep period the stylus marking arm was kept touching the straight edge of the guiding plate installed beneath the inner guide block. This plate was also made from a 0.3 mm. thick brass sheet.

(3) Light triggering unit (Fig. 5f and Fig. 5g)

This unit consists of a light source (17) and a photo-transistor (18) mounted in light shield tubes to minimize the effect of stray light. It is installed in such a way that when the marking arm of the stylus touches the line y = 0, a band of aluminium reflector (19) attached to the belt moves into the incident beam from the light source. Consequently, the reflector reflects the beam of light to the photo-transistor. It is essential that the axis of the light source and the light beam has been aligned so that the photo-transistor recieves maximum reflection intensity.

2.3-2 Light Triggering Unit (Fig. 4 block No. 15) and One Shot Multivibrator (Fig. 4 block No. 2)

The light triggering circuit serves as a sensing device for the starting point of the stylus sweep (marking end of the stylus is just above line y = 0). The circuit employs a photo-transistor operating near cut-off at dark.[6] The transistor was a general purpose type No. OC 71, but the paint above its base region was removed so that it can be used as a photo-transistor. The transistor is brought into conduction region when the reflector on the belt is passing between the light source and the transistor. The collector voltage rise, from -14 volts to -3 volts, is used for triggering a mono-stable circuit.[4] The transition period of the monostable must be a little longer than the stylus sweeping time which is 26.9 ms. During the transition period, voltage output of the ramp-fuction generator (block 3) is in the state of rising. Schematic diagram and waveforms of which are shown in Fig. 6 and Fig. 7.

2.3-3 Ramp-function generator (Fig. 4 block 3 and Fig. 8)

The ramp-function generator circuitry is basically a constant current source operating in conjunction with a switching transistor and a charging capacitor. Voltage at the base of transistor TR4 is kept constant by a zener diode (Z_1). Thus the emitter voltage is also kept constant as well as the collector current. The charging capacitor, connected between the collector and 0 volt of the power supply, is periodically clamped to ground via the collector of the switching transistor TR5 which is controlled by a positive going pulse from the preceeding stage, a one shot multivibrator.

2.4-4 Buffer Amplifier (Fig. 4 block 4 and Fig. 9)

The purpose of the amplifier is to isolate the loading effect of the comparator from the generator. A complementary emitter follower[3] connection is used because of its high isolation and very small offset voltage. The circuit in Fig. 9a was constructed and tested. Voltage gain and input impedance were measured to be 0.975 and 4.34 meg-ohms, respectively.

2.3-5 Voltage Comparator (Fig. 4 block 5 and Fig. 9)

The comparator circuitry operates as follows, the sweep voltage from the buffer amplifier and the input signal (voltage drop across cathode resistor) to be compared are fed into a resistive difference network. Output from the difference network is clamped by two diodes and amplified by an integrated circuit type No. SL 701 B produced by Semiconductors Limited, schematic diagram of which is shown in Fig. 9b. The high gain DC amplifier will provide a sharp output voltage swing from +5 volt to 0 volt. At the moment, the voltage level from the ramp-function generator is greater than the voltage level from the cathode dropping resistor.

2.3-6 Schmitt Trigger (Fig. 4 block 6 and Fig. 10)

Schmitt trigger circuit[7] is used to minimize interference effect of the pulsing circuit from the preceeding comparator amplifier and provide a negative going pulse to trig the one shot multivibrator (Fig. 4 block 7). This circuit also provides a positive going pulse to trig the digital counter (Fig. 3 block 12). The output voltage jumped measured from the collectors of TR8 and TR9 were +10 volt to +1.5 volt.

2.3-7 One shot multivibrator (Fig. 4 block 7 and Fig. 11)

The purpose of the one shot multivibrator(4) is to adjust the marking pulse width which has to be about 200 μ sec in order to obtain a 1.5 mm trace width.* According to the measurement, output voltage from the collector of TR11 was a negative going pulse of 0 to -10 volt amplitude and 200 μ sec pulse width.

2.3-8 Pulse Output Amplifier (Fig. 4 block 7 and Fig. 11)

A circuit of the direct couple pulse amplifier(4) was employed here. A low plate resistance dual triode 12AV7 was used in order to obtain low output impedance of the amplifier. Plate resistance R1 was so chosen that the plate voltage was about 40 volts at 0 volt input voltage level. Since it is coupled directly to the next stage the cathode voltage (pin 8) was about 40 volts also. When negative going marking pulse was fed to the grid of V_{1a}, it was brought into cut-off region, plate voltage rise, resulting in jumping of the output voltage at the cathode of V_{1b}.

Tested output pulse amplitude was +200 volts and 200 μ sec pulse width. A push button switch S4 was provided for recording a continuous marked line indicating location of x-scale as required.

2.3-9 Power Supply (Fig. 4 block P4 and Fig. 13)

This unit supply the DC voltage to the pulse output amplifier as mentioned in section 2.3-8. It consists of a full-wave rectifier transformer,

* See appendix A-1

primary winding 0-110, 220 volt AC, secondary winding 250-0-250 volts, a pair of silicon rectifiers and an R-C filter network. The operating output voltage measured was 300 volts.

2.3-10 Variable Voltage Power Supply (Fig. 4 block 9 and Fig. 14)

In this particular type of recorder, the x- axis is a plate voltage and the y-axis is a plate current. In order to control plate voltage, a control potentiometer is coupled directly to the chart driving drum shaft. The original electronic circuit (Fig. 14) is an adjustable regulated power supply published in the Radio and Electronic Magazine.

Operation of the Adjustable Regulated Power Supply

The output voltage is set by potentiometer R1 which is one of the voltage divider resistors, connected between an output terminal and a -300 volts constant voltage source. Since the cathode of the 6AU6 is also kept constant by the voltage supplied from the -300 volts constant voltage source and the grid to cathode voltage is nearly constant. Therefore the output voltage multiplied by the ratio ot the voltage divider is nearly constant. Consequently the output voltage varies as the position of the potentiometer (see appendix A-2) . The 6AQ5 cathode follower amplifier stage serves as a variable series resistor between power source and load. This vacuum-tube series resistor automatically changes its resistance to compensate for the variation of the voltage difference between the grid and the cathode of the 6AU6 tube. The voltage regulator circuit was constructed and tested. It was found that tracking linearity between the angular displacement of the voltage control potentiometer and the output voltage was poor. Circuit analysis revealed that relation between the output voltage and the resistance is non linear, as shown in the Appendix A-2.

Modification of the Adjustable Regulated Power Supply (Fig. 15)

An interstage difference amplifier between the output of the voltage divider network and the grid of the 6AU6 tube was added. Operating condition of the difference amplifier was arranged in such a way that at the minimum setting position of the control potentiometer the grid voltage of V_{7a}, Eg_2, is theoretically equal to the grid voltage of V_{7b}, Eg_1, and the output voltage is zero. If the initial operating point is set correctly, any variation of Eg_2 resulting from the control potentiometer R_1 will reflect variation of the same magnitude and polarity to Eg_1, thus Eg_2 equals to Eg_1 at any output voltage level.

Therefore, the output voltage multiplied by the ratio of the voltage divider is kept equal to the voltage from centre-leg of the control potentiometer. Since the voltage supplied to the potentiometer is regulated at -300 volts, so the voltage from centre-leg of the potentiometer is proportional to its angular displacement. Consequently, the output voltage is varying directly to the angular displacement of the potentionmeter or the angular displacement of the paper driving drum. The voltage-control circuit is also response to any variation of load or line.

The modified circuit was constructed and tested. It was found that Eg_1 and Eg_2 were slightly different, about 2 volts at the minimum output voltage and decreased as the output voltage was increased. At the maximum output voltage $Eg_1 - Eg_2 = 0.6$ volt. Linearity of the power supply as shown in the Appendix A-4 was strongly affected by this non-constant grid voltage difference.

To improve linearity, a 2.7 volt zener diode was connected in series between the cathode of V_2 and the cathode of V_1 as shown in Fig. 15. Voltage drop across the zener diode will raise the grid voltage of V_2 up. Test result is shown in section 2.4-2.

Final setting of the output voltage range was between 20 and 276 volts which gave the best graphical proportion of the plate voltage and plate current scale.

2.3-11 Digital Pulse Counter (Fig. 4 block 12 and Fig. 17)

In order to operate as a multi-channel recorder, an electronic switch circuit for switching the input signals from one parameter to another, is required. Switching over is made just after the previous input has already been recorded. The electronic circuitry has four different states of collector voltage which is used to control the 4 positions code operate electronic selector switch.(4) Sequence of operation of the binary circuit is tabulated in Fig. 17b.

2.3-12 Electronic Selector Switch and Grid Voltage Supply (Fig. 4 block 11 and block 10 and Fig. 18)

The output leads from collectors of the binary circuits are connected to a code operated multi-position switch as shown in Fig. 18. Suppose now that the binaries are reset by a light triggering monostable. The binary registered state as shown in the tabulation of Fig. 17b are

	TR12 off	TR13 on,	TR15 off	TR14 on,
which cause	TR18 and	TR16 to turn on,		
and	TR19 and	TR17 to turn off.		

To ensure that TR19 and TR17 are completely brought into cut-off region, the emitters of TR12 to TR25 are connected to +2.7 volt instead of connected to 0 volt of the supply voltage. In this case leads number 0, 1 and 2 are shorted to ground through one or more diodes, so that voltage at each of these leads is zero. On the other hand, lead No. 3 is not shorted, so the output voltage to the grid of the tube being tested is determined by the calibrated potentiometer (1) only. The binary circuit and multi-position switch are arranged in such a way that after the first marking pulse has been triggered the binary circuit shifts its registered instruction inorder to short circuit leads No. 0, 1, and 3 to ground. So that the grid voltage is determined by the calibrated potentiometer 2. The above operation is repeated until the fourth plate characteristic curve of the tube being tested has been recorded, then a pulse emitted from the light triggering monostable circuit at the beginning of each sweep, resets the selector switch to the first pre-set grid voltage level again. The plotting operation is continued from a minimum plate voltage of 20 volts to a maximum voltage of 276 volt.

2.3-13 Tube Tester Panel (Fig. 4 block 14 and Fig. 19) 006956

In order to record characteristics of different type of vacuum-tube, various types of valve-socket were mounted on an aluminium plate. Each of the socket pin was connected in parallel to the same socket pin number of the other sockets and then connected to the test plugs as shown in Fig. 19. Plate current of the tube being tested was detected by a selectable dropping resistor. The resistors used were the 10% tolerance type but trimmed by shunt resistors of a high resistance. The maximum voltage drop for full scale of the recorder is 2.5 volt. Grid voltage supply is fed directly between the grid terminal and the output terminal of the buffer amplifier, the output voltage of which is theoretically equal to the cathode voltage.

2.3-14 Buffer Amplifier (Fig. 4 block 13 and Fig. 20)

This unit consists of two separated buffer amplifier both input terminals were connected in parallel and fed by the voltage drop across current sensing resistor. Otuput terminal of the TR22 single stage emitter follower amplifier was used as a positive return of the isolating grid voltage supply unit. This buffer stage was found necessary after a test which had been carried out with direct connection of the positive return of the isolating grid voltage supply unit to the cathode of the tested tube. It is seen from the schematic diagram of Fig. 4 that the positive return of the grid voltage supply unit is connected directly to the high-impedance input terminal of the comparator amplifier. Therefore, 50 cps hum can be induced into comparator amplifier resulting in a blured trace.

Transistors TR20 and TR22 were connected as a phase reversing amplifier at unity gain. Potentiometer R_1 and R_2 were provided for adjusting output voltage level and stage gain as required. As noted earlier in the operating description of a multi-channel recorder, sequence of plate current plotting must be started from the higher one then switched over to the next lower one. If the voltage drop across the cathode resistor is fed directly to the comparator, the highest current would be plotted at the latest. So even switching over to the next lower value of plate current had been taken-place, comparison of the next lower plate current could not be accomplished because the corresponding point had been passed already. By means of the phase inverter, voltage drop across the cathode resistor is reversed and compared to the sweep voltage resulting in reversing of the plotting sequence and enable plotting of the next lower plate current.

2.4 Test Procedure

After the individual circuits had been constructed and separately tested some of them were combined and again tested. The purpose of which is to determine overall error resulting from such circuit-combination which should be known prior to the testing of the complete circuit.

2.4-1 Y-axis linearity Test

The test was set up in such a way that plate current of the tube being tested could be controlled manually by potentiometer R_1 (Fig. 15) of the plate supply unit while grid voltage was kept constant. By means of a milliamp meter connected in series to the plate circuit and the manual control potentiometer (1), an equal amplitude step current curve could be automatically plotted on the paper. It is obvious that the error resulting from the recorded curve is the overall error involving stylus speed variation, triggering point stability, linearity and DC voltage level of the ramp-function generator, comparator accuracy. The test results are shown in Fig. R1 and R3.

Fig. R2 and R4 were the results from the same test set up, but plate voltage was fixed and the pre-set grid voltage was changed by means of a manual triggering switch (Fig. 17). By this method transition period from one plate current level to another one is shortened.

2.4-2 Variable Voltage Power Supply Linearity

The test was divided into three individual tests:-

(a) The relation between voltage control potentiometer R_1 and no load output voltage. The test was performed by measuring output voltage at equal angular displacement of the control potentiometer as shown in Fig. R5a and R5b.

(b) Relation between chart driven mechanism and output voltage. Output voltage from the plate power supply unit was attenuated by a resistor to the ratio of 100:1 and fed directly to the input terminal of the voltage comparator unit, in order that relationship between output voltage and chart displacement could be automatically recorded as shown in Fig. R6a and R6b. The plot should be a straight line with constant slope. Deviation from the straight line is due to errors from voltage control circuit and or nonlinearity of the chart take up mechanism including the voltage comparator circuit. This error is also an overall error.

(c) Test of plate voltage scale, in order that the printed x-scale on the paper can be employed as a plate voltage scale, the operating output voltage range was finally set between 20 and 276 volts. Fig. R7 and Fig.R8 show relationship between output voltage and the corresponding plate voltage scale. The test also shows the effect of loading by a 10 k-ohm resistor on the output voltage.

2.4-3 Buffer Amplifier

Input and output voltage tracking of the two buffer amplifiers were checked. During the test, the input terminals were separated and connected to the different adjustable voltage source. Input voltages and their corresponding output voltage were then measured as the tabulation shown in Fig. R9a.

2.4-4 Final Test and Wave-forms

Various types of vacuum triode were tested. The tube being tested was first inserted into its appropriate socket on the test panel, the test plugs which connected from the tube sockets were then connected to the corresponding power supply sockets.

Grid voltage parameters were set by the calibrated grid voltage potentiometer. Actual grid voltage levels can be checked by connecting the DC voltmeter between grid and cathode terminals. By means of the push button switch provided, any pre-set grid voltage could be switched to the grid of the tube.

The plate voltage control potentiometer R_1 was set at the lowest position (output Voltage = 20 volts) by rotating the paper driving drum in the forward direction. The chart paper was then positioned so that the stylus was on one of the y-scale line in order that the y-scale line could be used as a plate voltage scale (see Appendix A-5).

After the above setting up had been made, the plate characteristics were plotted as shown in Fig. R11 to Fig. R24.

Under normal operating condition of the recorder some of the circuits wave-forms were also checked as shown in Fig. R25 to R33.