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70 MeV Injector

Auto Tuning System Handbook

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JUNE 1976

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Internal Report

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June 1976

70 MeV INJECTOR - AUTO TUNING SYSTEM HANDBOOK

Introduction

This handbook describes the Auto Tuning System for the 70 MeV Injector.
It is in 3 sections.

Section 1. Describes the external features of the system and their location as seen by the operator.

Section 2. Describes the operating procedure.

Section 3. Describes the principles of operation and gives design details useful in servicing of modules.

CONTENTS

Section 1 - DESCRIPTION AND LOCATION

The purpose of the Auto Tuning System is to maintain the 'tune' of the four tanks and debuncher to within a few Hz, stabilizing against changes of temperature and other physical factors affecting the resonant frequency of the tanks. Fig 1 is a comprehensive block schematic.

The equipment for tanks 1, 2 and 3 are housed separately in racks in the trench under the accelerator, that for tank 3 also containing the monitoring system electronics (Fig 2). The system for tank 4 and the debuncher share a rack also in the trench. All racks are clearly labelled.

Operation of the system may be performed by local control, or remotely in the ICC via CAMAC. It is better to carry out critical setting up locally as more status information is available, including a monitoring unit consisting of analogue indication of the tuner head motor velocity and direction plus several other parameters.

Description of Local Control Functions and Status Indication

1. Power Supply Crate (Fig 3)

The red 'mains on' lamp indicates that ac mains is switched on to the unit and that the mains fuse is intact.

The 'supplies on' lamp lights when <u>all</u> the low voltage supplies and their respective fuses are healthy. NB Due to the wiring procedure employed to avoid earth loops, the 'supplies on' lamp will not light if the servomotor driver module is removed. See also System Healthy Indication.

2. Control Module (Figs 4, 7)

Status Indication

a. System Healthy (green). Indicates that all low voltage supplies are healthy and that RF is present in the tank <u>when system is in auto mode</u>. In the manual mode, providing low voltage supplies are healthy, the lamp will light whether RF is present or not.

The Servomotor is clamped if the system is not in the 'healthy' condition.

b. RF on (yellow). Lights when an RF field is present in the tank. The signal is derived from the Field Shape Monitors.

c. Local (white). Indicates local control as selected by mode buttons on front panel.

d. Camac (yellow). Indicates Camac control as selected by mode buttons on front panel.

e. Auto (white). Indicates auto mode selected either by <u>local</u> auto/manual buttons or via <u>Camac</u>.

f. Manual (yellow). Indicates manual mode selected as for e.

g. h. Tuner Limits (red). Indicates that the tuner has reached either the upper or lower limit of its travel. In this condition the motor will clamp. To move the tuner off the limit select manual mode and <u>lower</u> for <u>upper</u> limit and vice-versa.

Control Indicators

a. Control. Camac/Local selects local or Camac control. Camac controls are ineffective if local is selected and vice-versa. This does not affect status information which is displayed locally and remotely at all times.

b. Mode. Auto/Manual selects mode of operation when switched to local control.

c. Manual Tuning. Raise and Lower alters position of tuner when manual mode is selected.

d. Phase Shift. Raise and Lower. This function alters the control voltage applied to the strip-line phase shifters thereby altering the point to which the system will tune. (For a fuller description see operating notes in Section 2).

Monitor Points

a. Tuner Position. At this point, an analogue voltage is available indicating the relative position of the tuner. The full scale voltage is ±5 volts for upper and lower limits respectively and 0 volts at the mid point.

b. Phase Shift. The control voltage applied to the strip-line phase shifters is available at this point (±15 V). This voltage is proportional to the amount by which the incoming RF signals are altered in phase. 1 volt corresponding to 10 degrees of phase shift ±10%.

3. Servomotor Driver Module

A signal lamp on the front panel labled unclamp indicates that the motor is energised. This unit is fitted with 2 Amp internal fuses which may blow under a fault condition.

4. Sample and Hold Module (Figs 8, 9)

Gain Adjust

This preset control sets the gain of the amplifier and hence the loop gain of the auto-tuning system when in the automatic mode. Too high a setting will result in instability shown by overshoot and hunting of the system. Too low a setting results in the system failing to adjust to the 'on tune' point in the one or two pulses normally required.

Monitor Sockets

a. Trigger. This pulse Fig 11c (10 V, 10 μs) determines the point at which the unit will sample the error pulse and is controlled from the timer rack in the ICC.

b. Gate Pulse. This is the pulse applied to the sampling gate, occuring at the same point in time as the trigger, the pulse width being preset by the internal circuitry (approximately 10 μs). The pulse is -ve going, TTL level.

c. Error Pulse. This is the amplified output of the phase bridge that is read by the sample and hold circuit.

d. Error Signal. This is the dc output of the sample and hold circuit that is fed to the servomotor driver control input. This voltage is relative to the tuning error when the phase bridge is correctly adjusted to give zero voltage for the 'on tune' position. Its range is ±3 volts.

Section 2 - OPERATING INSTRUCTIONS

The autotuning system may be operated either locally or via Camac from the ICC.

Local Operation from Control Module

1. Set control to LOCAL by means of the push button switch.

NB It is possible to depress both sections of the switch at the same time. If this should occur, no harm will result but the system will not operate correctly.

2. Set mode switch to MANUAL.

3. Manually tune the tank referring to the reflected power from the tank or some other suitable method.

4. Display the ERROR PULSE signal available from the Sample and Hold module on an oscilloscope. The oscilloscope 'Y' amplifier should be ac coupled to avoid displaying any dc offset present in the system.

If a signal similar to Fig 11a appears, the phase shifter is incorrectly set for the tank to be 'on tune'.

5. The PHASE SHIFT raise and lower buttons should now be operated until the oscilloscope trace is similar to Fig 11b. Note that Fig 11a shows a +ve 'off tune' error, it is also possible to obtain a -ve going 'off tune' error signal.

The object of the exercise is to reduce the error pulse to zero, over most of its length by means of the phase shifter. The voltage output of the Monitor Phase Shift socket on the Control Module should now be noted. If all is well this should not normally exceed the limits ±5 V, the full scale voltages being ±15 V. Figs 11a and 11b assume that nothing abnormal (ie multipactor, breakdown, etc) is occurring in the tank. If further information is required concerning the strip-line phase shifters, refer to REF 1.

6. Switch the system to Auto

A check may now be made for correct operation of the system. Revert to Manual control and 'de-tune' the tank, using the Manual Tuning Raise and Lower buttons, until an error pulse of approximately 1.5 volts +ve or -ve is displayed. On switching to Auto the system should restore the tank 'on tune' within two machine pulses. If the system overshoots or hunts about the 'on tune' position, the loop gain is too high and should be reduced by means of the Gain Adjust preset on the Sample and Hold module. If the system does not restore the tank 'on tune' within two machine pulses, the loop gain is too low and should be increased.

Local Operation Using Monitor Unit

The monitor unit fitted to the Auto-tuning system rack may be used for setting up as well as for diagnostic purposes. Whilst the left-hand meter indicates the relative motor velocity and direction of travel, the right-hand meter measures either the phase shifter volts or error signal according to the switch position.

Setting up procedure is similar to that using an oscilloscope but instead of the error pulse, the error signal voltage is monitored. The error signal voltage should read zero volts with the system 'on tune'.

Operation via the Camac System

For operation of the Auto-tuning system via Camac, the Local/Camac push button should be set to Camac. When Local is selected the Camac controls are inhibited.

Firstly, the tuner for the appropriate tank should be selected and the monitoring cables patched through to the oscilloscope in the ICC or MCR. The cable references may be found on the Auto tuning System Block Diagram OR-859-803 (Fig 1)

The digital display on the Camac system will display the relative tuner position in volts. With reference to the reflected power RF waveform from the appropriate tank, the system should be manually tuned to give a minimum over the length of the pulse. Fig 11d.

The phase shifter of the tank being tuned should be selected, this giving the phase-shifter voltage at the display ($10\ V \equiv 100^{o}$ phase shift). The phase shift is now adjusted by means of the raise/lower buttons to optimise the error pulse as described in the Local Operation section.

The system may now be set to Auto by selecting the appropriate tank tuner and pressing Auto. The operation may be checked as in the Local Operation section.

References

Ref 1. The Construction and Calibration of a Strip-line Prototype Phase Comparator for use on the 70 Mev Injector.

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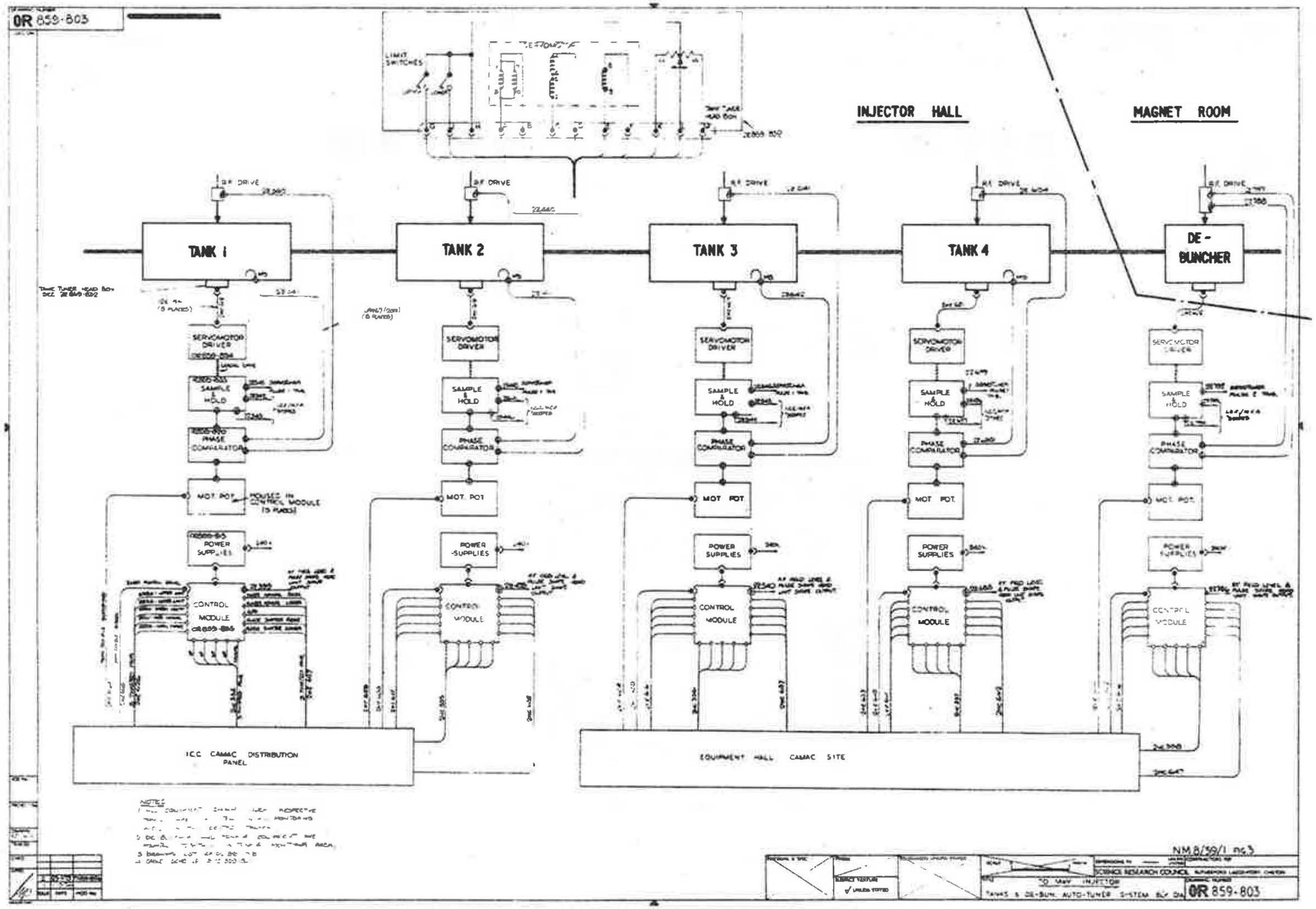
N Perera
E G Sandels



0R 859-803
LIMIT SWITCHES
INJECTOR HALL
MAGNET ROOM
R.F. DRIVE
TANK 1
TANK 2
TANK 3
TANK 4
DE-BUNCHER
SERVOMOTOR DRIVER
SAMPLE & HOLD
PHASE COMPARATOR
MOT. POT.
POWER SUPPLIES
CONTROL MODULE
HOUSED IN CONTROL MODULE (5 PLACES)
I.C.C. CAMAC DISTRIBUTION PANEL
EQUIPMENT HALL CAMAC SITE
NOTES
NM.8/59/1 no.3
SCIENCE RESEARCH COUNCIL
70 MeV INJECTOR
0R 859-803

FIG 1

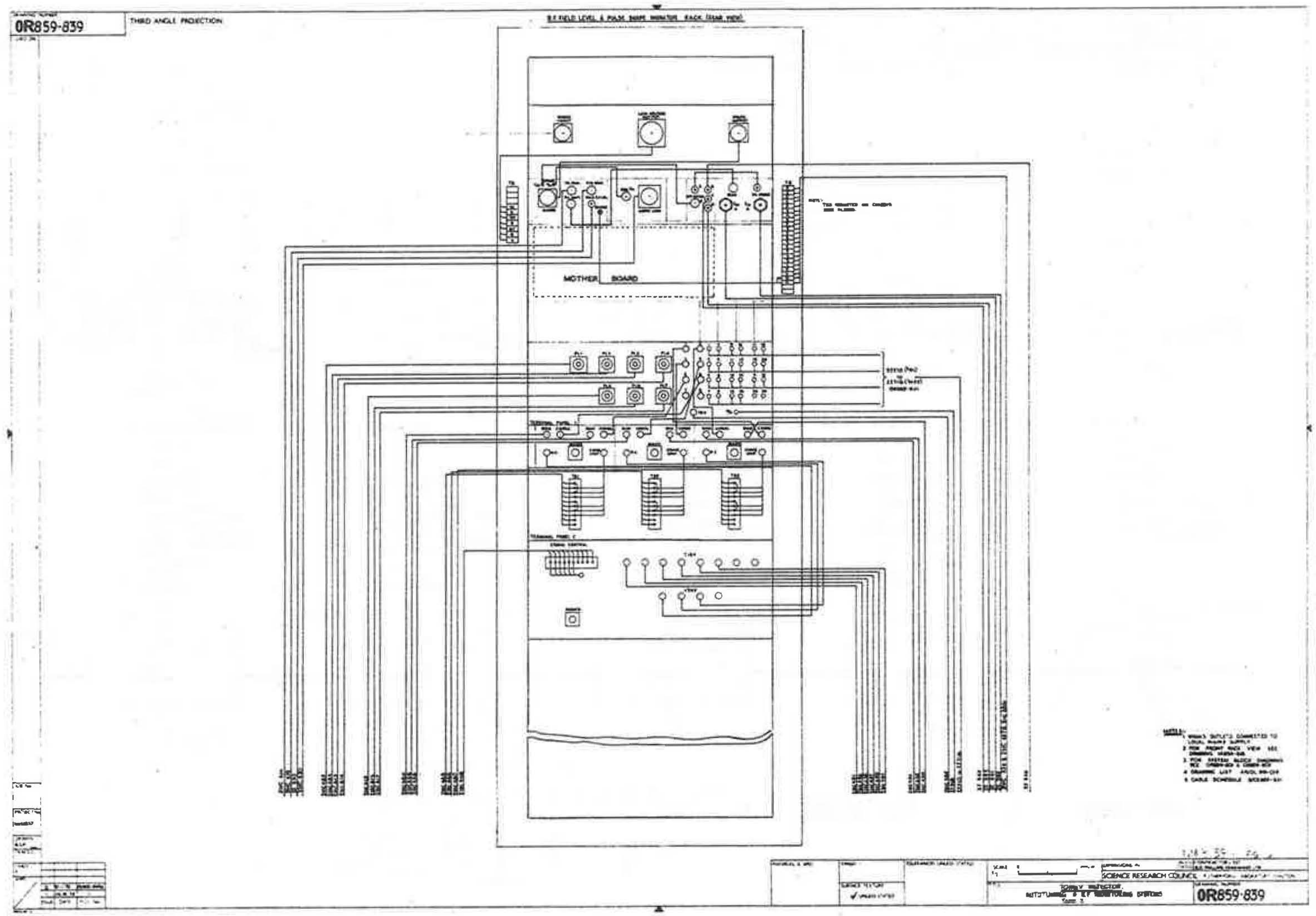

0R859-839
THIRD ANGLE PROJECTION
MOTHER BOARD
SCIENCE RESEARCH COUNCIL
0R859-839

FIG 2

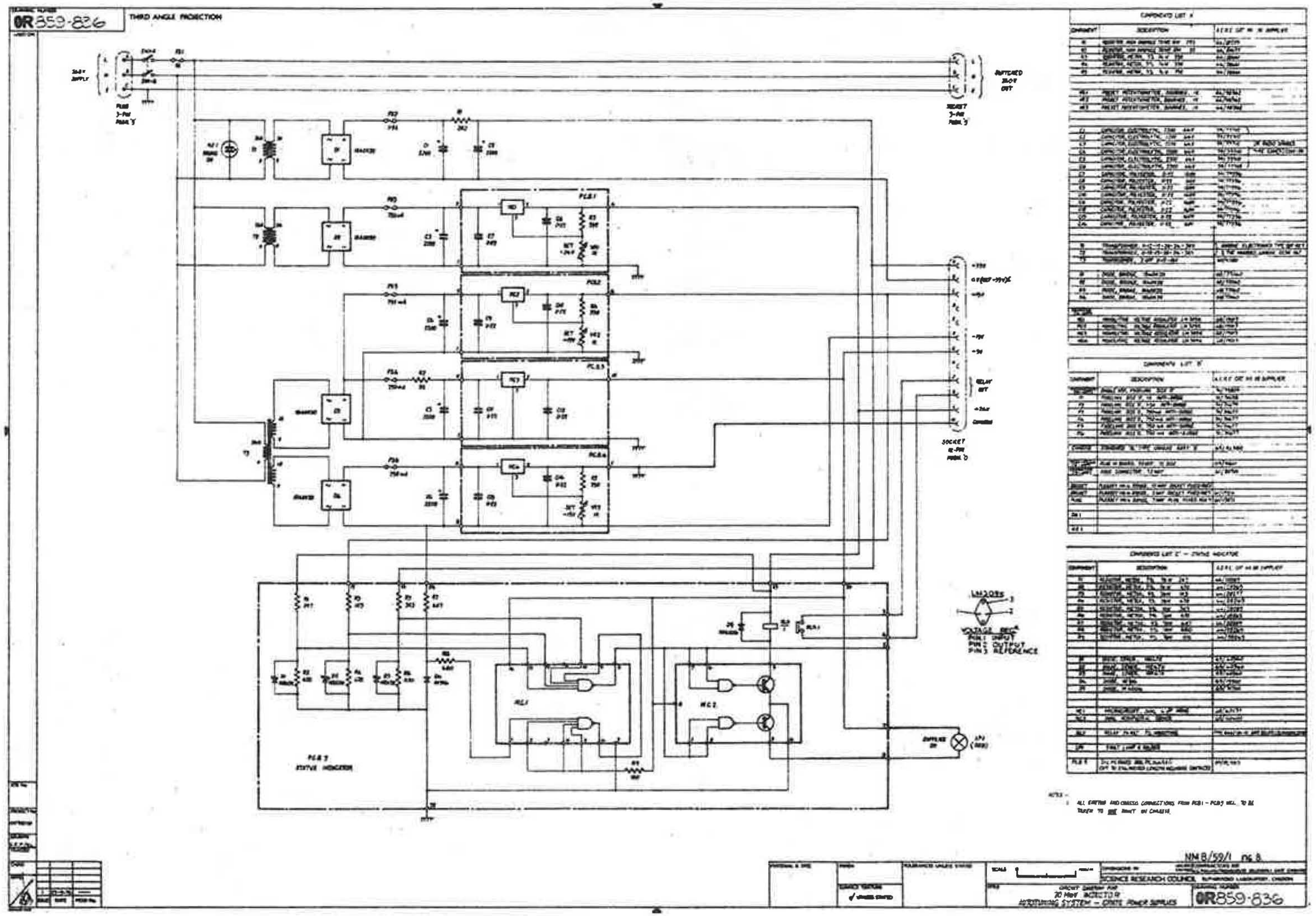

0R859-836
THIRD ANGLE PROJECTION
LM309K
VOLTAGE REG
PIN 1 INPUT
PIN 2 OUTPUT
PIN 3 REFERENCE
NM8/59/1 ns 8
SCIENCE RESEARCH COUNCIL
0R859-836

FIG 3

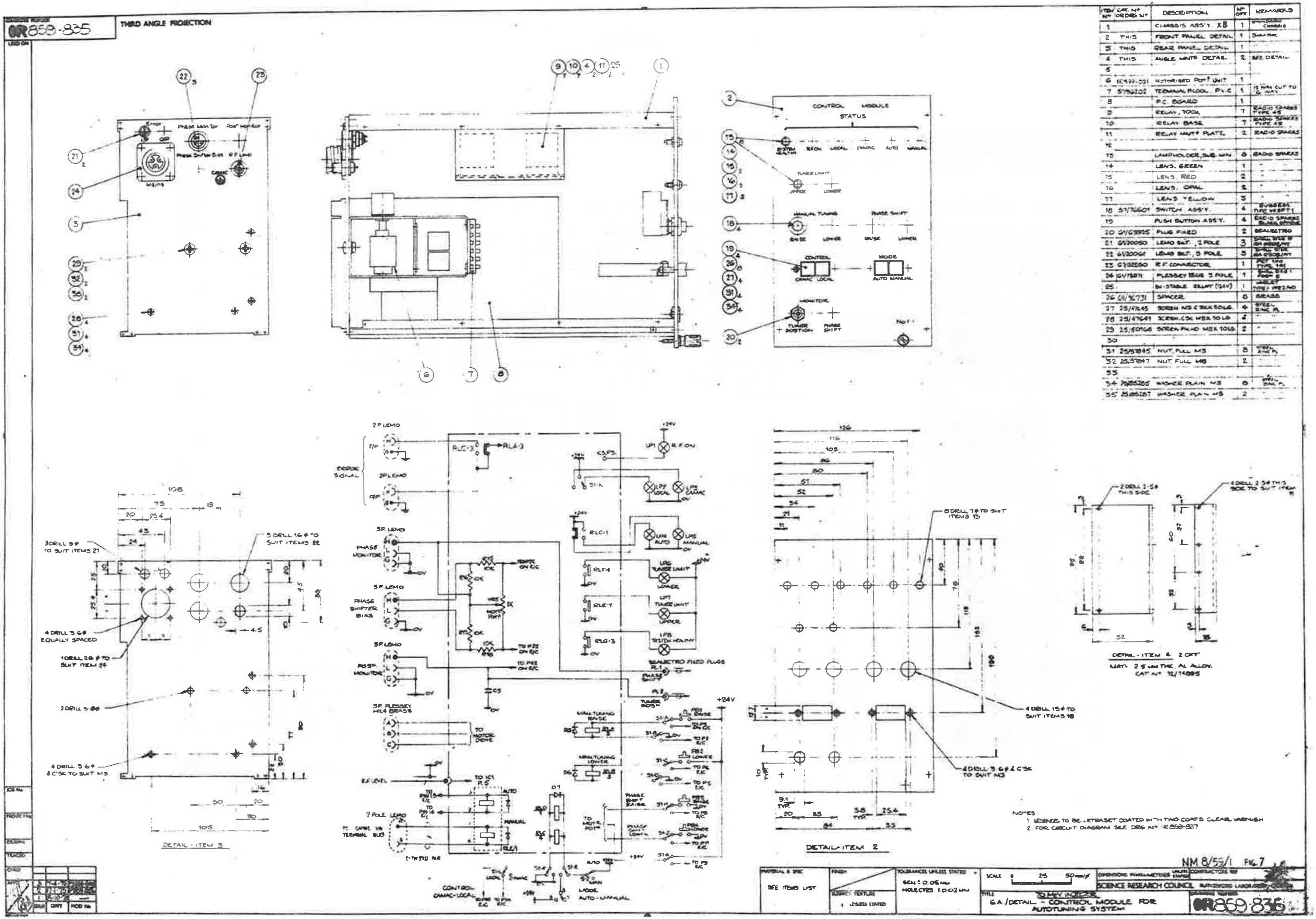
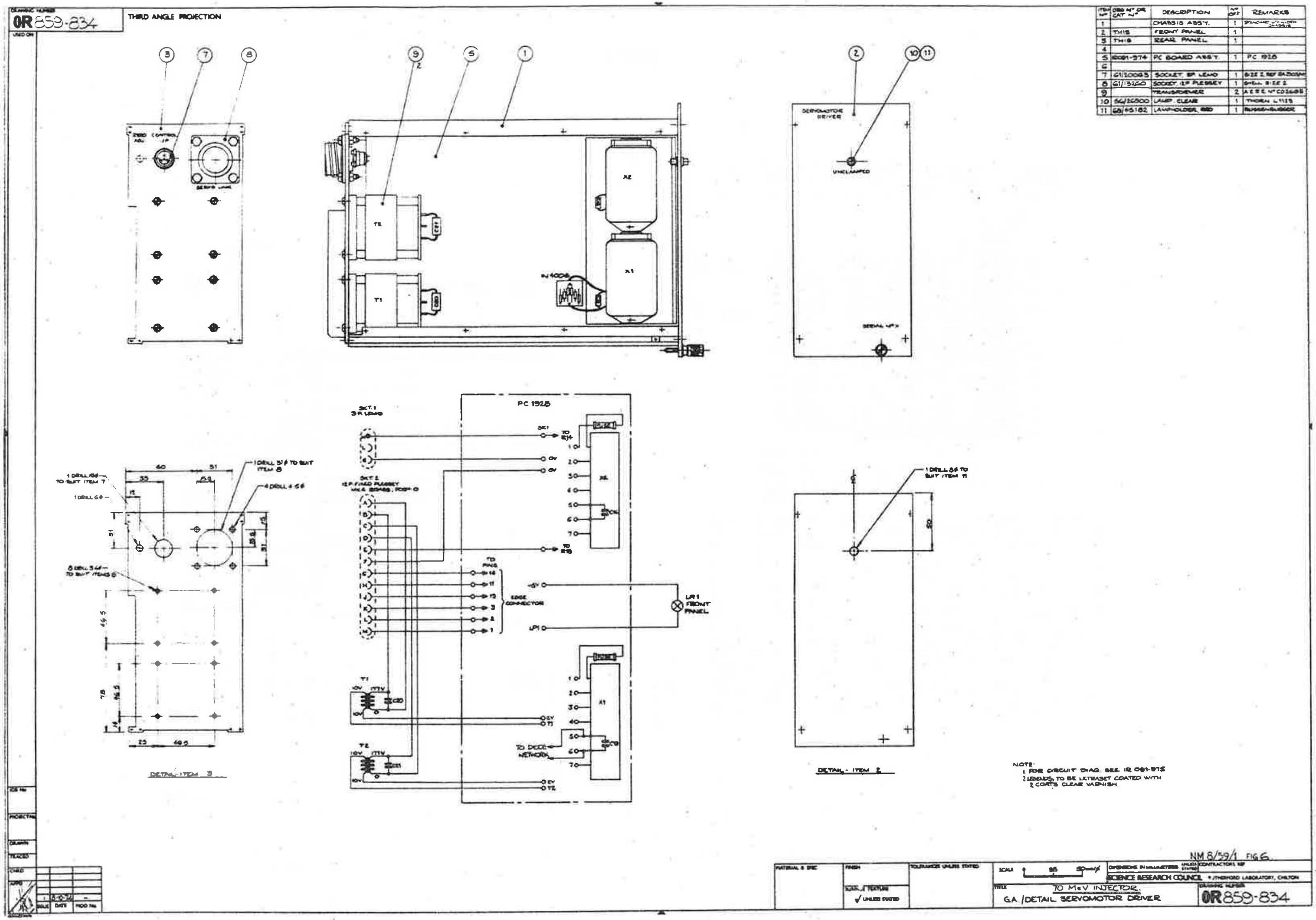

THIRD ANGLE PROJECTION
CONTROL MODULE
STATUS
DETAIL - ITEM 3
DETAIL - ITEM 2
DETAIL - ITEM 4 2 OFF
NOTES
1 LEGENDS TO BE LETRASET COATED WITH TWO COATS CLEAR VARNISH
2 FOR CIRCUIT DIAGRAM SEE DRG N° R 859-827
SCIENCE RESEARCH COUNCIL
G.A./DETAIL - CONTROL MODULE FOR AUTOTUNING SYSTEM
NM 8/55/1 FIG 7
R859-836

FIG 4



ITEM No	DRG No OR CAT No	DESCRIPTION	No OFF	REMARKS
1		CHASSIS ASS'Y.	1	STANDARD ... CHASSIS
2	THIS	FRONT PANEL	1	
3	THIS	REAR PANEL	1	
4				
5	2081-374	PC BOARD ASS'Y.	1	PC 1928
6				
7	61/10083	SOCKET 3P LEMO	1	SIZE 2 REF RA3003
8	61/13260	SOCKET 12P PLESSEY	1	SHELL SIZE 2
9		TRANSFORMER	2	A.E.R.E. No CD1608
10	56/26000	LAMP CLEAR	1	THORN L1125
11	68/45162	LAMPHOLDER, RED	1	BULGIN

FIG 5

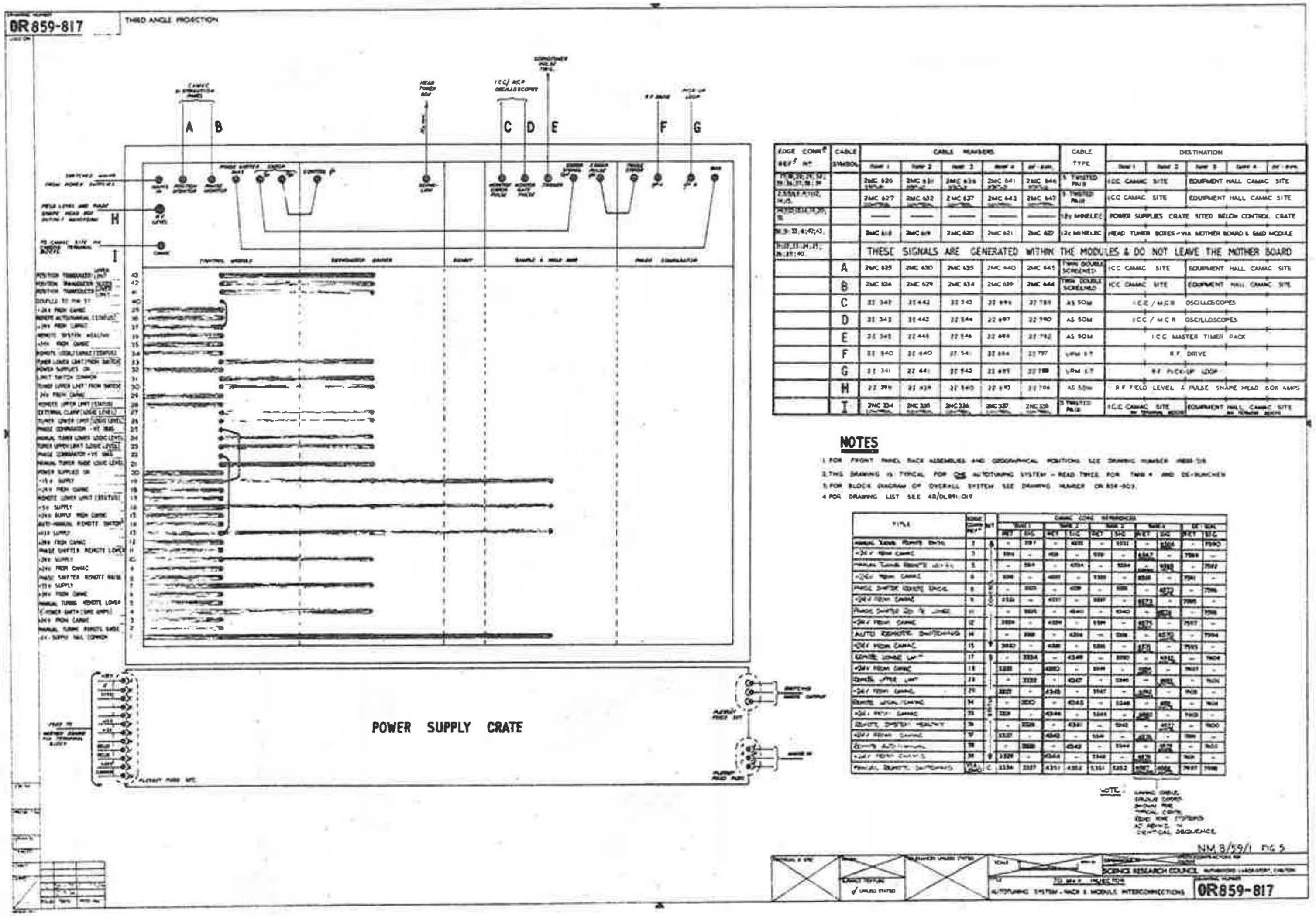

0R859-817
THIRD ANGLE PROJECTION
A
B
C
D
E
F
G
H
I
THESE SIGNALS ARE GENERATED WITHIN THE MODULES & DO NOT LEAVE THE MOTHER BOARD
NOTES
POWER SUPPLY CRATE
NM 8/59/1 FIG 5
SCIENCE RESEARCH COUNCIL
AUTOTUNING SYSTEM - RACK & MODULE INTERCONNECTIONS
0R859-817

FIG 6

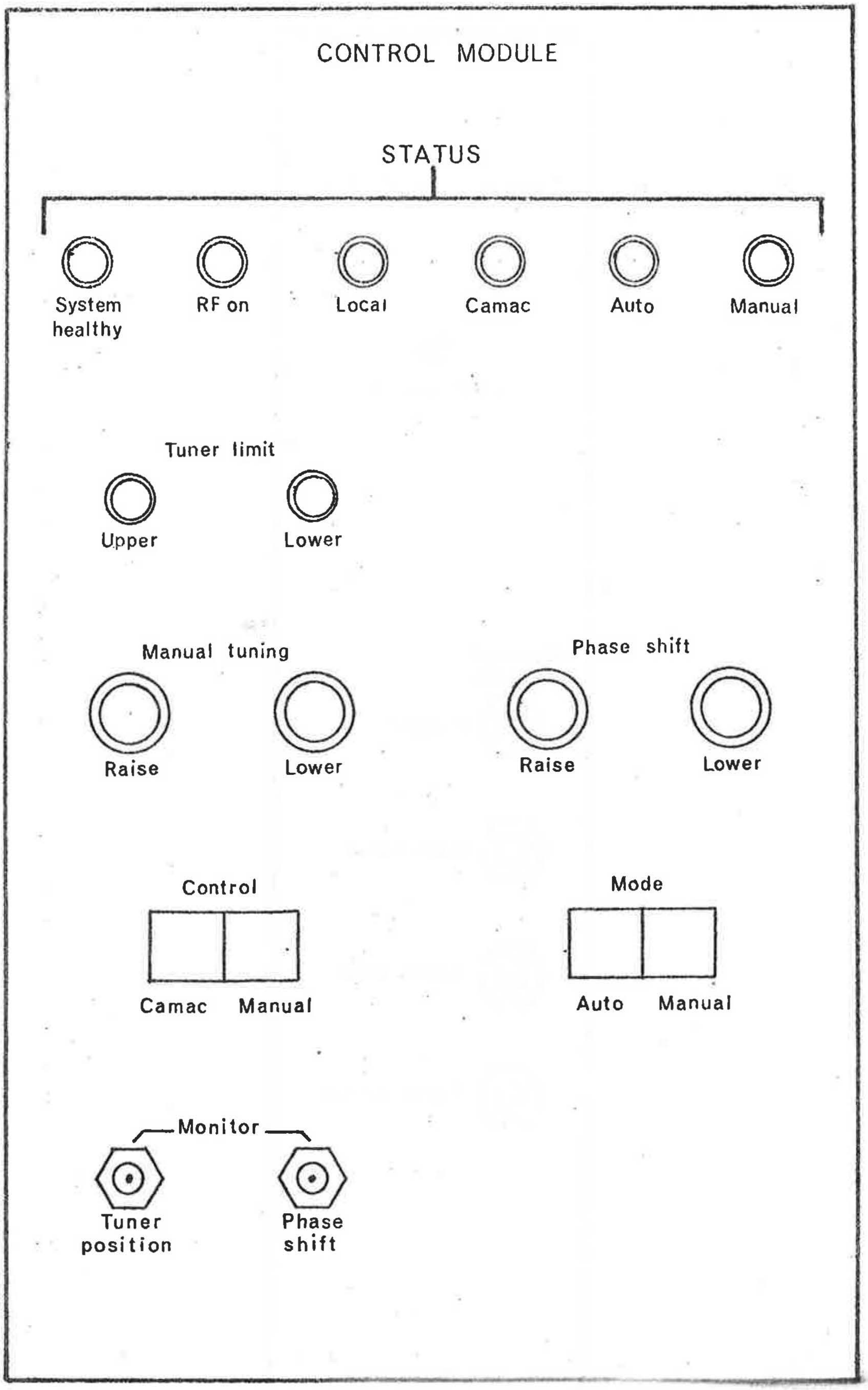


FIG 7 CONTROL MODULE FRONT PANEL LAYOUT

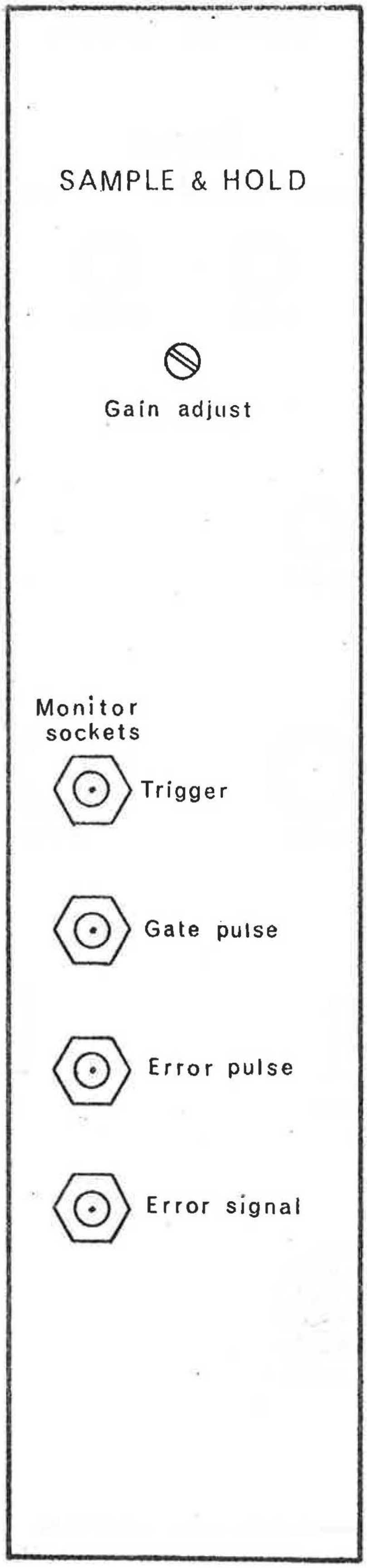


FIG 8 SAMPLE & HOLD FRONT PANEL LAYOUT

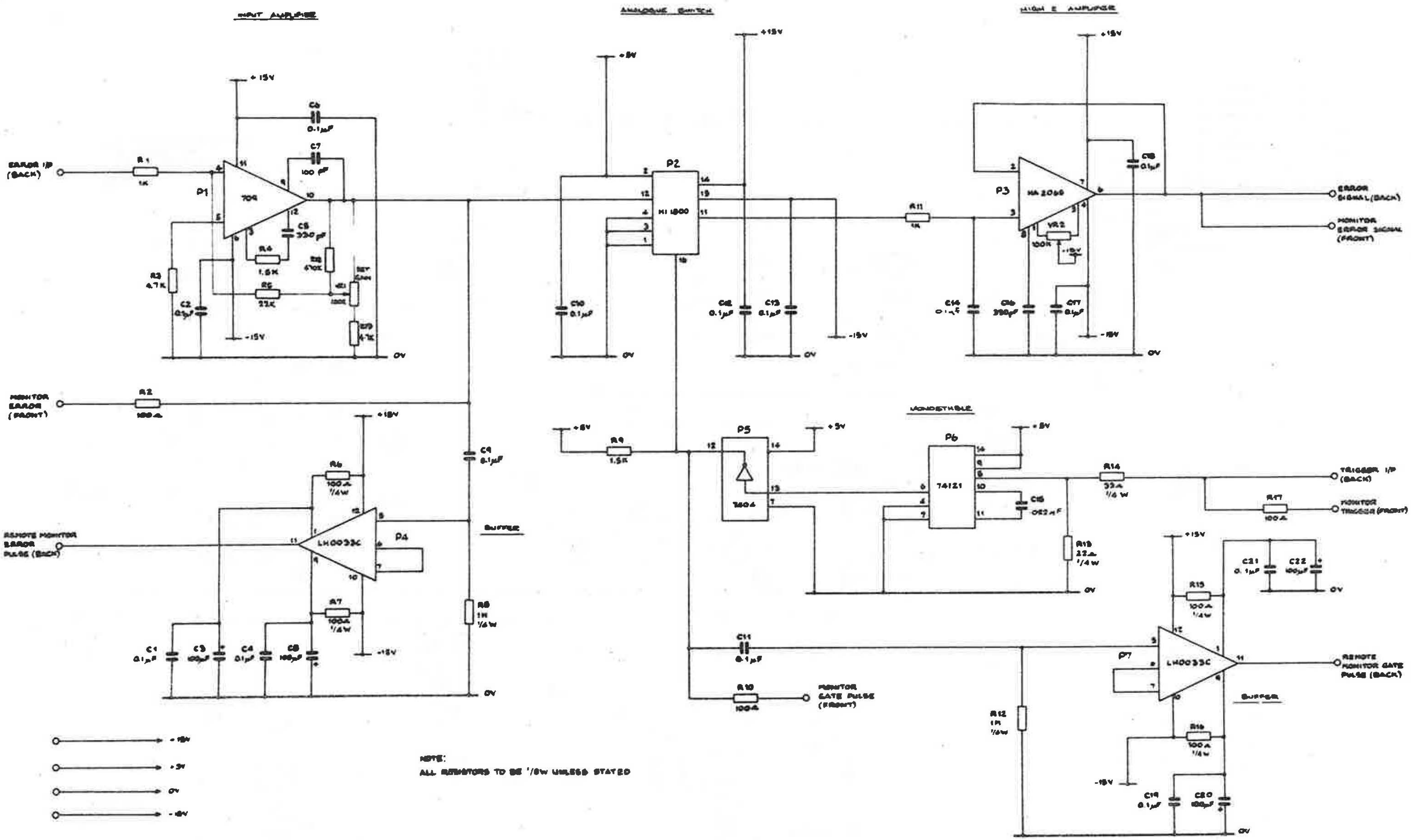
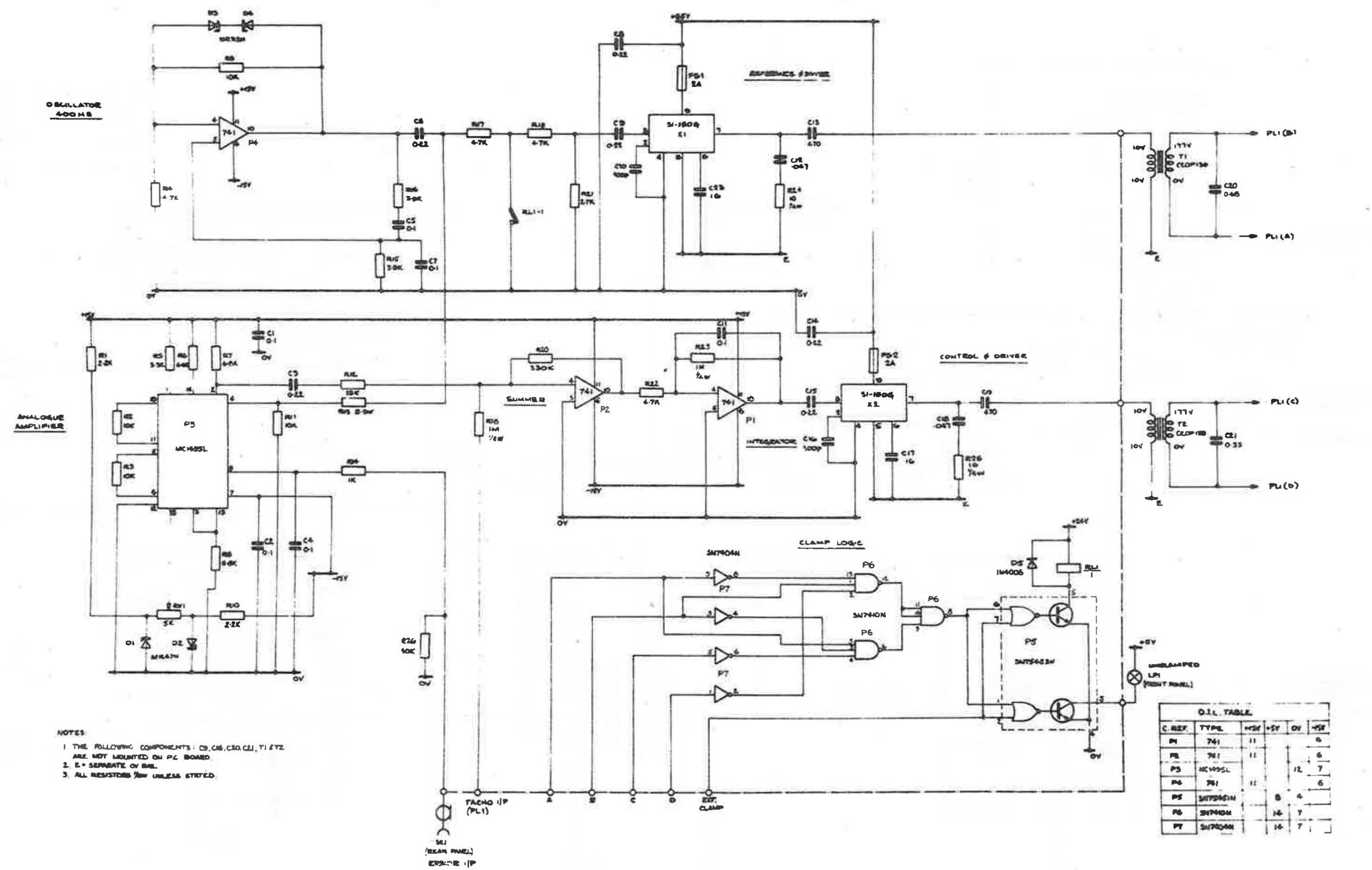


FIG 9

PC1931

CIRCUIT DIAGRAM FOR SAMPLE AND HOLD **1R** 091983



NOTES:

1 THE FOLLOWING COMPONENTS: C9, C18, C20, C21, T1 & T2 ARE NOT MOUNTED ON P.C. BOARD.
2. E = SEPARATE 0V RAIL
3. ALL RESISTORS ¼W UNLESS STATED.

O.I.L. TABLE					
C. REF.	TYPE	+15V	+5V	0V	-15V
P1	741	11			6
P2	741	11			6
P3	MC1495L			12	7
P4	741	11			6
P5	SN75451N		8	4	
P6	SN7400N		14	7	
P7	SN7404N		14	7	

FIG 10

PC 1928
CIRCUIT DIAGRAM - SERVOMOTOR DRIVER

1R 09/975

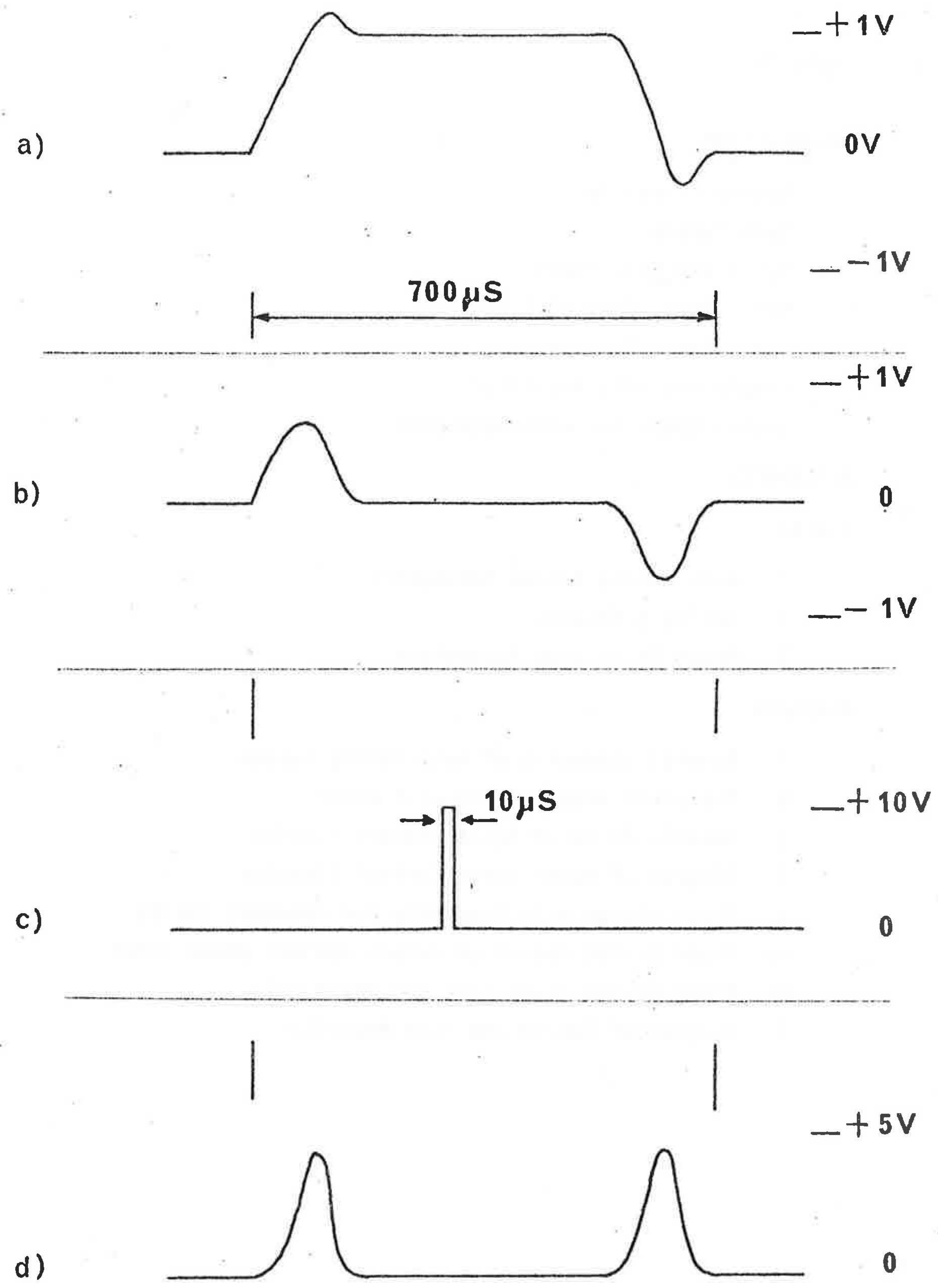


FIG 11 WAVEFORMS FOR OPERATING INSTRUCTIONS

SECTION 3 - DESIGN NOTES ON THE TANK AND DEBUNCHER AUTO TUNING SYSTEMS

CONTENTS

INTRODUCTION

The Auto Tuning Systems described below are part of the linac control equipment for maintaining the accelerating field to the correct amplitude and phase. The four tanks and the debuncher cavity must be held on tune to within a few Hz if phase errors are to be held within design limits. Very small dimensional changes in these cavities can cause serious detuning errors. These changes during operation are due mainly to fluctuations in temperature of the walls of the tanks which although water-cooled and temperature stabilised remain variable with $\pm\frac{1}{2}$°C.

In each cavity either copper tuning plates or a slug (ie, cylinder) are inserted or withdrawn appropriately to compensate for the dimensional changes. The general arrangement of the tuning system is shown in Figure 1. The tuned cavity is fed with RF current in a drive loop which is monitored by a pick up loop set in the coaxial power line a half wavelength from the cavity. The cavity field is monitored by a second pick up loop set in the wall of the cavity. The monitor signals are appropriately adjusted in phase via electronic phase shifters and compared in a phase bridge which produces a DC current in proportion to the phase error. (These components comprise the Phase Comparator). When the linac pulse occurs the output from the phase bridge is stored as a voltage on a capacitor in a sample and hold amplifier until the next pulse occurs. The sampled phase error signal is used to control an AC servo motor in its own feedback loop, the motor controlling the position of the tuner via a gear train and a coupling mechanism. When the cavity is exactly on tune there is a 90° phase difference between the RF drive current and the accelerating field and this is arranged to give zero phase error current in the comparator.

In tanks 2 and 3, the tuners comprise 4 copper plates mounted on flexible phospher bronze strips set in the tanks walls allowing radial movement. These are linked by hydraulic transmission to a cam actuator. The Debuncher has a single plate similarly mounted. Tanks 1 and 4 each have a single cylindrical brass tuning slug 5'' diameter moving radially through vacuum seals and controlled by a ball bearing screw. In each instance the tuner position is monitored by a linear potentiometer coupled into the gear train and displayed remotely. The motor may be operated manually, the phase shift through the phase comparator controlled and monitored and the phase error current displayed all through the camac control system.

This report describes a criterion for stability in the auto tuning systems. The servo motor gear train and the electronic units are discussed with reference to this criterion and their parameters listed for each of the five cavities.

SYSTEM STABILITY

The auto tuning systems operate continuously at a velocity proportional to the tuning errors. The state of error is sampled at every machine pulse, ie about 24 pulses/minute. Since the time between samples is much longer than any lags due to servo motor or gear train inertia a simplified criterion for stability is readily obtained. The response of such a system to unit error is illustrated in Figure 2. Where T_s is the time between samples

T_c is the time to reduce unit errors to zero.

Figure 2a shows an instance where $T_c = \frac{3}{4}\, T_s$. Here the error is reduced to zero and then reverses in sign as the motor continues at constant velocity to the next sampled error, hence the optimum unit error reduction rate = $\frac{1}{TS}$ = 0.4 sec^{-1} at 24 pulse/minute.

The product of the output/input transfer parameters of tanks, tuners, motors and electronic units gives the unit error reduction rate. These parameters are listed in Table 1 which is the basis for discussion of the parts of the systems and their design as described below.

TANK TUNERS

To a first approximation the frequency change expressed as a fraction of the resonant frequency is taken as half the fractional change in cavity volume due to the tuner displacement. However, this factor depends also on the shape of the tuner and its position in the cavity.

For example in a 900 mHz scale model of a linac tank section including 3 unit cells:

The fractional volumetric change $\Delta v/v$ was 62 parts per 10^6/mm tuner displacement
The fractional frequency change $\Delta f/f$ was 36 parts per 10^6/mm tuner displacement

Further data relating errors in tank dimensions to the resonant frequency can be found in References 1 and 2 where the effect of the tuner is assessed by assuming an effective cavity diameter change equivalent to the inserted volume of the tuner, but this predicts a much lower frequency shift than that measured in the model.

An estimated tank tuner constant based on the model measurements is given in Table 1 for Tanks 1 and 4. Those given for Tanks 2-3 are quoted from Reference 4 and that for the Debuncher estimated as for Tanks 1 and 4 above.

MOTOR AND GEAR TRAINS

The principle factors are:

1 The maximum rate of change of resonant frequency in an uncorrected tank. Here temperature variations in the tank walls exceed other factors mechanical and electrical (such as beam loading) by an order of magnitude.

  From consideration of the ambient temperature variations and the temperature stability of the cooling water it is estimated that temperature change rates in the tank walls will not exceed 3°C/minute corresponding to a frequency detuning rate of 10 kHz/minute.

2 The tank tuner constant, 179 Hz/mm (Tank 4).

3 The friction and vacuum load on the tuning slug. In tanks 1 and 4 the slug moves through RF finger strip contacts and is actuated via a vacuum seal via a ball bearing screw. The maximum torque required at the screw allowing for screw efficiency and a safety factor to ensure static friction override is 7,800 gm cm with a ball-screw lead of 5 mm/rev.

combining 1 and 2 with the ball screw lead and the torque at the ball screw gives the power required:

7,800 gm cm at 11.2 rev/min for Tank 4

allowing 60% efficiency in the gear train a motor shaft power of 1.5 watts is required.

This is shown at the point A in Figure 3a, the output power torque curves for a Vactric size 18 AC servo motor. The corresponding power for Tank 1 is shown at point B. These points designate, with suitable gear ratios, the maximum power and torque under normal running conditions. For Tank 4 this corresponds to 60% of maximum control volts. Reference point C (100% volts with speed unchanged) shows a working torque margin of about 70% and to point D (100% volts with torque unchanged) a speed margin of about 50%. It is considered that these place the motor near optimum working conditions.

For Tanks 2 and 3 and the Debuncher the existing PLA auto tuning system has been adapted with changes to new electronic units. However the ex PLA gear boxes are used unchanged apart from the new position read-out potentiometers and the Type 18 Vactric AC motor quoted above is comparable although somewhat more powerful than the Type 15 employed in the PLA. It is estimated that these motors will operate at about $\frac{1}{4}$ the rate of the Tank 4 motor and should not require more than about 20% of the full control volts under the maximum load. See point E in Figure 3a.

SERVO MOTOR SPEED CONTROL CIRCUITS

The motor speed and direction of rotation is controlled by means of the circuit represented by the block diagram, figure 4. The oscillator provides the 400 Hz excitation for both the reference and control windings of the motor, also the field winding of the tachogenerator which is integral with the motor frame. The reference and tacho-windings are supplied directly via a hybrid integrated circuit power amplifier and transformer T1. The control winding is supplied by a similar amplifier and transformer T2 but here indirectly via an integrated circuit four-quadrant multiplier, the output of which is added in phase opposition to the tachogenerator output in the summing amplifier A1, thus forming a velocity feedback loop. The combined output undergoes a 90° phase-shift in the amplifier A2 relative to the reference winding signal to provide a rotating magnetic field in the motor. The multiplier output is amplitude modulated and phase shifted by means of the bipolar DC control signal derived from the sample and hold circuit, the output amplitude being dependent on the amplitude of the DC signal and the phase, 0° or 180°, on the polarity, thus controlling the motor velocity and direction of rotation.

The stability of the motor servo loop and its performance in the auto tuning system depends on its loop gain ie, the product of its circuit transfer parameters and the motor characteristic slopes. Figure 3b shows the motor speed control voltage characteristic for three conditions of constant shaft torque. The voltage threshold for rotation increases with increasing load, however, the slopes of these characteristics are reasonably uniform above the threshold. Table 3 lists the parameters controlling the motor servo loop gain assuming constant slope and a rotating motor. The loop gain is given by their product. Table 1 lists the parameters controlling the auto tuning loop gain.

<u>Tachogenerator constant</u> Is a fixed parameter determined by the manufacturer and dependent only on the Reference winding voltage.

<u>Servo amplifier Tacho O/P.control I/P</u> Is determined by the ratio of the summing resistors in amplifier A2 ie, R2/R1.

<u>Multiplier constant AC OUTPUT/DC INPUT</u> Is determined by the two multiplier inputs; 400 Hz AC from the oscillator and the DC error voltage from the sample-and-hold amplifier, a maximum of 8v DC corresponding to 20 degrees phase error producing 0.57 V AC at the multiplier output.

PHASE ERROR CIRCUIT

As described in the Introduction the phase error circuit compares the phase of the drive current and cavity field the phase error current being proportional to their difference. The change of phase with resonant frequency depends directly on the Q of the cavity and is given closely by:

$$\frac{d\phi}{df} = \frac{2Q}{f_o}$$

where ϕ = phase difference (rads)
f = drive frequency
f_o = resonant frequency
Q = cavity Q factor
See figure 5

expected figures for the tank Q factors are given in Table 2 (Reference 4) with the calculated system parameter $\Delta\phi/\Delta f$.

The phase comparator is formed in strip lines on copper clad Rexolite substrates and it is described fully in Reference 5.

The terminated bridge is fed from two phase shifting bridges with varicap reactive elements on their terminals to provide controlled phase shifts. The phase shifted signals at A and B (Figure 1) feed power into the terminating loads at C and D respectively. If a phase difference exists between the A and B signals the power into the loads is shared unequally and rectification and subtraction of the load RF potentials in the diodes D_1 D_2 yield a corresponding phase error current. Figure 6a shows the calibration of a typical phase bridge with 100K detector impedances and 1V RMS inputs. Also shown is the output obtained when one input is changing in amplitude as from an off-tune cavity. Because of restrictions in the threshold potentials of detector diodes and large signal distortion in the varicap diodes operation of the device is limited to between 0.3V and 1.0V RMS. Figure 6b shows the calibration of the phase shifters ie, the relationship between DC bias potential applied to the varicap diodes necessary to nullify the phase difference between the incoming signals.

Phase Bridge rectified output/phase error Is given by the slope of the phase bridge calibration at zero phase error (Figure 6a). The quantity depends on the RF signal voltages and the detector impedances.

SAMPLE AND HOLD AMPLIFIER

This unit, Figure 7, is the means of storing the output current of the phase bridge at the time of the linac beam pulse in the form of an analogue voltage held on a storage capacitor. The differential current from the phase bridge detectors is fed into an operational amplifier. During a short period (10 microseconds) within the duration of the linac pulse, an integrated circuit switch is closed feeding the amplifier output to a storage capacitor. After this period the switch is opened leaving the analogue voltage stored on the capacitor and operating on the motor servo until updated by the next pulse. A high impedance voltage follower amplifier monitors the capacitor voltage and feeds the motor servo. The gain of the amplifier is made variable by choice of its feedback resistor to give an error reduction rate for the particular auto-tuning system as required by the stability criterion described above. A range from 0.03 to 1.0 volts/μamp is available.

ACKNOWLEDGEMENTS

The authors would like to record their thanks to those members of the Nimrod Division who contributed data and offered helpful criticism on this report, also to J S Clair and J Canavan who co-operated with many of the prototype measurements.

REFERENCES

1 J J Wilkins, Design Notes on Resonators for proton linear accelerator. AERE GP/R 1613.

2 J J Wilkins, Design of RF Resonant Cavities for acceleration of protons from 50 to 150 MeV. PLAC 11.

3 PLA Handbook TK/2.

TABLE I

Auto Tuning System Parameters

Auto Tuning System Parameters	Units	Tank 1	Tank 2	Tank 3	Tank 4	Debuncher
Cavity $\Delta\phi/\Delta f$	deg/Hz	.034	.057	.057	.034	.0099
Phase Bridge rectified output/phase error	μa/deg	.28	.28	.28	.28	.28
Sample and Hold gain max. min.	Vdc/μa	1.8 0.18	.40 0.040	0.4 0.040	2.0 0.2	0.4 0.04
400 Hz Oscillator Multiplier constant $\frac{\text{AC OUTPUT}}{\text{DC INPUT}}$	Vac/Vdc	.071	.071	.071	.071	.071
Servo Amplifier Tacho Output/Control Input	Vac/Vac	32.9	32.9	32.9	32.9	32.9
Tachogenerator constant	Rev/Sec.Vac	4.9	4.9	4.9	4.9	4.9
Tuner to Motor velocity ratio	mm/Rev	.0154	.0028	.0028	.0230	.0028
Tank Tuner Constant	Hz/mm	312	4330	4330	179	26,250
Unit Error Reduction Rate max. (product of Parameters) min.	1/sec	0.94 0.094	0.89 0.089	0.89 0.089	0.91 0.091	0.93 0.093

TABLE 2

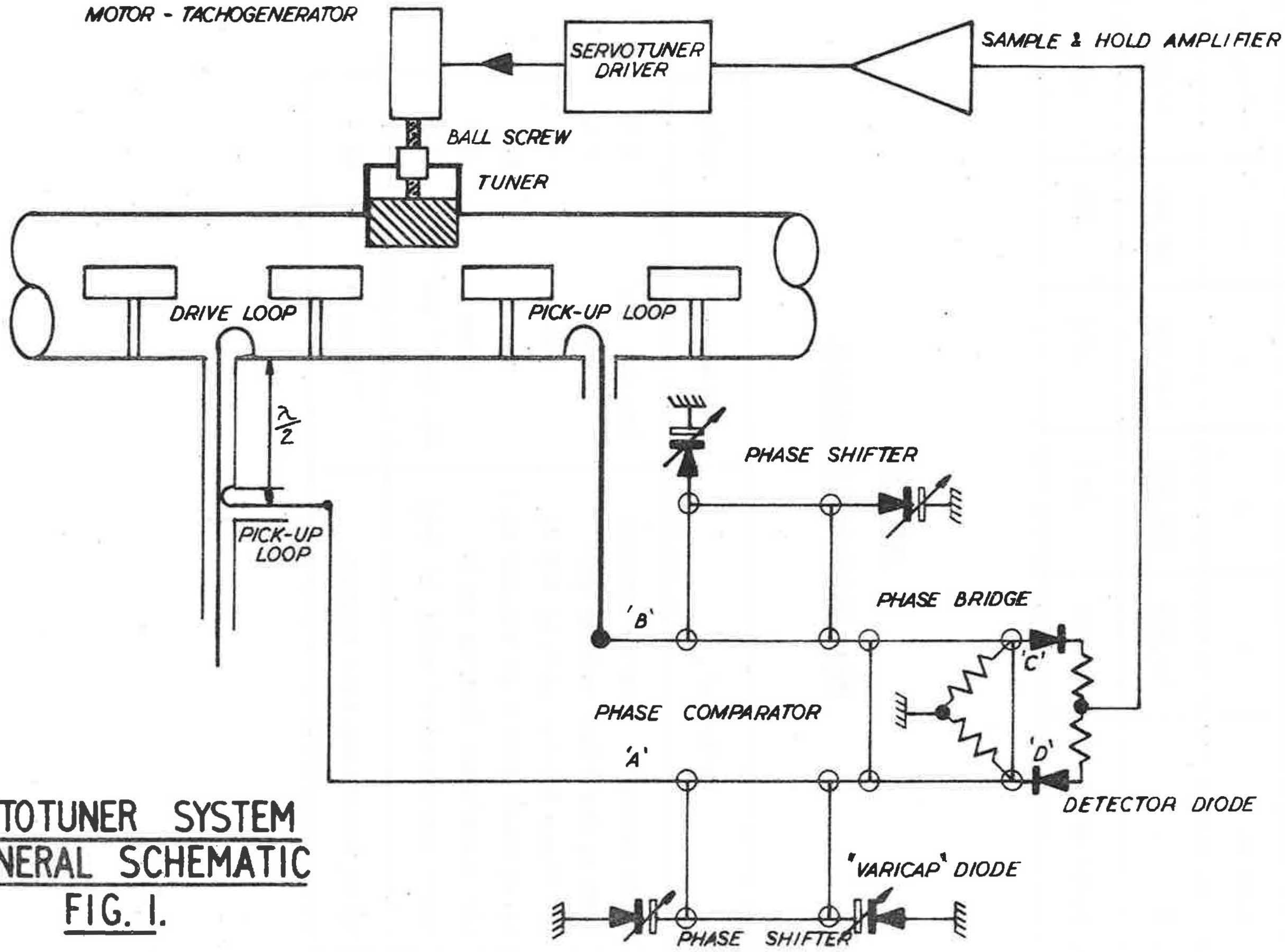
Cavity Q Factors

Tank No	1	2	3	4	Debuncher
Cavity Q	60,000	100,000	100,000	60,000	17,500
Cavity $\Delta\phi/\Delta f$ deg Hz^{-1}	.034	.057	.057	.034	.0099

TABLE 3

Motor Servo-Loop Parameters

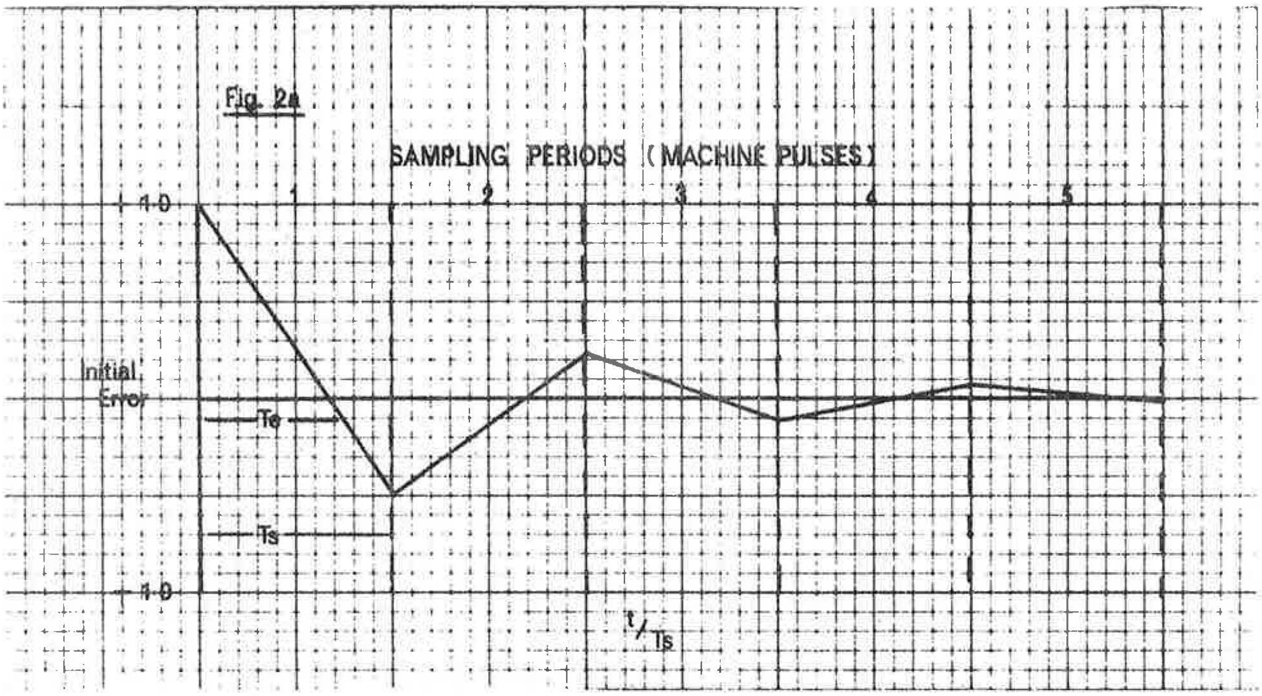
Parameter	Dimension	Value
Tacho Generator Inverse Constant	Vac Sec Rev^{-1}	0.2
Summing Amplifier voltage gain	none	0.56
90° Phase Shifter gain at 400 Hz	none	1
Servo Power Amplifier Voltage Gain	none	32
O/P Transformer Step-up ratio	none	9:1
Motor Speed/control volts on load	Rev Sec^{-1} Vac^{-1}	1.5
Motor Servo Loop Gain Product	None	48.4

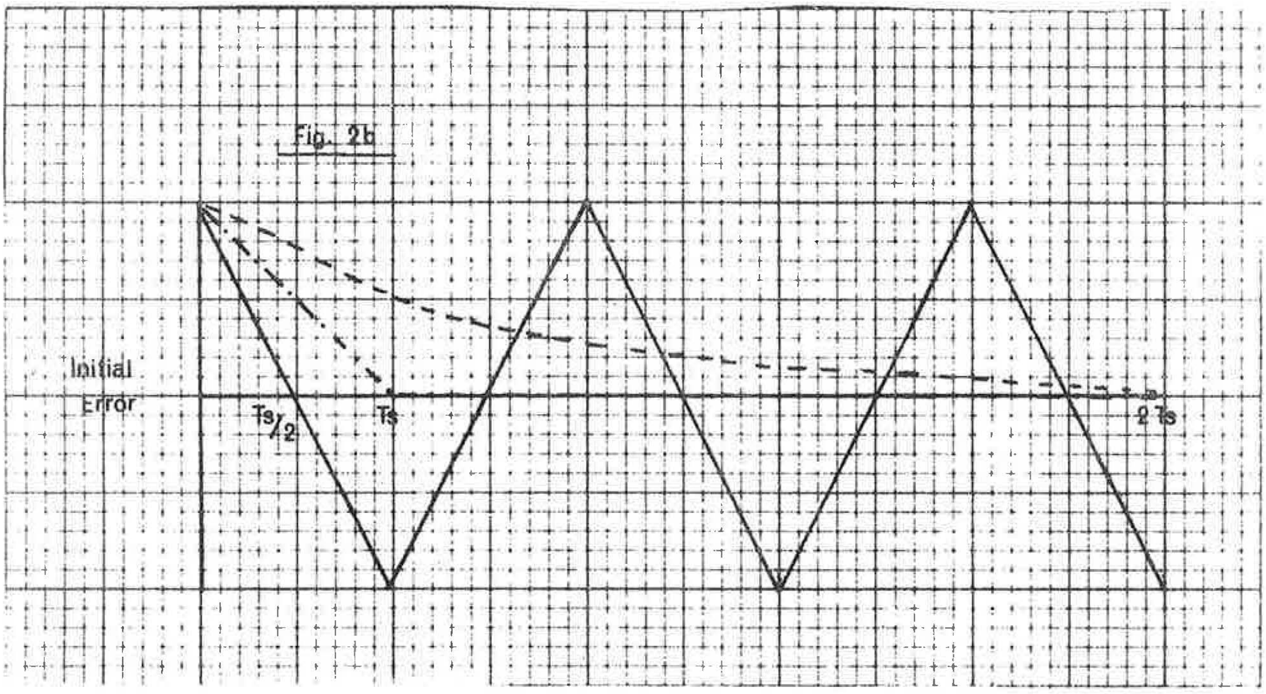


AUTOTUNER SYSTEM
GENERAL SCHEMATIC
FIG. I.

FIG. 2

Transient Responses to Unit Error





$Te > Ts$: Overdamped, quasi-exponential reduction of initial error

$Te > Ts$: Critically damped, quasi-exponential reduction of initial error

$Ts > Te > \frac{Ts}{2}$: Underdamped, quasi-exponential reduction of initial error

$Te < \frac{Ts}{2}$: Oscillatory, quasi-exponential growth of error

FIG. 3a Vactric 18 ac motor characteristics

Power vs Torque

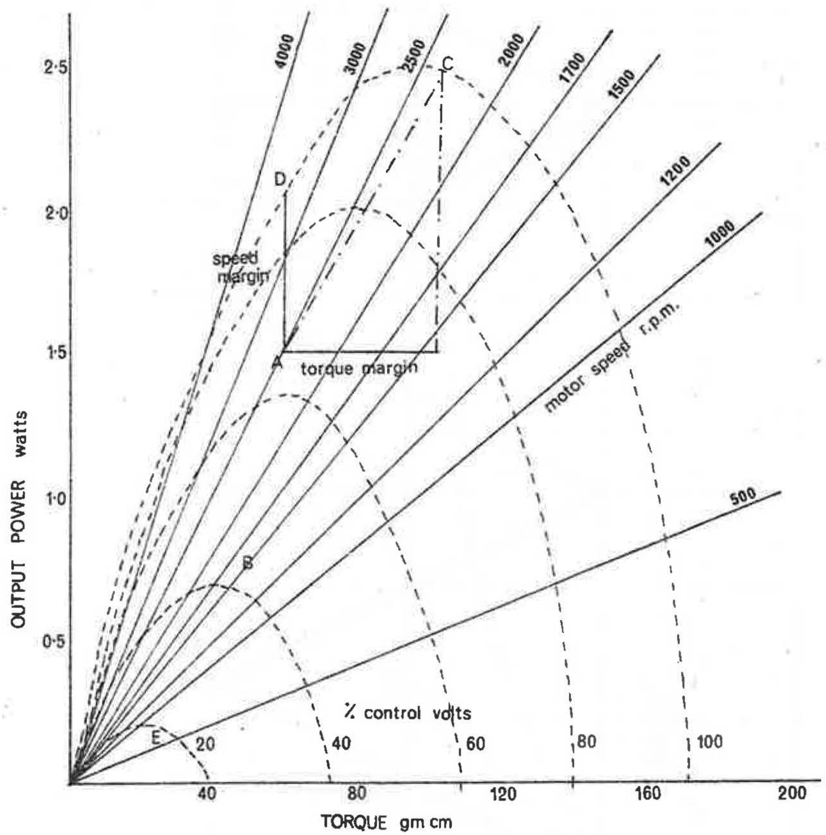
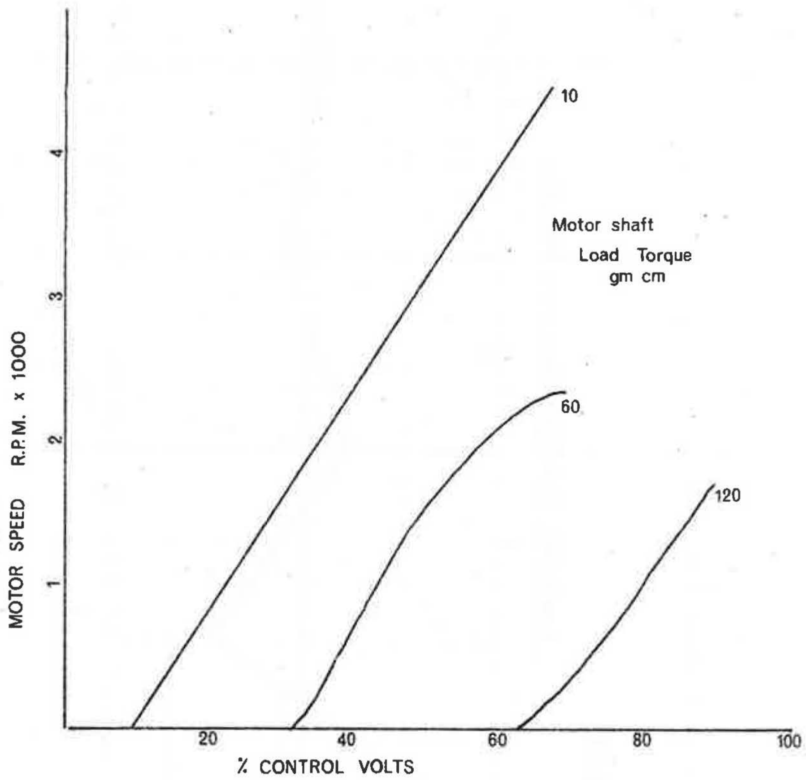


FIG. 3b

Speed vs Volts



SERVOMOTOR CONTROL

FIG. 4.

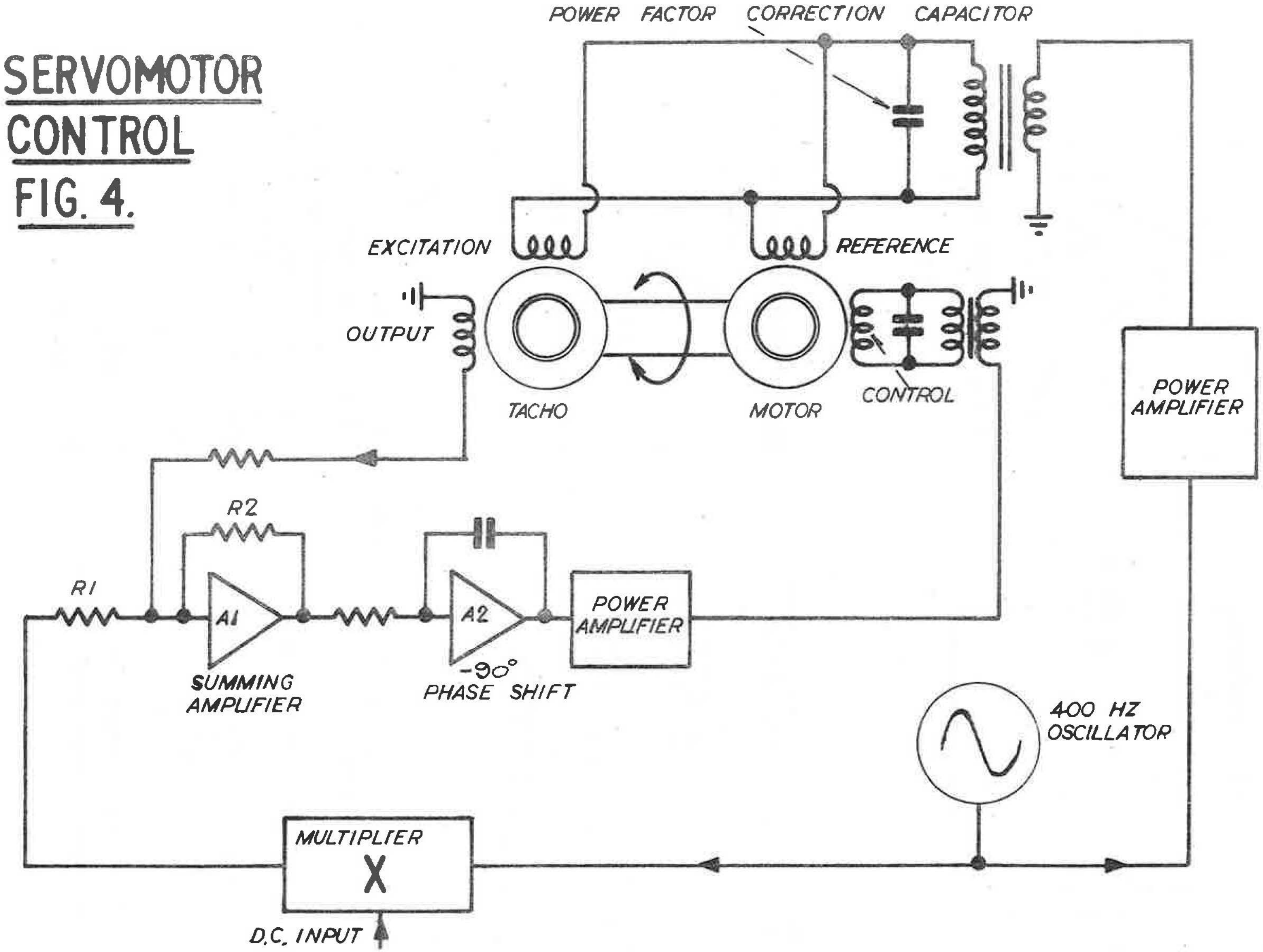
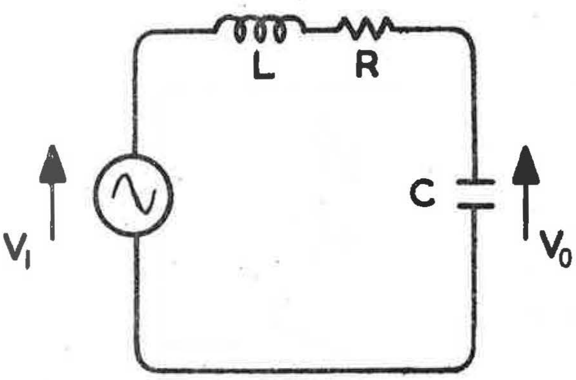
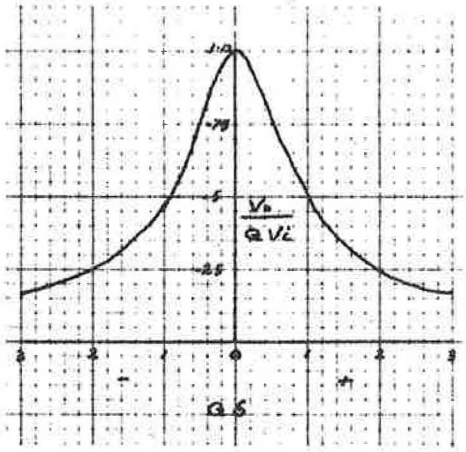
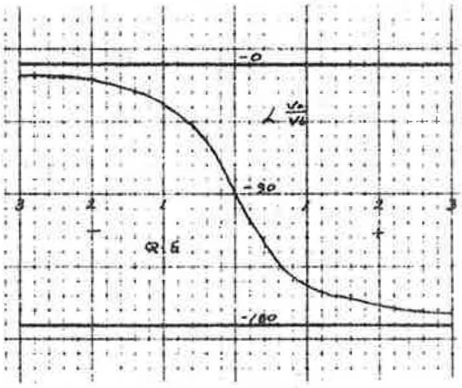


FIG. 5

Phase change with frequency for a Resonant Cavity







$$\frac{V_o}{V_i} = \frac{1/j\omega C}{R + j\omega L + 1/j\omega C}$$

$$= \frac{1}{1 - \left(\frac{\omega}{\omega_o}\right)^2 + j\omega CR}$$

$$\frac{V_o}{QV_i} = \frac{1}{Q\left(1 - (1+\delta)^2\right) + j}$$

$$= \frac{1}{Q\left(2\delta + \delta^2\right) + j}$$

WHEN $\delta \ll 1$:-

$$\frac{V_o}{QV_i} \doteq -\frac{1}{2Q\delta + j} \quad \text{— (1)}$$

FOR $2Q\delta \ll 1$ $\quad Q \doteq 2Q\delta$

AND $$\frac{d\phi}{df} = \frac{2Q}{f_o} \quad \text{— (2)}$$

(1) IS PLOTTED ABOVE AS A UNIVERSAL RESONANCE CURVE

WHERE:- V_o = CAVITY FIELD
V_i = VOLTAGE ACROSS COUPLED INDUCTANCE OF DRIVE LOOP
L = CAVITY INDUCTANCE
C = CAVITY CAPACITANCE
R = CAVITY LOSS RESISTANCE

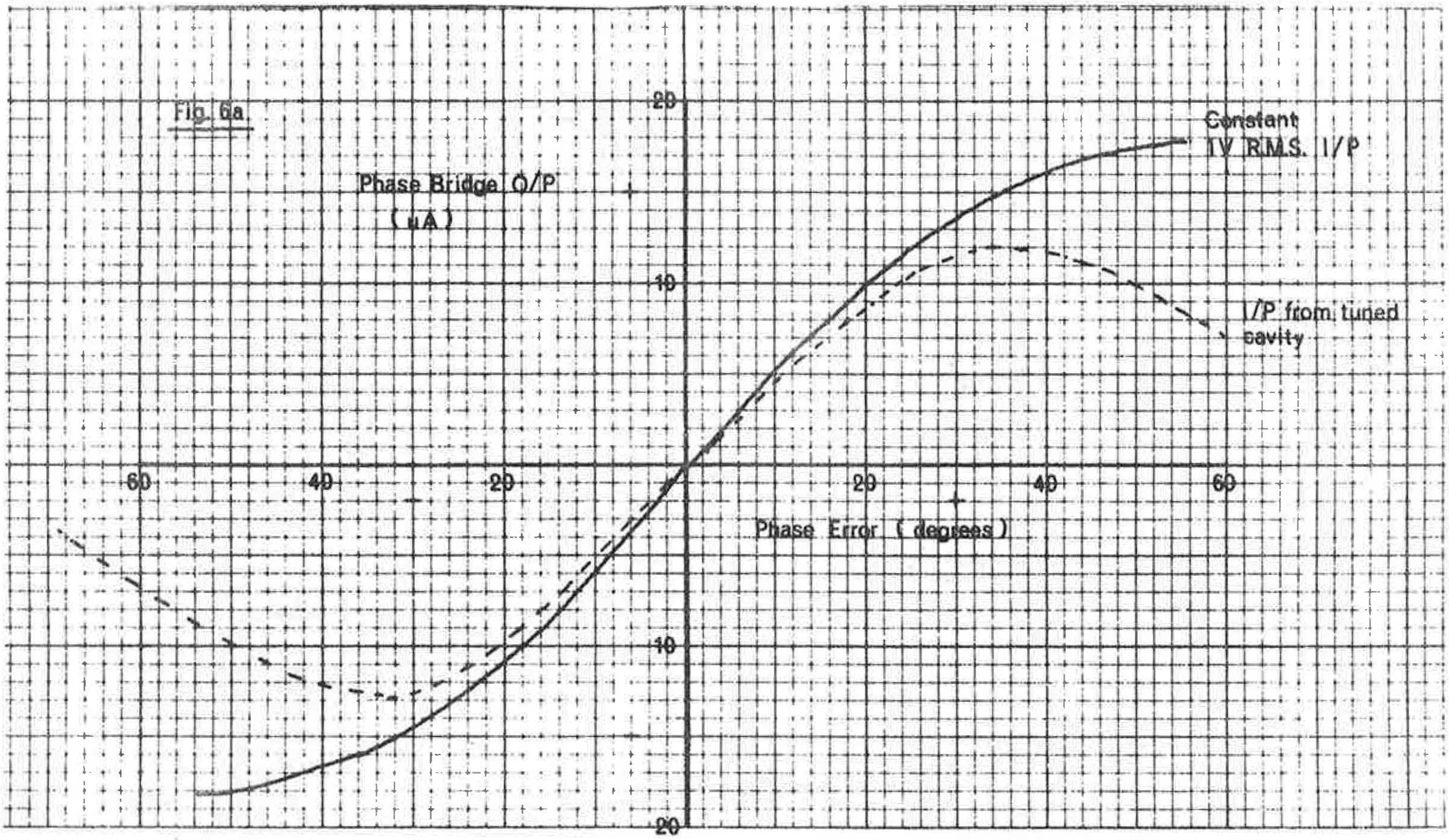
$$W_o = \frac{1}{\sqrt{LC}}$$

$$\delta = \frac{\omega}{\omega_o} - 1$$

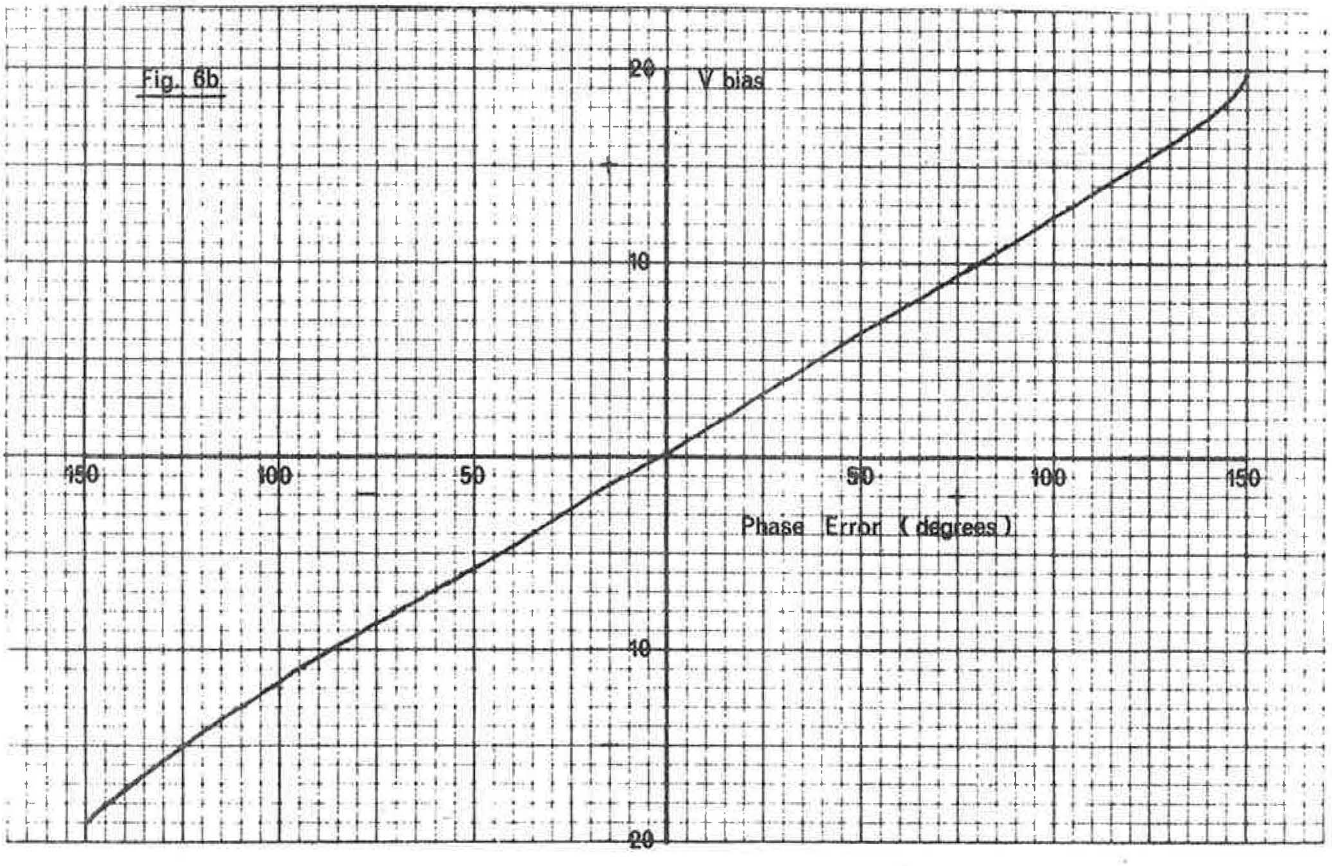
$$Q = \frac{1}{\omega CR}$$

FIG 6

Phase Bridge rectified output against Phase Error



Phase Bridge reset bias for phase null against phase error



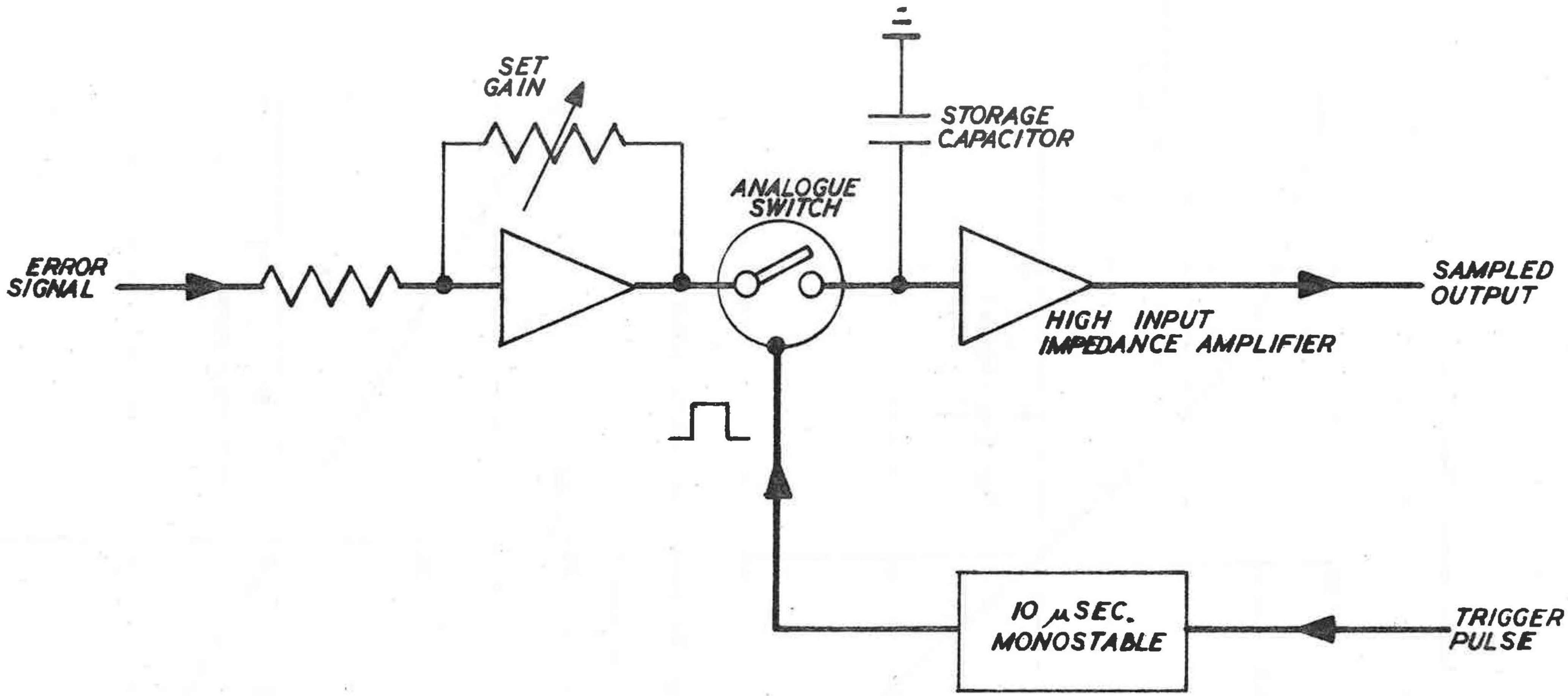


DIAGRAM OF SAMPLE & HOLD AMPLIFIER

FIG. 7