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CS100 Stabilization System

INSTRUCTION MANUAL

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With compliments

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INTRODUCTION

The versatility and efficiency of the Fabry-Perot interferometer have led to its widespread use for solving a number of spectrometric problems ranging from the detection and analysis of faint extra-galactic sources of astronomical interest to the study of rapidly changing phenomena in high powered lasers. However, to achieve optimum performance from the interferometer its plates must be held parallel and the distance between them must be controlled to a very high degree of accuracy; in fact departures from parallelism and required spacing should be much less than the surface irregularities of the plates themselves.

Modern interferometer plates can be polished so that surface irregularities are less than about 2.5 nm ($\lambda/200$ at λ = 500 nm) so to avoid degrading the performance of the instrument, mechancial errors should be less than about 1 nm. It is very difficult to achieve stabilities of this order for any appreciable length of time in a system that must also allow the plate-spacing to be varied by accurately controlled amounts, unless some form of active feedback is employed to sense the actual plate position.

Until now active feedback systems have used light beams to sense errors, or require a bright spectral line in the source being investigated. This obviously limits the application of the instrument to fairly bright sources as in the first case stray light from the control beams can easily swamp the signal being investigated and the nature of the second technique requires a bright source if long time-constants for correction are to be avoided.

The CS100 is an active Fabry-Perot interferometer control system that provides the necessary accuracy without using light in any way to derive the required error signals. It will thus maintain the instrumental function of the instrument whether the source of interest be bright or faint, correcting errors in typically less than 0.5 mS.

The fore-runner of the CS100 was developed in the Astronomy Group at Imperial College, London, by a small team of people who later became the founder members of Queensgate Instruments Limited. The original instrument was first used in 1973 (1, 2) and since then has undergone continuous and considerable improvement so that, with the CS100 and the associated 'ET' series of etalons, the Fabry-Perot interferometer becomes not only a very powerful tool for spectrometric analysis but also one that is both reliable and easy to use.

The Manual

This manual is divided into three parts. Part 1 describes the operating principles of the CS100 system. Part 2 gives instructions for its general use and Part 3 contains circuit diagrams.

It is not necessary to fully digest Part 1 to be able to use the CS100; Part 2 is all that is required for this, but as with any new piece of instrumentation a knowledge of the operating principles will help to realise the full potential of the CS100 in a particular application.

Part 3 need only be consulted for servicing and fault finding.

SPECIFICATION

Where necessary, performance figures given below are related to place displacements of an ET series etalon. Displacements are normally expressed in pm, 1pm = 10^{-12}m.

Micrometer capacitance	..	nominally 22 pF
Capacitor pad spacing	..	nominally 50 µm
Piezo-electric transducer sensitivity	..	2.4 nm V^{-1}

Servo performance

Loop Gain	..	100-51200 switchable
Electronic Noise Equivalent Displacement per metre of etalon connecting cable	..	1pm $Hz^{-\frac{1}{2}}$RMS
Electronic Drift Equivalent Displacement	..	0±50 pm K^{-1}
Total electronic noise(0.5mS Time Const.)		1.5 nm p-p
Response Time with ET series Etalon	..	Typical 1 ms
Capacitance Bridge drive voltage	..	10V p-p nominal
frequency	..	15.625 kHz
Output voltage to piezo-electric transducers	..	±750 V
Operating temperature range	..	0-50°C ambient

Open loop gain and time constant may be selected either by front panel controls or digitally via the logic interface.

Etalon Parallelism and Spacing adjustments

Manual parallelism and spacing controls are provided, on the front panel, for initial adjustment of the etalon. External controls for subsequent etalon tuning are provided via the Logic Interface module.

	Range	Resolution
Manual parallelism	±0.5 µm	0.1 nm
Manual spacing	±5.0 µm	1.0 nm
External parallelism	±0.5 µm	0.25 nm (12 bits)
External spacing	±1.0 µm	0.5 nm (12 bits)

Non-linearity:plate displacement vs. External spacing adjustment	..	±0.1% FSR nominal

Temperature coefficient of adjustments	0 ± 5ppm K^{-1}

Logic Interface

A TTL compatible parallel interface module for external adjustments and control functions is supplied as standard. Other interfaces are available on request.

Power requirements

Voltage ..	105-125 or 210-250V A C
Power ..	120W
Frequency ..	50-60 Hz

Mechanical

19 inch rack mountable chassis:	Width	- 483 mm
	Height	- 133 mm
	Depth	- 417 mm
Cabinet for above:	Width	- 494 mm
	Height	- 154 mm
	Depth	- 445 mm

PART 1 - PRINCIPLES OF OPERATION

1.1 How does it work

The CS100 uses capacitance mictrometers to sense variations in parallelism and departures from required spacing and piezo-electric transducers to correct these errors. The techniques of capacitance micrometry have been developed to a high degree by R.V. Jones and J.C.S. Richards (3) who showed that it was possible to detect pico-metre displacements this way (1 pm = 10^{-12}m). We have developed and applied these principles in the CS100.

1.2 Construction of an ET series etalon

Fig. 1a shows schematically a plan view of an ET series etalon and Fig. 1b a side view. The interferometer plates are held apart by three piezo-electric transducers A, B and C. CX1, CX2, CY1, CY2 and CZ are five capacitors formed by evaporating gold pads onto one of the interferometer plates and fused-silica pillars optically-contacted to the etalon baseplate. The optical gap is set at time of manufacture by working the central fused silica 'filler' to the thickness that will give the required optical spacing. This filler is also optically contacted to the baseplate.

In operation parallelism information is obtained by comparing CX1 with CX2 (X channel) and CY1 with CY2 (Y channel). To monitor the spacing, CZ is compared with a fixed capacitor (CREF) mounted in the etalon (Z channel). Obviously, this fixed reference capacitor must be very stable, as any variation in its value will be falsely interpreted as a change in etalon plate spacing and the CS100 will actually cause an error. The reference capacitor may be a specially selected zero temperature coefficient ceramic capacitor or an air-spaced capacitor built onto one of the plates. The latter is an optional extra (not available on the ET28), but has a considerable advantage over the ceramic type.

1.3 Dielectric-constant variations

It is unfortunate that phenomena other than departures from parallelism and variations in mean optical spacing can cause capacitance variations. The biggest offender is variations in the dielectric-constant of the air in the capacitor gaps caused by variations of temperature, pressure and relative humidity. The CS100, however, detects differences in capacitance so if the dielectric-constant varies in the same way for both capacitors being compared, there will be no effect. This is always true of the X and Y parallelism control channels but is only true of the Z channel when an air-spaced reference capacitor is used.

To minimise dielectric-constant changes when a ceramic capacitor is in use, a gas connector is provided on all ET series etalons. This enables the etalon to be flushed with a dry inert gas (such as dry nitrogen), eliminating humidity variations. Temperature effects are also reduced as the dielectric-constant temperature-coefficient is small for dry air.

Normal humidity changes over a few days can cause about 5-10 nm plate spacing change using a ceramic capacitor and no dry-nitrogen flush. With the nitrogen flush this will reduce to less than 5 nm. Using an air-spaced reference capacitor, variations are generally less than ~ 1.0 nm with or without the nitrogen flush. Variations in parallelism are generally less than ~ 1.0 nm.

1.4 Static properties of the closed servo loop

This section deals with the basic principles of mechanical error correction and scanning.

1.4.1 The Capacitance Bridge

Fig. 2 shows schematically the bridge circuit used for comparison of the capacitors, and how the error signals are combined and applied to the piezo-electric transducers to form three closed servo loops.

The three capacitance bridges are excited by four A.C. bridge drive voltages of amplitude Vx, Vy, Vz and Vcom. Vx, Vy and Vz are nominally equal to each other and are nominally equal in amplitude but of opposite phase to Vcom. Thus, taking the X channel as an example, if CX1 is the same as CX2 and $|Vx|=|Vcom|$ no current will flow into the current amplifier Ax, i.e. the bridge is balanced. If now the etalon were to go out of parallel such that CX1 $\neq$ CX2 then a current would flow into Ax. This would be 90° phase advanced on Vcom if CX2 $>$ CX1 and 90° phase retarded if CX2 $<$ CX1. The phase sensitive detector PSDx, which uses Vcom phase shifted by 90° as a reference, will thus generate a voltage proportional to the error in magnitude and sense. This voltage is amplified by the B High Voltage amplifier and applied to transducer B in the correct sense to reduce the error, i.e. a closed-loop servo is formed. Moving the B transducer in response to an X channel error will actually generate a Y channel error, but, of course, this is corrected by the Y servo-channel. The Y servo-channel acts via transducer A which does not cause an X channel error. The Z channel works in the same way but the error signal is applied to all three piezo-electric transducers.

1.4.2 Correction of mechanical errors and scanning

In practice when the interferometer plates are parallel CX1 will not be exactly equal to CX2 and CY1 will not equal CY2 due to manufacturing tolerances. Also CZ will not equal CREF at the required optical spacing. Vx, Vy and Vz can be individually controlled to compensate for this and adjust parallelism and plate spacing. Fig. 3 shows a simplified diagram of the Z channel servo loop. We have

$$i = j\omega \text{ (Vcom CREF - VzCZ)} \qquad (1)$$

where i is the current into the current amplifier Az. Az has a transfer impedance (voltage out/current in) of Zt and feeds the PSD which has a gain jg (d.c. voltage out/a.c. voltage in). It is assumed here that g also includes the high voltage amplifier gain. The voltage applied to the piezo-electric transducers, which have coefficients of P $m.V^{-1}$, is thus ji Zt g. Equation 1 can be used to determine the effect of altering Vz or moving one of the plates. To illustrate the latter, it is assumed that one plate moves a distance dS1 (due to a mechanical disturbance, etc.) and the other is attached to the transducer and is moved dS2 by it. Assuming Vcom and CREF are constant:-

$$di = j\omega(VzdCZ + CZdVz) \qquad (2)$$

also

$$\frac{dCZ}{CZ} = \frac{dS1 - dS2}{So} \qquad (3)$$

and

$$dS2 = jZt\ gP\ di \qquad (4)$$

Combining equation 2, 3 and 4 gives:-

$$dS2 = (dS1 + So\ \frac{dVz}{Vz})\ \frac{M}{1+M} \qquad (5)$$

where

$$M = \frac{\omega Zt\ PVz\ CZ}{So}$$

The quantity M is the amount the transducer would move for a given plate movement if it were not coupled back to the etalon and is known as the open loop gain of the system. Equation 5 can be written in terms of the actual gap change ε :-

$$\varepsilon = dS2 - dS1 = \frac{dS1}{1+M} + So\ \frac{dVz}{Vz}\ \frac{M}{M+1} \qquad (7)$$

So any mechanical disturbance will be reduced by a factor of (1+ M) and the spacing will change linearly with dVz, a small voltage added to VZ. In practice M is very large (up to 50000) so residual errors are very small, but as will be shown even this small error can be eliminated. The same analysis applies to the X and Y channels.

The small voltages dVx, dVy and dVz are generated by adding voltages controlled by the front panel X and Y PARALLELISM controls and Z SPACING controls to voltages produced using digital to analog converters accessible via the control bus. In practice the front panel controls are used for initial set-up and the digital control bus for scanning and remote parallelism adjustments: varying dVx and dVy will adjust the parallelism of the interferometer plates and varying dVz will adjust their spacing.

1.4.3 The Resistive Offset

In practice losses in the cables and non-ideal behaviour of the bridge drive circuitry produce a component of current into the amplifiers aX, Ay, Az that is in phase with Vcom or Vx, etc., rather than 90^o out of phase. This 'resistive' component is not detected by the PSD's so causes little harm, but it is best to null it out to avoid the possibility of overloading the amplifiers. To enable this an R BALANCE control is provided on each channel which adds a signal at $\pm 90^o$ to Vcom to Vx, Vy and Vz. Three auxiliary PSD's are provided in the CS100 that are referred to Vcom and thus generate a d.c. signal proportional to the resistive component. This may be monitored by the front panel meters (METER DISPLAY switch set to RESISTIVE COMPONENT) and manually nulled using the R BALANCE controls.

1.5 Dynamic behaviour of the servo-loop

This section examines the response of the system to varying mechanical offsets and scan voltages.

1.5.1 Servo-loop controls - etalon resonance

The remaining controls on the front panel set various parameters affecting the performance of the servo-loop. The most important of these are the open loop gain and time constant controls.

From equation 7 it would seem that the open loop gain, M, should always be set as large as possible but in practice it is convenient to be able to vary it from about 100 to 50,000. This aids setting up unknown etalons and as will be shown helps in setting the closed-loop time response of the system.

Also in practice the system will not respond instantaneously to an input displacement error and, in fact, it is highly desirable that it should not respond instantaneously. The 'sense' of the transducer movement is arranged so that displacement errors are reduced rather than increased, but all etalons have a mechanical resonance and at the resonant frequency there is a reversal of phase between the driving force (the piezo electric transducer) and the sensor (the capacitance micrometer). Thus if the open loop gain is greater than unity at the resonant frequency, oscillations will build up and the system will behave as a very expensive high voltage oscillator. The frequency response of the system can be optimised by selecting an open loop time constant between 1s and 500s (there is also a 1.6 mS time constant available but this is only useful during setting up). This time-constant produces a 6 dB per octave roll-off in frequency response and is selected so that the open loop gain is very much less than unity at the etalon resonance. In practice etalon resonances occur around 5 k Hz but the exact frequency will vary from etalon to etalon. The fall-off in open loop gain with frequency is plotted in fig. 4 for various open loop time constants and with M equal to 50,000 (94 dB).

1.5.2 The system transfer function

At first sight it may seem that time constants of 1s to 500s would lead to a very sluggish system correcting errors very slowly. This is not the case. For a full treatment of the time response of servo systems reference should be made to a text on the subject, e.g. B.C. KUO (4) but some of the relevant results will be dealt with here.

The variation of gain with frequency is known as the transfer function of the system, but it is usual to express this in terms of complex Laplace operator s, ($s = \sigma + jw$). Transformation from the time domain (t domain) to the Laplace domain (s plane) can be done via the Laplace and inverse Laplace transforms, but more usually by using a set of Laplace transform tables. In terms of the Laplace operator, equation 7 becomes:-

$$\mathcal{E}(s) = \frac{dS1}{1+G(s)} + So.\frac{dVz}{Vz}.\frac{G(s)}{1+G(s)} \qquad (8)$$

where G(s) is the open loop transfer function of the system.

Fig.5 shows schematically the part of the CS100 circuitry that sets the open loop time response of the system and thus the system transfer function. Switch SW1 is controlled by the front panel INTEGRATE switch: SW1 is open when the INTEGRATE function is operative. Most of the following analysis deals with the simpler transfer function obtained when SW1 is closed.

With SW1 closed the open loop transfer function is the transfer function of the circuit of Fig. 5 and is:-

$$G(s) = \frac{M}{1 + s.\tau} \qquad (9)$$

where τ is the open loop time constant C1R1, and M is the open loop gain, in this case $A.(R1/R2)$

From equation 8 we can define two closed-loop transfer functions, one for mechanical disturbances:-

$$G'(s) = \frac{1}{1 + G(s)} \qquad (10)$$

and one for scan signals, etc.

$$G'(S) = \frac{G(s)}{1 + G(s)} \qquad (11)$$

The transfer function of equation 11 is the most useful to evaluate as it gives the response to scan commands and electronically induced noise. Also the effect of mechanical disturbances that should be treated by equation 10 can be found from it.

Substituting from equation 9 into 11:-

$$G'(s) = \frac{M}{M + 1} \cdot \frac{1}{1 + s.\left(\frac{\tau}{M + 1}\right)} \qquad (12)$$

This is the same form as equation 9 but with replaced by $\tau/(1 + M)$, i.e. the time constant has been reduced by a factor of $(1 + M)$. We can thus define a closed loop time constant:-

$$\tau' = \frac{\tau}{1 + M} , \qquad (13)$$

1.5.3 Response to a step function

In general the closed-loop response $C'(s)$ to a stimulus $R(s)$ is simply:-

$$C'(s) = G'(s)\ R(s) \qquad (14)$$

For a unit step function stimulus, e.g. a scan step, $R(s) = \frac{1}{s}$ giving:-

$$C'(s) = \frac{M}{1 + M} \cdot \frac{1}{(1 + s\ \tau').s} \qquad (15)$$

Transforming back into the time domain:

$$C'(t) = \frac{M}{1 + M} \cdot (1-\exp(-\frac{t}{\tau'})) \qquad (16)$$

Thus, if the CS100 is given a scan step it will move the plate connected to the transducer to (1-exp(-1)) of where it should be in a time τ'. Typically, τ will be 50s and M 25,000 giving $\tau' = 2$ mS but operation down to $\tau = 10$s and M = 50,000 giving $\tau' = 0.2$ mS is possible with some etalons. If the step function is applied mechanically, the gap will simply change by $(1 - C'(t))$, i.e.

$$\mathcal{E}(t) = \frac{1}{1+M} + \frac{M}{1+M} \exp(-\frac{t}{\tau}) \qquad (17)$$

The CS100 system thus responds very quickly to scan commands and rapidly corrects mechanical disturbances.

1.5.4 Closed loop frequency response and electronic noise

The frequency response of the system is, of course, directly related to the time response and the form of it can be found by substituting the sine stimulus $R(s) = \frac{\omega}{S^2 + \omega^2}$ into equation 14 and retransforming. The result is:-

$$C'(t) = \frac{M}{1+M}\left[\frac{\tau'\omega}{1+\tau'^2\omega^2}\exp\left(-\frac{t}{\tau'}\right) + \frac{1}{(1+\tau'^2\omega^2)^{\frac{1}{2}}}\sin(\omega t - \phi)\right] \qquad (18)$$

where $\phi = \tan^{-1}\omega\tau'$

This gives the response of the F.P. plate attached to the transducers to a signal generated in the electronics, e.g. a sinusoidaly varying scan, or to a motion of the other plate, i.e. a sinusoidal vibration. For a steady sine wave stimulus the term of interest is the amplitude of the steady state response.

This response is down to half the 'd.c.' value when:-

$$\omega_{\frac{1}{2}} = \frac{3^{\frac{1}{2}}}{\tau'} \qquad (19)$$

With $\tau' = 0.2\,\mathrm{mS}$, $\omega_{\frac{1}{2}} \approx 8.7\times10^3$ or $f = 1.4\,\mathrm{kHz}$.

Equation 19 can be used to derive an approximate noise bandwidth for the system but it is not strictly correct to ignore the transient response when dealing with noise signals. Using the figures quoted and a typical electronic noise figure of 3.5 pm $\mathrm{Hz}^{-\frac{1}{2}}$ there would be approximately 130 pm RMS noise displacement on the plates or approximately 370 pm p-p motion ($\lambda/1400$ at $\lambda = 500$ nm). In practice transient effects and sources of noise outside this bandwidth (generated in circuitry after the bandwidth determining element of fig. 5) contribute to the overall p-p plate motion but the total noise is less than $\lambda/200$ and is generally better than $\lambda/500$ p-p at $\lambda = 500$ nm. The best F.P. plates are only polished to $\lambda/200$ so in most circumstances electronic noise is negligible. In spite of these effects, however, one can do a certain amount of 'trading off' between time response and noise by altering the gain and time constant of the system (and thus τ') to suit the experiment in hand.

1.5.5 Response to vibrations

If a sine wave stimulus is applied to the etalon, e.g. a steady vibration, the F.P. plate spacing will vary as the difference between the applied stimulus and the response of equation 18. Thus the steady state amplitude of the variation in the gap will be roughly:-

$$\varepsilon(\omega) = \left(a^2 + 1 - 2a.\cos\phi\right)^{\frac{1}{2}} \qquad (20)$$

where $a = \dfrac{1}{(1+\tau'^2\omega^2)^{\frac{1}{2}}}$ and $\phi = \tan^{-1}\omega.\tau'$

This function is plotted for various values of τ' in fig. 6 as can be seen with τ' =0.2ms, vibrations up to 480 Hz will be reduced to one half. Vibrations at 100 Hz will be reduced to $\approx \frac{1}{8}$.

These are theoretical figures and in practice the response may not be exactly as shown in fig. 6 which just plots the steady state response: vibrations are rarely steady sine waves, but the ET series etalons are rigidly constructed and vibrations have little effect even without the CS100 servo operating. Under normal conditions the CS100 will reduce any remaining vibration effects to negligible levels ($\ll \lambda/200$).

1.5.6 Integrate mode

Referring to equation 17, there is still a small residual error, $^1/1+M$, in the response of the F.P. gap to a mechanical disturbance and from 16 the gap can only get to M/1+M of where it really should be in response to a scan command. At normal gains ($\sim$25000) these two figures are so close to zero and unity that the error is negligible, but at low gains there could be a noticeable effect. This can be eliminated by switching to INTEGRATE mode, i.e. SW1 of fig. 5 open.

With SW1 open the open loop transfer function becomes:-

$$G(s) = M.\frac{1+\tau_1 s}{s(\tau_1+\tau+\tau_1\tau s)} \tag{21}$$

where $\tau = R_1C_1$ and can be selected by the time constant controls as before, and $\tau_1 = R_1C_2$ and is fixed at 11s. The closed loop transfer function G(s)/(1+G(s)) becomes:-

$$G'(s) = \frac{\omega^2(1+\tau_1 s)}{s^2+2\zeta\omega s+\omega^2} \tag{22}$$

where

$$\omega = \frac{M}{(\tau\tau_1)^{\frac{1}{2}}} \tag{23}$$

$$\zeta = \frac{\tau_1+\tau+M\tau_1}{2(\tau\tau_1 M)^{\frac{1}{2}}} \tag{24}$$

The response to a unit step function $^1/s$ is thus

$$C'(s) = \frac{\omega^2(1+\tau_1 s)}{s(s^2+2\zeta\omega s+\omega^2)} \tag{25}$$

which for $\zeta > 1$ transforms to

$$C'(t) = K_1(1-\exp(-\alpha t))-K_2(1-\exp(-\beta t)) \tag{26}$$

where

$$K_1 = \frac{\omega^2(1-\alpha\tau_1)}{\alpha(\beta-\alpha)} \quad (27)$$

$$K_2 = \frac{\omega^2(1-\beta\tau_1)}{\beta(\beta-\alpha)} \quad (28)$$

$$\alpha = \omega\left(\zeta-(\zeta^2-1)^{\frac{1}{2}}\right) \quad (29)$$

$$\beta = \omega\left(\zeta+(\zeta^2-1)^{\frac{1}{2}}\right) \quad (30)$$

This is valid for all gain and time constant combinations on the CS100. The steady state response is $(K_1 - K_2)$ and using equations 27 to 30 this can be shown to be unity for all values of $M > 0$, i.e. the steady state error is eliminated. At large M:-

$$\begin{aligned} \alpha &\longrightarrow 1/\tau_1 \\ \beta &\longrightarrow 1/\tau' \\ K_1 &\longrightarrow 0 \\ K_2 &\longrightarrow -1 \end{aligned}$$

and equation 26 reduces to equation 16. Thus at normal (high) gains the INTEGRATE function does not affect the system performance noticeably.

1.6 General Comments

The preceding analysis of the dynamical behaviour of the CS100 gives a rough idea of how it will perform in most practical situations. No account of the etalon resonance has been taken in calculating the system transfer functions so there will be some departure from theory at low time constants. In general, the effect of the resonance is to make τ' apparently shorter than would be expected from the equations given, and as has been stated in section 1.5.1 the system will actually oscillate if τ' is made too low: this is not apparent from the transfer functions quoted.

The CS100 has a number of features not yet mentioned but dealt with in the next section. One of these is the PROTECTION circuit which detects oscillations due to incorrect setting of the gain and time constant controls and opens the servo-loop automatically, avoiding potential damage to the etalon. Other fault conditions are also detected. Also, reference is made to the front panel controls but these functions are also duplicated via the control bus, enabling full remote operation or computer control of the system.

The full capabilities and potential of the CS100 system will be realised as the system is used, and as will be apparent from the next section we have made its use as simple as possible, allowing the experimenter to concentrate on the experiment in progress without having to worry about operation of the instrumentation.

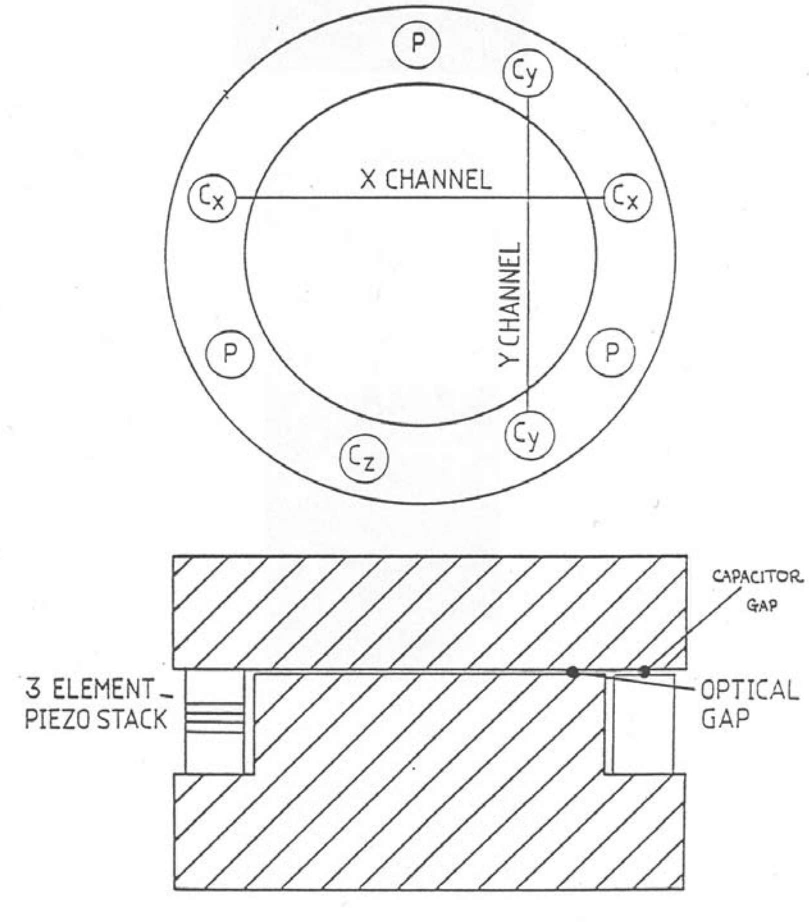

FIGURE 1. ET SERIES ETALON

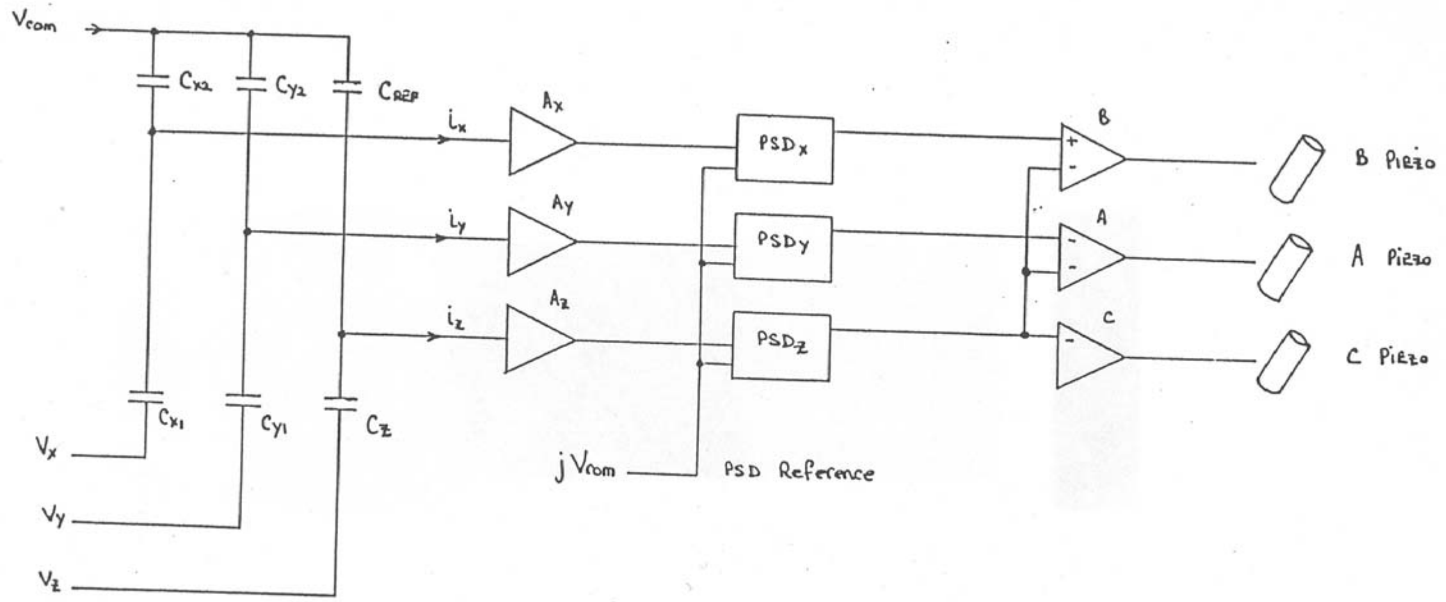

FIGURE 2 BRIDGE, P.S.D.s AND P.Z.T.s

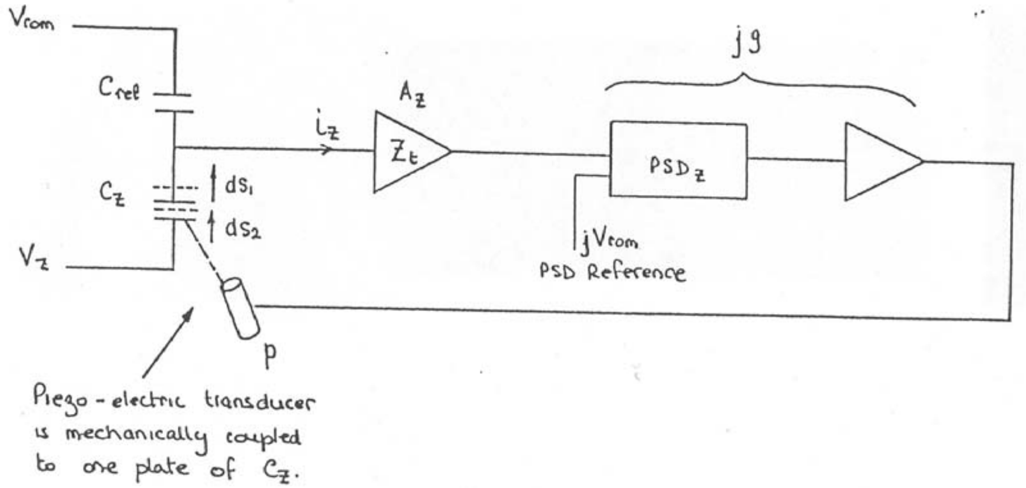

FIGURE 3 SIMPLE Z CHANNEL LOOP

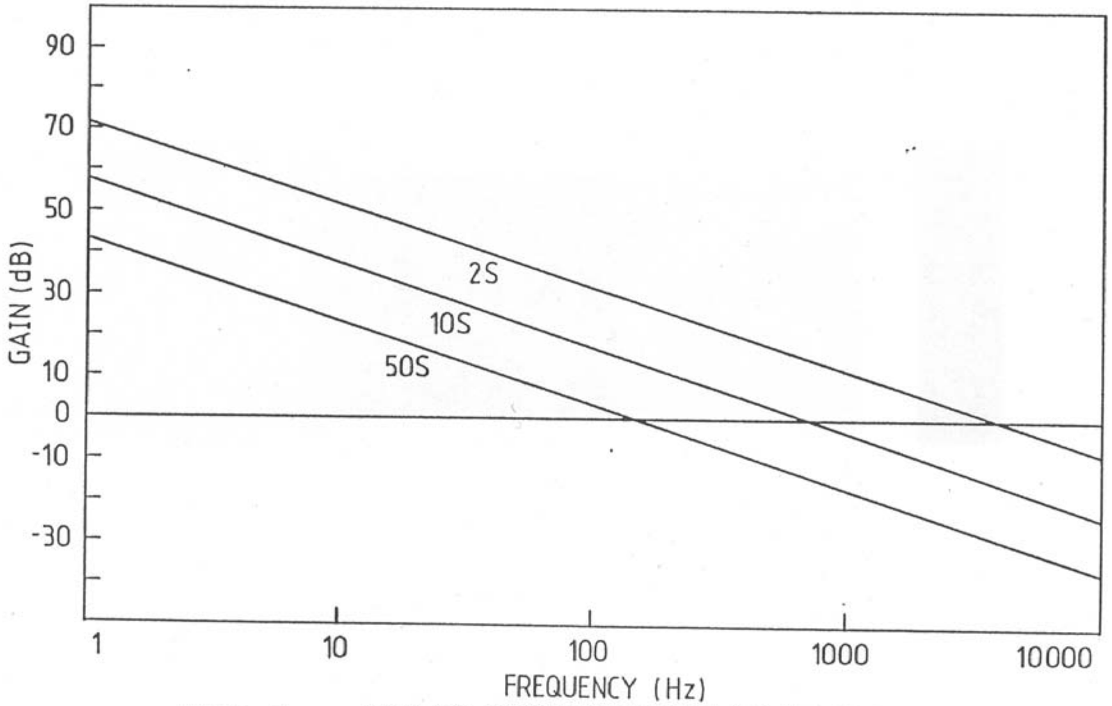

FIGURE 4. GAIN VS FREQUENCY (OPEN LOOP) M=50,000

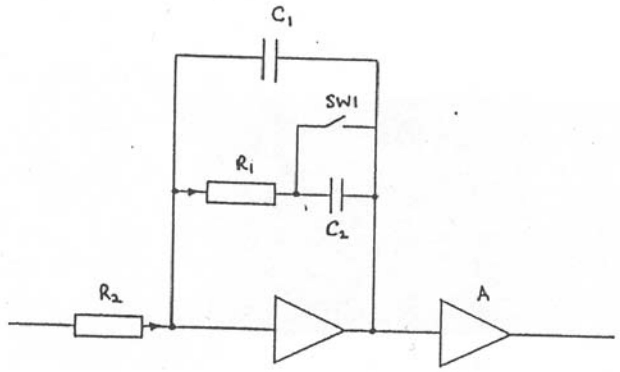

FIGURE 5 AMPLIFIER AND INTEGRATOR

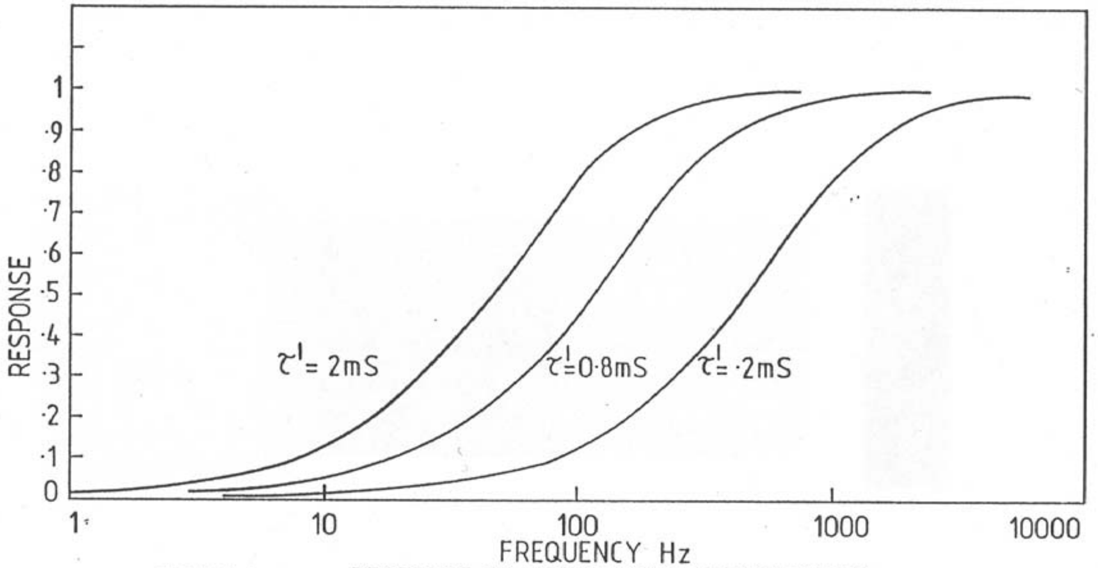

FIGURE 6. RESPONSE TO VIBRATIONS (STEADY STATE)

PART 2 - USING THE CS100 SYSTEM

2.1 Selecting the line voltage

The CS100 can be operated from either a 110-120V or 220-240V, (50-60 Hz) supply line. Each system is factory set for the standard line voltage in the user's country and is clearly labelled. Should operation be required over the voltage range other than the one set, this may be changed by re-arranging wire links inside the CS100. ENSURE THAT THE LINE AND OTHER BACK PANEL LEADS ARE UNPLUGGED BEFORE COMMENCING.

2.1.1 Access to the voltage selection links

The voltage selection links are inside the rear section of the CS100. (See fig. 7). To gain access, remove the seven cross-headed screws holding the rear panel in place (six on units with serial numbers up to and including 8004) and remove the rear panel. On units with serial number 8005 or greater removing the top middle two of these screws enables the centre section of the top of the case to be lifted off for inspection of the whole chassis. Having removed the case back panel, loosen the four captive screws holding the chassis back panel in place and allow it to hinge downwards. The chassis back panel is now only held by the electrical connections to the fan, etc: take care not to strain these. A screw terminal block is now visible, mounted on the unit base-plate and should be wired for the correct voltage as shown in fig. 8. When replacing the chassis back panel take care not to trap wires between it and the rest of the chassis.

WARNING: Although on most units the top of the case is removable for inspection purposes, the CS100 should not be operated with it removed as there are lethal voltages on the power transistors and resistors thus exposed. Also overheating will occur due to disturbance of the fan-induced air flow.

2.1.2 Connecting to the line supply

A three core lead with IEC connector is provided for connection of the CS100 to the user's line supply. The user must provide a suitable plug. Connection should be made as follows:-

BROWN - LIVE
BLUE - NEUTRAL
GREEN/YELLOW - GROUND

WARNING: For correct operation and safety the CS100 must be grounded.

2.1.3 Fuses

The CS100 is protected by two fuses mounted on the rear panel of the instrument. The LINE fuse should be 5A for 110-120V operation or 3A for 220-240V operation, The HV fuse should be 250 mA. Both fuses should be fast-blow types.

2.2 Connecting an etalon

2.2.1 ET Series Etalons

The etalon should be connected to the CS100 rear panel BRIDGE DRIVE (5 Way socket), BRIDGE RECEIVERS (three one-way sockets) and PIEZO DRIVES (multiway connector with locking screw) using the cable provided. Take care to connect the X, Z and Y sockets on the CS100 to the corresponding sockets on the CS100, the three individually screened cables are numbered 1, 3 and 2 to aid this. Also take care when inserting the 5 way BRIDGE DRIVE connector as it is possible to misalign and bend the connection pins if it is carelessly inserted.

2.2.2 Other etalons

Queensgate Instruments is able to offer ET series etalons to cover most applications however the user may wish to construct an etalon for a special purpose. In this case Queensgate Instruments will be happy to advise at the design stage of the etalon to ensure compatibility with the CS100 and to discuss the performance that should be achieved.

The CS100 cannot be used with Queensgate Instrument's EL series etalons.

2.3 Controls and front panel monitors

There are three main groups of controls on the front panel, illustrated in fig. 9. These are nine bridge balance controls grouped together to the left of the instrument, six loop gain and time constant ten way rotary switches in the centre, and four control toggles and a power rocker switch to the right. There is also one rear panel switch.

2.3.1 Bridge Balance Controls

These are labelled X PARALLELISM, FINE and COARSE; Y PARALLELISM, FINE and COARSE; Z GAP FINE and COARSE and X, Y, Z, R BALANCE.

The X and Y PARALLELISM controls are used to set the etalon plates parallel with the system in closed loop mode and to balance the X and Y capacitance bridges in open loop mode. With the loops closed there is nominally ± 1 µm of plate parallelism adjustment available with the COARSE eleven position rotary switches and 0.21 µm available with the FINE ten-turn potentiometers. The FINE controls thus just overlap the COARSE increments.

The Z GAP controls are used to set the initial mean spacing of the etalon plates with the system in the closed loop mode and to balance the Z capacitance bridge in open loop mode. With the loops closed there is nominally ± 5 µm of offset available with the COARSE eleven position rotary switch and 1.05 µm available with the FINE ten turn potentiometer. The FINE control thus again overlaps the COARSE increments. Although ± 5 µm of offset is provided, the standard transducers in the ET series etalons only have a range of about ± 2 µm maximum. The large offset range is provided to cater for non-standard transducers and errors in the reference capacitor (see section 1.2).

The X, Y and Z R BALANCE controls are provided to balance out the unwanted component of the bridge drive frequency in phase quadrature with the capacitative error signal from the bridges. They are used in both open and closed-loop modes. (See section 1.4.3).

2.3.2 Open loop GAIN and TIME CONSTANT controls

The full function of these controls is described in section 1.5. They are used to set the static and dynamic response of the etalon to mechanical disturbances and scan commands. (See section 2.5 for set-up procedure). In general, low gains and time constants are used for setting up the system in open loop mode. With the loops closed the gains are set high and the time constants are selected for optimum time response.

2.3.3 Control toggles

RESET: This spring-loaded toggle initializes the system by taking the loop gains to zero independently of the front panel settings and discharging the capacitors in the phase-sensitive detector and integrator circuitry. It is used mainly when changing the TIME CONSTANT controls in closed-loop mode, and reclosing the loops when they have been opened by the protection circuitry.

CLOSE LOOPS: When switched up this immediately activates a reset (see above) to initialize the system. After a delay of about half a second the high voltage supply to the piezo-electric transducer drive amplifiers is turned on and after a further half-second the reset is released to enable correct closed-loop operation. At this stage the CLOSE LOOPS LED will light.

INTEGRATE: When switched up, this modifies the loop transfer function to remove any residual static error (see section 1.5.6). The INTEGRATE LED will light with INTEGRATE active.

METER DISPLAY: When up (ERROR SIGNAL) the three centre zero meters monitor the outputs from the X, Y and Z capacitance micrometer phase-sensitive detectors. In closed-loop mode these can be used to determine the voltage applied to the transducers to maintain parallelism and required gap. In open loop mode they are used to balance the capacitance bridges or measure the flexure of an etalon in response to a mechanical disturbance (see section 2.10 for a full description).

With the METER DISPLAY toggle down(RESISTIVE COMPONENT) the three meters monitor the unwanted resistive component of the bridge signal enabling it to be nulled using the X, Y and Z R BALANCE controls.

POWER: Turns on the power. The POWER LED indicates that the system is turned on.

2.3.4 Front panel monitor sockets

X, Y and Z AC MONITOR: The outputs from the AC amplifiers are available at these sockets, i.e. the amplified 16 k Hz error signals from the bridges. See section 2.11 for the use of these signals.

X, Y and Z DC MONITOR: The outputs from the X, Y and Z phase sensitive detectors are available at these sockets, i.e. the demodulated and smoothed error signal (it is this signal that is displayed by the meters when the METER DISPLAY switch is set to ERROR SIGNAL). The Z channel DC MONITOR is particularly useful when setting the time response of the system as it shows the signal fed to all three piezo electric transducers to control the etalon plate spacing, i.e. it will show the scan waveform. For a full analysis of these signals see section 2.5 and 2.11.

REF. MONITOR: The 16 k Hz square-wave reference for the phase sensitive detectors is available here. This can be used to trigger an oscilloscope when investigating signals at the AC MONITOR points.

2.3.5 OVERLOAD LED's

Under normal closed-loop operation the signals at the outputs of the AC amplifiers will be small ($< 1V$ p-p). The OVERLOAD LED's will be triggered by an output greater than 15V p-p. Such signals would be generated by violent oscillation of the system due to incorrect GAIN and TIME CONSTANT setting or by a large unbalanced resistive off-set. Fault conditions such as an open or short circuited etalon connection would also generate such signals.

2.3.6 PROTECTION feature

All ET series etalons are of rugged construction and should not be damaged even by gross misalignment or oscillations. However, to avoid such conditions persisting a protection circuit is provided that detects such non-standard operation and opens the servo-loops, switching off the high voltage supply to the piezo-electric transducer drive amplifiers. This circuit is enabled when the rear panel protection switch is ON and is triggered by the presence of an X, Y or Z OVERLOAD. When the protection circuit is thus triggered, the CLOSE LOOPS LED will go out. After the fault condition has been rectified normal operation can be restored by pressing and releasing RESET or switching CLOSE LOOPS down and up again.

2.4 Switching on

Before switching on the CS100 ensure that the line voltage is correct, the etalon is correctly connected and the rear panel PROTECTION switch is ON.

2.4.1 Using an etalon for which the CS100 settings are known

Each ET series etalon provided by Queensgate Instruments has a table of suggested settings for the CS100 PARALLELISM, R BALANCE, GAIN and TIME CONSTANT controls.

1. Set the controls to the values supplied.
2. Ensure that the CLOSE LOOP and INTEGRATE switches are down and the METER switch is up (ERROR SIGNAL).

3. Turn on power. The meters will probably go off scale and one or more OVERLOAD lights may come on - this is normal.
4. Switch the CLOSE LOOP switch to the up position. The meters should instantly come to within ± 0.5 volts of zero and the OVERLOAD lights should go out. After a delay of about one second the CLOSE LOOPS LED should light indicating correct operation. The meters will move away from zero but be on scalė, reading somewhere between plus or minus 5V.
5. Switch the METER DISPLAY switch to RESISTIVE COMPONENT and if necessary zero the reading using the relative R BALANCE controls. Switch the METER switch back to ERROR SIGNAL, and the INTEGRATE switch up.

The etalon should now be parallel, but this should be checked when used for the first time and subsequently after about every week of use as described in section 2.6.

If the CLOSE LOOP LED fails to light at 4 above, check the R BALANCE as in 5 before closing the loop. If the loops still fail to close turn the X, Y and Z GAINS down to 32 and try again. If the loops now close, increase the gains step by step to the recommended setting. If the CLOSE LOOP LED then goes out, operate at a lower gain and check the time response optimisation as described in section 2.5. Failure of the loops to close after the above have been tried probably indicates a faulty connection to the etalon: check all the connections and if they are correct follow the complete set-up procedure as described in the next section.

An operable gain setting less than that recommended does not necessarily mean there is a fault. If the etalon was not supplied at the same time as the CS100, the suggested front panel settings would have been determined by reference to a 'standard' held at Queensgate Instruments. Account is taken of any difference between the user's CS100 and the standard when compiling the suggested settings and though the procedure is generally accurate there is scope for error. This is especially true of the gain settings.

2.4.2 Using an etalon for which the CS100 settings are not known

If the front-panel settings for a particular etalon are lost or not known, or if the procedure of section 2.3.1 fails, the following procedure should be adopted. This consists of balancing the capacitance bridges with the etalon in its 'relaxed' state, i.e. with the plates parallel only to the tolerance of manufacture, and then optimising the gain and time constants and finally aligning the plates parallel.

The initial balance is done with the loops open and low gain and time constant.

1. Set the X, Y and Z GAIN's to 8 and TIME CONSTANT's to 1.6 ms.
2. Ensure that the CLOSE LOOP and INTEGRATE switches are down, and the METER DISPLAY switch is up. (ERROR SIGNAL).
3. Turn on the power.
4. Null the X, Y and Z meters using the X, Y and Z COARSE and FINE PARALLELISM controls. There will be some interaction between the three channels so some iteration may be necessary. Do not aim to achieve an exact null: even at this gain the capacitance micrometers are very sensitive, the full scale meter reading corresponds to approximately ± 2 nm of plate movement at gain 8. The meters will also flicker due to electronic noise.

   NOTE: Turning the COARSE and FINE controls clockwise results in a meter needle movement from left to right.
5. Switch the METER DISPLAY switch to RESISTIVE COMPONENT and null the readings using the R BALANCE controls. This can be done quite accurately but note that this time a clockwise rotation of the R BALANCE control

moves the meter needles from right to left.

6. Switch back to ERROR SIGNAL and repeat 4. Iterate between 4 and 5 until the meters read zero when switched to RESISTIVE COMPONENT and are on scale when switched to ERROR SIGNAL. The bridges are now well enough balanced for the loops to be closed easily.
7. Set the gains to 32 and time constants to 250s and switch the CLOSE LOOP switch up. After a delay of about 1s the LOOP CLOSED LED will light indicating correct closed-loop operation.

The etalon is now under servo control but the GAIN and TIME CONSTANTS are not optimised and the plates will not necessarily be parallel. The X, Y and Z meters should be at or near zero with the METER DISPLAY switch in the ERROR SIGNAL position and at zero with it in the RESISTIVE COMPONENT position.

2.5 GAIN and TIME CONSTANT optimization

The aim of this procedure is to get the best possible response to a scan step input. A dual trace oscilloscope and a pulse generator capable of producing TTL compatible square waves from 10 Hz to a few hundred Hz are required.

1. Connect the TTL pulse generator to pin n and pin y (ground) of the back-panel CONTROL BUS connector (full use of this bus is described in section 2.8).
2. Also connect the pulse generator output to one channel of the 'scope and the Z DC MONITOR output to the other. Trigger the 'scope on the pulse generator.
3. Close the servo-loops as described in section 2.4 and turn on the pulse generator, set for 10 Hz square waves.

The Z DC MONITOR output will probably be a highly damped square wave of about 0·25V amplitude - see fig.10a.

Increasing the gain or decreasing the time constant will sharpen up the response. Increase the Z GAIN step by step, after each step incrementing the X and Y GAINS and checking and, if necessary, nulling the resistive offset until either a gain of 256 (x 100) is reached or the response is critically damped as in fig. 10b. If the response is critically damped at gain settings lower than 256, the TIME CONSTANT settings are too low: increase them (Z first) until a gain of 256 gives critical damping.

NOTE: When changing the TIME CONSTANT settings in closed-loop mode, hold RESET down, change the TIME CONSTANT setting and release RESET. This avoids transients tripping out the protection circuit.

As the response is sharpened up, the pulse generator frequency can be increased to ease viewing on the 'scope. The response will probably still be over damped at 256 so reduce the TIME CONSTANT settings (Z first then X and Y) until it is critically damped. If the time constant is reduced further the response will become underdamped as in fig. 10c and finally the system will oscillate if the time constant is taken too low. Most systems end up with the X, Y and Z GAINS at 256 (actual gain 25600) and OPEN LOOP TIME CONSTANT's of 10s or 25s, though some may need X and Y OPEN LOOP TIME CONSTANT's a step higher than Z to prevent oscillation. The closed-loop time constant (the rise-time of the displayed Z MONITOR output) will be around 0.2 mS for a critically damped response with an ET28, 50 or 85.

If the user does not require such a fast response, i.e. if there is no vibration and rapid scanning is not going to be used, it is better to increase the time constant to reduce the elctronic noise bandwidth (see section 1.5.4). This, however, should be done after the plates have been aligned parallel (see next section) as if large increments of the COARSE PARALLELISM controls are required, the system may not respond fast enough and the protection circuit will trip. The protection circuit may also trip if large scan steps are made, (see 'Using the Control Bus', section 2.8).

2.6 Aligning the plates parallel

First optimise the time response as in 2.5. Alignment is easiest done by observing the ring pattern produced when a diffuse source of a suitable spectral line is viewed through the etalon. For most etalons intended for use in the visible region, rings can be produced from an ordinary fluorescent lamp source. As the observer's eye is moved from side to side across the etalon the ring pattern will appear to contract or expand if the etalon plates are not parallel. First move along the X axis (see fig. 11 for a definition of the axes) and adjust the COARSE X PARALLELISM control to minimise the expansion or contraction of the rings as the eye is moved. Then move along the Y axis and repeat with COARSE Y. The FINE Z control should now be used to make a ring just appear in the centre of the field and the alignment procedure should be repeated observing this ring and adjusting the X and Y FINE PARALLELISM controls. This small central ring is very sensitive to departure from parallelism so provides an accurate indication of alignment. Some iteration between X and Y may be necessary to get perfect alignment. After aligning, or, if the protection circuit opens the loops while adjustments are being made, check the RESISTIVE COMPONENT and null if necessary - some plate realignment may then be required if there was a large R component to null.

2.7 Switching off

Once the system has been optimised, the CS100 can be switched off simply by turning off the power, leaving all the controls in the optimised position and the CLOSE LOOPS and INTEGRATE switches up. Switching on the power again will initiate the close loop sequence and the CLOSE LOOPS LED should light after about 1s indicating correct operation.

With some systems a brief 'buzz' may be heard from the etalon when the system is switched off this way. This is not harmful but can be avoided by opening the loops before switching off, closing them after switching on again.

2.8 Using the Control Bus

The function of all the controls on the front panel apart from the POWER switch are operable in some way via the rear panel CONTROL BUS. Table 1 lists the pin connections and their functions. All inputs to the CONTROL BUS use negative logic and are TTL compatible presenting one standard TTL load pulled up to 5V with a 4k7 resistor. All outputs are TTL and can drive eight standard TTL loads.

2.8.1 External parallelism adjustment

The X OFFSET and Y OFFSET inputs (input pins A to N and R to c) can be used to align the etalon plates by computer or other control logic. Both inputs are 12 bit binary numbers giving a range of -2048 to +2047 which corresponds to approximately -0.5 um to +0.5 um of adjustment with a resolution of 0.25 nm. These offsets act in the same way as the front panel X and Y PARALLELISM controls, the amount of parallelism adjustment applied to the etalon is the sum of the front panel setting and the offset applied. Using negative logic and 2's complement coding for these inputs ensures that the offsets from the CONTROL BUS are zero when nothing is connected to it.

The main use of these offsets is the implementation of automatic alignment systems. If the user's light detection system is interfaced to a computer or microprocessor, a program can be written to maximise the finesse of the etalon by varying the X and Y offsets while observing a standard emission line. This provides a quick and efficient way of checking and, if necessary, realigning the etalon when it is in use.

2.8.2 Scanning the etalon

The Z OFFSET input (input pins e to t) can be used to vary the gap of the etalon and thus scan its transmission in wavelength. It is the most often used facility of the CONTROL BUS. As with the X and Y OFFSET inputs, Z OFFSET is a 12 bit binary number giving a range of -2048 to +2047 but for Z this corresponds to approximately ± 1.0 μm of plate separation adjustment (see section 2.10.1 for a discussion of range constraints). The smallest increment of plate separation adjustments is thus ~ 0.5 nm or 1/500 of a Fabry-Perot order at a wavelength of 500 nm. Again the actual offset applied to the etalon is the sum of the front panel Z GAP setting and the offset applied via the CONTROL BUS, and the use of negative logic and offset binary coding ensures that the Z offset is zero with nothing connected.

To scan the etalon passband in wavelength, the user's control logic or computer must provide a sequence of numbers to vary the plate spacing by the required amount. The gap increases with step number, i.e. scanning from lower (more negative), to higher numbers scans the wavelength passband from blue to red. For example, if it is required to scan one order at a wavelength of 500 nm the total plate gap change must be 250 nm or 512 steps of Z OFFSET. This could be done in 512 increments of 1 step, 256 increments of 2 steps, etc. depending on the requirements of the observation.

After every increment the user should arrange to pause for a length of time before starting data collection to allow the F.P. plate position to stabilise. This time should be about twice the response time measured in section 2.5.

Very large increments for example that may occur at scan flyback may cause the CS100 protection circuit to trigger though, in fact, there is no fault. Under these circumstances and when no further adjustment of the GAIN and TIME CONSTANT controls is anticipated, the protection circuit can be turned off by switching the rear panel PROTECTION switch down. The OVERLOAD LED's may flicker during flyback but the loops will stay closed. If one or more OVERLOAD lights come on and stay on, the reason for the overload should be found and rectified before continuing with the observations.

An alternative to switching off the protection circuitry is to arrange the scan control logic to scan up and then down again, i.e. use a triangle rather than a 'sawtooth' scan with flyback. The hysterysis of the system is very much less than one scan step so accurately reproducible scans result independently of the scan direction. The data acquisition system must, of course, make allowance for the alternating scan direction.

2.8.3 Status indication

The logic levels that turn on the front panel X, Y and Z OVERLOAD LED's and the CLOSE LOOP LED are available at pins U, V, W and X. TTL 'high' corresponds to the LED on. These levels may be monitored by a computer, etc. to verify correct operation of the CS100.

2.8.4 External gain and time constant control

The gains of the X, Y and Z channels can be set simultaneously by applying a 4 bit binary number to pins z through CC. The numbers 0 to 9 that can thus be applied refer to the front panel GAIN switch position, e.g. 0 will give 1 (x 100), 3 will give gain 8, 9 will give gain 512.

Similarly the time constants of the X, Y and Z channels can be set by applying a 4 bit binary number to pins DD through HH: 0 will give 1.6 mS, 5 will give 25 s, etc. Both the gain and time constant inputs control all

three channels together so it is not possible to set different parameters on X, Y and Z via the CONTROL BUS. Also these inputs are only active when the EXTERNAL pin, pin LL, is held low. With LL high, the gains and time constants will be as set on the front panel.
NOTE: When changing the time constants in closed-loop mode, the RESET pin (KK) should be taken low, the time constants changed and RESET taken high again (see note to section 2.5).

2.8.5 System control

Pins KK, MM and NN duplicate the RESET, INTEGRATE and CLOSE LOOP switches on the front panel. They are only active, however, when LL is held low. With LL high, the status will be as set on the front panel. RESET need only be pulsed low for 100 nS to cause a system reset in closed-loop mode, the others must be held high or low as the function demands.

The CONTROL BUS has been designed to provide complete remote operation capability for the CS100 system and, if a computer is used to drive the bus, programs can be written to perform all the set up procedures automatically.

2.9 Rear Panel MONITOR Facility

Table 2 lists the pin connections and signals available at the rear panel MONITOR socket. The signals appearing at the front panel AC and DC MONITOR sockets are available here, as are the outputs from the phase sensitive detectors that monitor the R offset. The latter provides continuous monitoring of the X, Y and Z R offsets independently of the position of the front panel METER DISPLAY switch.

The 16 k Hz bridge drive waveform (10 V p-p sine wave) is provided on the MONITOR socket for reference purposes. On units with serial numbers up to and including 8006 this reference is 90° out of phase with the bridge error signal as seen at the AC MONITOR points, i.e. it is in phase (or antiphase) with the error signal.

The MONITOR facility has been provided to allow for complete remote monitoring of system behaviour to complement the remote control capability available via the CONTROL BUS. Each output on the MONITOR socket is buffered and will drive up to 30 m of multi-core cable and loads down to 2 kΩ.

2.10 Interpretation of meter displays

The use of the Y and Z meters in setting up the CS100 system has already been described, but it is helpful to understand just what is being measured. The interpretation of the meter readings depends on whether the loops are open or closed, though electronically the same points in the circuitry are monitored in both cases, i.e. the output from the error-signal phase sensitive detectors.

2.10.1 Closed-loop mode and co-ordinate transformation

With the METER DISPLAY switch set to ERROR SIGNAL, the loops closed and etalon plates aligned parallel, the meters will display steady voltages between -7 and +7 volts. These voltages indicate the amount of correction that the system is applying in the three axes to maintain plate alignment and gap. A combination of these voltages is applied to each piezo-electric transducer to ensure plate movement about the correct axis (see section 1.4.1). The combination, or co-ordinate transformation, used is

$$V_A = 100\ (-V_y - V_z)$$

$$V_B = 100\ (+V_x - V_z)$$

$$V_C = 100\ (\qquad - V_z)$$

Where V_A, B, C are the voltages applied to the A, B and C transducers and Vx, y, z are voltages indicated on the meters (error signal phase sensitive detector outputs).

The meter reading will change for one of two reasons: to move the etalon plates in response to a variation of the front panel parallelism and gap controls or offset via the CONTROL BUS, or to correct a mechanical disturbance on the etalon. The amount the transducers move can be calculated using the meter readings and the co-ordinate transformation given, together with a knowledge of the tranducer sensitivity (2.4 nm V^{-1} average). Thus if a one order scan at a wavelength of 480 nm is performed, the tranducers will be required to move by 240 nm, i.e. the voltage across them will change by ~100V. The Z meter reading will thus change by ~1V, (this is independent of the GAIN settings). These voltages are approximate as there is a large variation in piezo-electric tranducer sensitivity from etalon to etalon, and from one end of the scan range to the other, due to transducer non-linearity. The resulting scan, however, will always be linear and accurate due to the action of the closed servo-loop - see section 1.4.2. A change of 1V in the Z meter reading in the absence of an offset or front panel control change implies that the servo is correcting a mechanical displacement that would have produced ~ 240 nm gap change if the servo were switched off: the gap will not be actually changing. The above also applies to the X and Y channels.

The full drive available for the piezo-electric transducers is ± 750V so the co-ordinate transformation should be used to check that this range is not exceeded. For example, if the Y and Z meters both read 5V, V_A will be - 1000V which is beyond the drive capability of the A piezo drive amplifier. 5V on both the X and Z meters will, however, give 0 V across the B piezo. In practice, with most ET series etalons, the X and Y meter readings will be within a couple of volts of zero and it will be Z that changes due to scanning. It is usually sufficient to ensure that the Z meter reading stays within ± 5V of zero. If the range is exceeded, a large error signal will result and an OVERLOAD will occur, opening the servo-loops if the protection circuit is switched on.

2.10.2 Open loop mode

With the METER DISPLAY switch set to ERROR SIGNAL and the loops open, the meters give a direct reading of the capacitance bridge balance condition. This is determined by the front panel PARALLELISM and GAP settings and any offsets introduced via the CONTROL BUS, and the difference in value of the relevant micrometer capacitors (see section 1.4.1). The meters thus give a direct reading of any mechanical drift in the etalons, though with the loops open this will not be corrected. This is a very sensitive measure of mechanical movement: with the GAIN's set at 16 the meters read 10V per nanometre of plate movement. Deforming the etalon by pressing on its metal end plate will give a significant reading. In this mode the meters will respond with the time constant set by the OPEN LOOP TIME CONSTANT switches (they may be brought to zero at any time by pressing RESET).

2.10.3 Resistive component

With the METER DISPLAY switch set to RESISTIVE COMPONENT, the meters monitor the component of the bridge signal 90° out of phase with the error signal, whether the loops are open or closed. This is provided for nulling purposes during set-up (see sections 2.4.1 and 2.4.2). The meter sensitivity is 0.5V dc per V p-p a.c. 90° out of phase with the reference at REF. MONITOR, the a.c. being measured at A.C. MONITOR.

The OVERLOAD LED's will be triggered by any signal greater than 15V p-p, so a meter reading of ± 7.5V when switched to RESISTIVE COMPONENT will cause an overload and the loops to open if the protection circuitry is on.

2.11 Interpretation of MONITOR outputs

2.11.1 DC Monitors

The front panel X, Y and Z DC MONITOR'S (duplicated on pins 5, 6 and 7 of the rear panel MONITOR socket) make available the voltages displayed on the meters when the letter are switched to ERROR SIGNAL, see 2.10.1, 2.10.2. The signals are available continuously independently of the METER DISPLAY switch position.

These monitor points allow rapid variations in plate position to be analysed: in particular the voltage waveform applied to all three transducers during a scan is available at the Z DC MONITOR. This is used in optimising the GAIN and TIME CONSTANT settings. If a linear scan is programmed on the user's control logic the plate separation will vary linearly but the voltage at Z DC MONITOR will not. This is because non-linearity is the piezo-electric transducers is being compensated automatically by the servo system (see section 1.4.2).

In closed-loop mode the piezo-electric transducers move ~ 240 nm V^{-1} at the DC MONITOR points, independently of the GAIN setting. In open loop mode (see also 2.10.2) the sensitivity is 10V per nanometre of plate movement at GAIN 16.

Pins 8, 9 and 10 of the rear panel MONITOR socket make available the voltages displayed on the meters when the latter are switched to RESISTIVE COMPONENT. Again the signals are available continuously independently of the METER DISPLAY switch position. See section 2.10.3 for sensitivity, etc. These signals are generated by three phase sensitive detectors with fixed time-constants of about 40 mS.

2.11.2 A.C. Monitors

The X, Y and Z AC MONITOR points on the front panel are duplicated on pins 3, 2 and 1 of the rear panel MONITOR socket. These points monitor the 16 k Hz error signal from the X, Y and Z bridges amplified by the A.C. amplifiers in the system. The three error signal phase sensitive detectors demodulate the component of this signal in phase with the reference signal (also available on the front panel) while the three 'resistive component' phase sensitive detectors demodulate the component at 90° to the reference.

With the loops open there will probably be large error signals present and the A.C. MONITOR points will show 16 k Hz sine waves or saturated square waves approximately in phase or antiphase with the reference. This waveform is most helpful in tracking down simple errors as described in section 2.12. It can also be used to balance the bridges during the set-up procedure of section 2.4.2: with the bridges balanced there will be no 16 k Hz component at the A.C. MONITOR points. Observation of the A.C. signals sometimes helps to 'home in' on the balance point if there are large initial resistive offsets present.

With the loops closed and the resistive component balanced, there will be no 16 k Hz component visible at the A.C. MONITOR points. What is left is residual harmonic components of the 16 k Hz bridge frequency and amplifier noise. In general, at gain 512 the harmonics will be less than 1V p-p and noise less than 0.5V p-p. A 16 k Hz component at 90° to the reference indicates that the resistive component needs balancing, a visible component in phase or antiphase with the reference with the loops closed indicates a fault: see section 2.12.

If the CS100 is operated in an area of high electrical interference, e.g. close to a high power transmitter, some pick-up may be experienced and be visible at the A.C. monitor points whether the loops are open or closed (normally this is easiest to see with the loops closed). The effect this will have depends on the nature of the interference, but unless it is very large (10V p-p at gain 512) or contains frequencies near 16 k Hz there is likely to be little effect on plate parallelism or gap.

2.11.2 Summary of MONITOR outputs and meter reading under normal conditions

Monitor Point	Loop Closed		Loops Open	
	Condition	Output	Condition	Output
X,Y,Z AC	GAIN=512(x100)	16 k Hz harmonics ~1V p-p noise ~0.5V p-p	GAIN=512(x100) Bridges balanced	16 k Hz harmonics ~ 1V p-p noise ~ 0.5V p-p
			GAIN 32(x100) Bridges unbalanced	16 kHz sine or square wave
X,Y,Z DC	Closed loop time constant 0.5 mS	0±7.5V d.c 2mV p-p noise	GAIN=8(x100) Bridges balanced Time constant 1.6 mS	2 V p-p Low frequency noise.
X,Y,Z R	GAIN 512(x100)	0± .5V d.c	GAIN 8 (x100) Bridges balanced Bridges unbalanced	0± 0.5V d.c 0± 8.0V d.c
X,Y,Z Meter reading	METER DISPLAY at ERROR SIGNAL	0± 7.5V	METER DISPLAY at ERROR SIGNAL GAIN=32(x100) Bridges balanced Bridges unbalanced	0.V. off scale
	METER DISPLAY at RESISTIVE COMPONENT GAIN=512(x100)	0± 0.5V	METER DISPLAY at RESISTIVE COMPONENT Bridges balanced Bridges unbalanced	0± 0.5V 0± 8V
Rear Panel REF.	16 k Hz 10V p-p sine wave			
Front Panel REF.MONITOR	16 k Hz TTL 1:1 mark space ratio square wave			

2.12 Some faults and their correction

Fault	Probable Cause	Test/Check	Action to be taken
1. Loops fail to close	1. Incorrect connection to etalon - damaged leads.	1. Check all connections and leads.	1. Try again if faulty lead found.
	2. Incorrect GAIN or TIME CONSTANT setting.	1. Check settings	1. Try again if settings incorrect. 2. Reduce GAIN and re-optimise response (section 2.5) 3. Follow procedure in section 2.4.4.
2. Bridges cannot be balanced at section 2.4.4 operation 4.	1. See 1 above		
	2. Incorrect GAIN, TIME CONSTANT, or control switch settings.	Check settings	Repeat attempt.
	3. Initial Resistive Offset too large.	Observe AC MONITOR points	Null AC signals.
		If AC signal can be nulled:	Repeat balance using meters
		If AC nulls but meters won't null:	Contact Q.I.
		If AC signals can't be nulled:	See cause 4.
	4. Short or open circuit in etalon or Bridge Drive lead.	Observe AC MONITOR points. If square wave in phase with REF., probable short or open circuit on pin 1,2 or 4 of Bridge drive lead (X, Z or Y) or inside etalon. If square wave 180° out of phase with REF. probable short or open circuit on pin 3 of Bridge Drive lead or etalon.	1. Check leads again. 2. If leads OK contact Q.I.

Fault	Probable Cause	Test/Check	Action to be taken
3. Loops fail to close at section 2.4.2 operation 7.	1. HV fuse blown	Check HV fuse	1. Replace with 250mA fast fuse. 2. If fuse blows again contact Q.I.
	2. One or more piezo-electric transducers open or short circuited	Check piezo drive cable	If cable OK contact Q.I.
4. Loops close but meter drifts rapidly.	1. Bridge receiver leads crossed or open or short circuited.	Check receiver leads	Try again if faulty lead found.
	2. Condensation in etalon	Verify that resistive component also drifting	Operate etalon in dry atmosphere or flush with dry inert gas, e.g. N_2.
5. Plates remain parallel but gap drifts.	1. Atmospheric variations in ET etalon with ceramic reference capacitor.		1. Flush etalon with dry inert gas. 2. Temperature control etalon.
6. Parallelism drifts by more than $\lambda/200$.	1. Plates buckling due to temperature gradients.	Check etalon temperature is constant to ± 0.5°C.	Temperature control etalon.
7. Sporadic reduction in finesse.	1. Interference from near-by source, e.g. noisy discharge lamp or transmitter.	Check for interference at AC MONITOR points.	1. Remove interference source if possible. 2. Improve grounding of CS100 and etalon. 3. Screen CS100 and etalon. 4. Increase time constants and/or reduce gains.
	2. System on verge of oscillation.	Check GAIN and TIME CONSTANT optimization section 2.5.	Increase time constants.

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CS100 Standard Control Interface

56 way receptacle Vero 166 – 3522G (Mating plug Vero 166 – 3521L)

All inputs are negative logic: 1 = TTL Low, 0 = TTL High
All outputs are positive logic: 1 = TTL High, 0 = TTL Low

Pin no.	Function	Input/ Output	Comments
A	X OFFSET Bit 0	I	LSB.
B	" 1	I	
C	" 2	I	
D	" 3	I	Offset range -2048_{10} to $+2047_{10}$
E	" 4	I	Negative numbers are 2's complement
F	" 5	I	coded. (Note 1)
H	" 6	I	
J	" 7	I	
K	" 8	I	
L	" 9	I	
M	" 10	I	
N	" 11	I	MSB.
P	N.C.		
R	Y OFFSET Bit 0	I	LSB.
S	" 1	I	
T	" 2	I	
U	" 3	I	Offset range -2048_{10} to $+2047_{10}$
V	" 4	I	Negative numbers are 2's complement
W	" 5	I	coded. (Note 1)
X	" 6	I	
Y	" 7	I	
Z	" 8	I	
a	" 9	I	
b	" 10	I	
c	" 11	I	MSB.
d	N.C.		
e	Z OFFSET Bit 0	I	LSB.
f	" 1	I	
h	" 2	I	
j	" 3	I	Offset range –2048 to +2047.
k	" 4	I	Negative numbers are 2's complement
l	" 5	I	coded. (Note 1)
m	" 6	I	
n	" 7	I	
p	" 8	I	
r	" 9	I	
s	" 10	I	
t	" 11	I	MSB.
u	X OVERLOAD	O	TTL High on overload of X servo channel
v	Y OVERLOAD	O	" " Y " "
w	Z OVERLOAD	O	" " Z " "
x	LOOP CLOSED	O	TTL High when servo loops are closed and system is functioning normally.

Cont.

Pin no.	Function	Input/ Output	Comments
y	0 V.	—	Logic ground
z	GAIN Bit 3	I	MSB.
AA	" " 2	I	Range 0_{10} to 9_{10}. Selects gain of
BB	" " 1	I	X,Y and Z channels simultaneously.
CC	" " 0	I	(Note 2)
DD	TIME CONST Bit 3	I	MSB.
EE	" " " 2	I	Range 0 to 9. Selects time constant
FF	" " " 1	I	of X,Y and Z channels simultaneously.
HH	" " " 0	I	(Note 2)
JJ	N.C.		
KK	$\overline{\text{RESET}}$	I	TTL High causes system reset (Notes 2,3)
LL	EXTERNAL	I	TTL Low enables external control.
MM	INTEGRATE	I	TTL Low switches integrator into servo loops. (Note 2)
NN	CLOSE	I	TTL Low closes servo loops. (Note 2)

Note 1

Offset Coding. 0 = TTL High 1 = TTL Low

Binary input	Decimal equivalent
0111 1111 1111	+2047
. . .	
. . .	
. . .	
0000 0000 0001	+1
0000 0000 0000	0
1111 1111 1111	−1
. . .	
. . .	
. . .	
1000 0000 0000	−2048

Note 2

These inputs are active only when EXTERNAL (pin LL) is held Low. X,Y and Z OFFSET inputs are active at all times.

Note 3

This input should be pulsed low (pulse width >100nS) to reset system after an overload (when under external control).

TABLE 1 cont

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Cont.

General

Inputs present one standard TTL load, outputs can drive eight standard TTL loads.

All control functions (except EXTERNAL) are duplicated by front panel controls. The front panel controls allow the X,Y and Z servo channels to operate with different gains and time constants if necessary: this is not possible via the control interface.

None of the inputs are latched: when under external control the user's control system must hold the required function on the inputs.

With nothing connected to the interface, external X,Y and Z OFFSETS will be zero and all the front panel controls will be active.

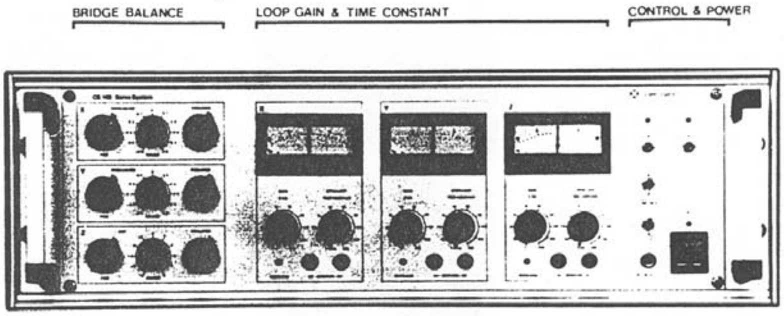

FIGURE 9 CS100 FRONT PANEL

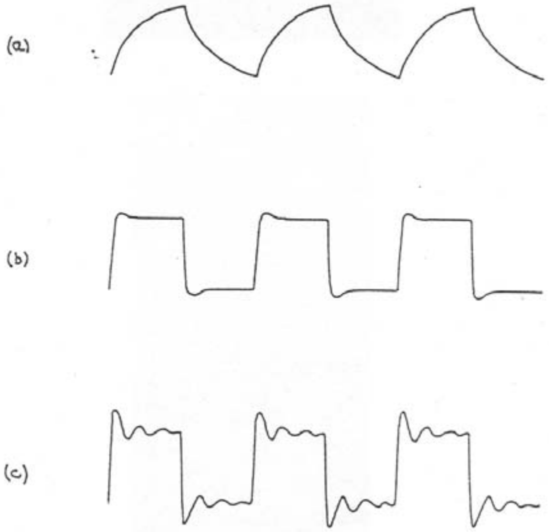

FIGURE 10 (a) DAMPED SQUARE WAVE.
(b) CRITICALLY DAMPED SQUARE WAVE.
(c) UNDERDAMPED SQUARE WAVE.

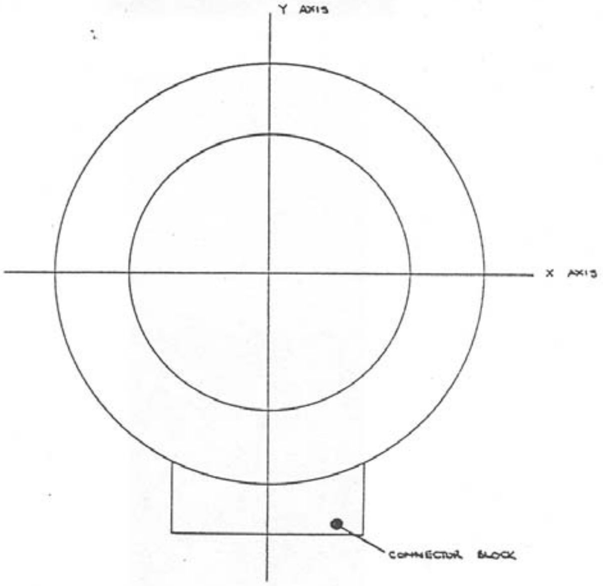

FIGURE 11 ETALON AXES

PART 3 - CIRCUIT DIAGRAMS

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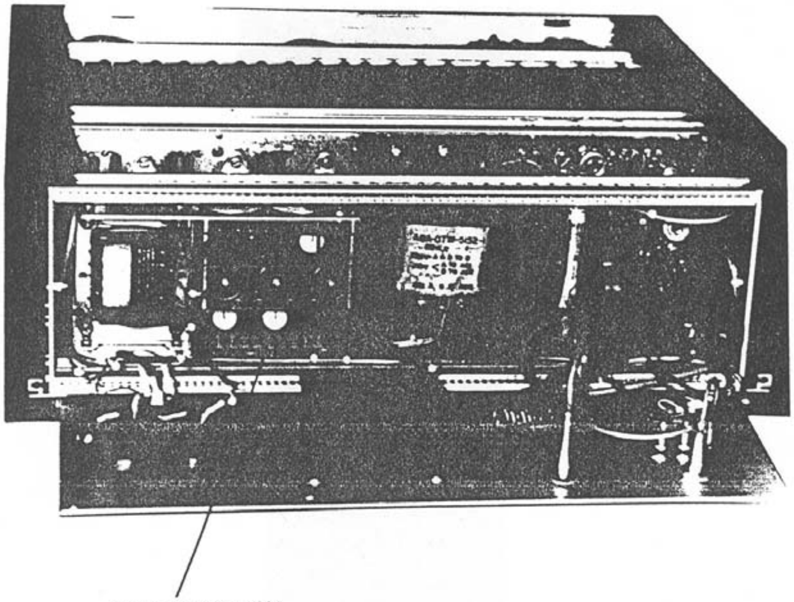
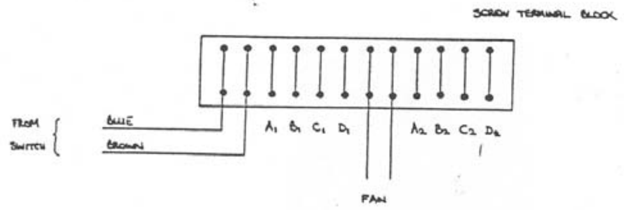
CSIOO Monitor Socket Connections.

I	Z AC
2	Y AC
3	X AC
4	Sine reference,IO V pk-pk.
5	ZC DC
6	YC DC
7	XC DC
8	XR DC
9	YR DC
IO	ZR DC



SCREW TERMINAL BLOCK

FIGURE 7 CS100 REAR VIEW



110/120 V OPERATION CONNECT A_1 TO B_1
C_1 TO D_1
A_2 TO B_2
C_2 TO D_2

220/240 V OPERATION CONNECT B_1 TO C_1
B_2 TO C_2

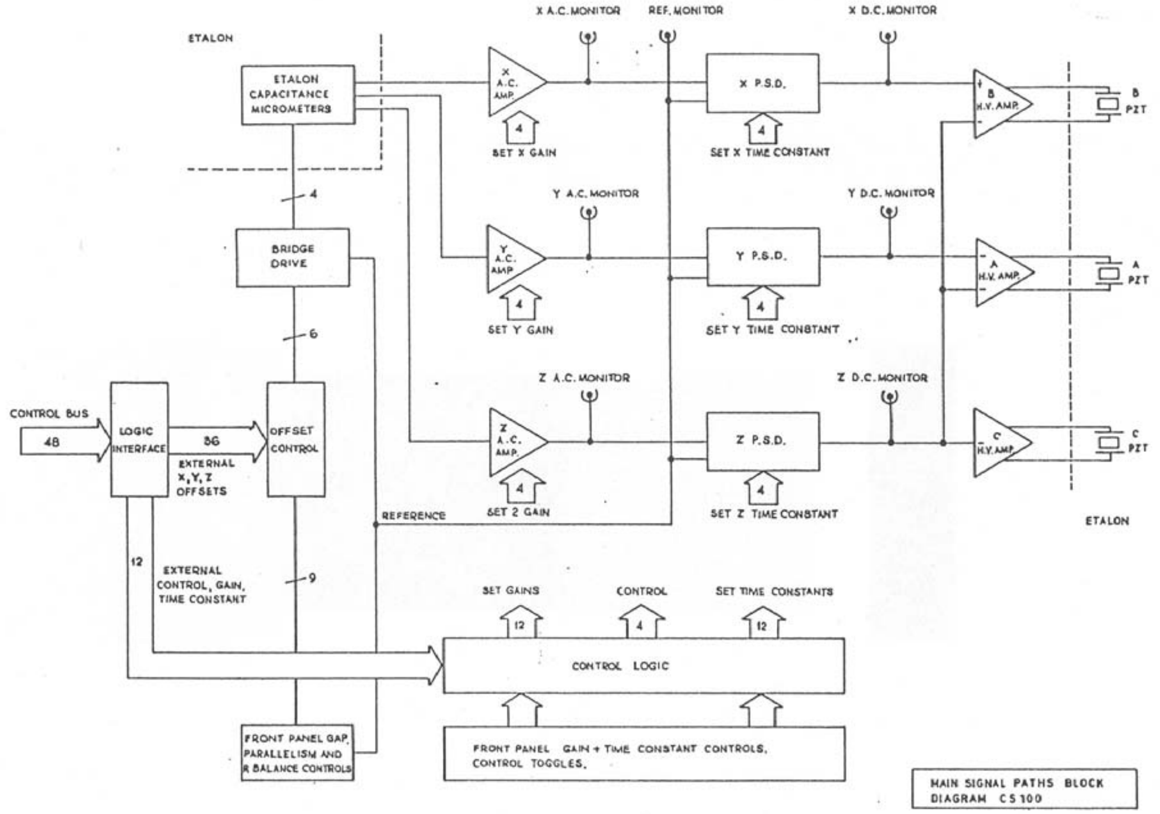
A_1, D_1, A_2, D_2 ARE ALL LEFT UNCONNECTED.

FIGURE 8 MAINS VOLTAGE SELECTION

45.3
9.2
906
4077
41676

1.282
126

652



MAIN SIGNAL PATHS BLOCK DIAGRAM CS100

DESIGNED				SCALE	QUEENSGATE INSTRUMENTS LTD	SYSTEM CS 100
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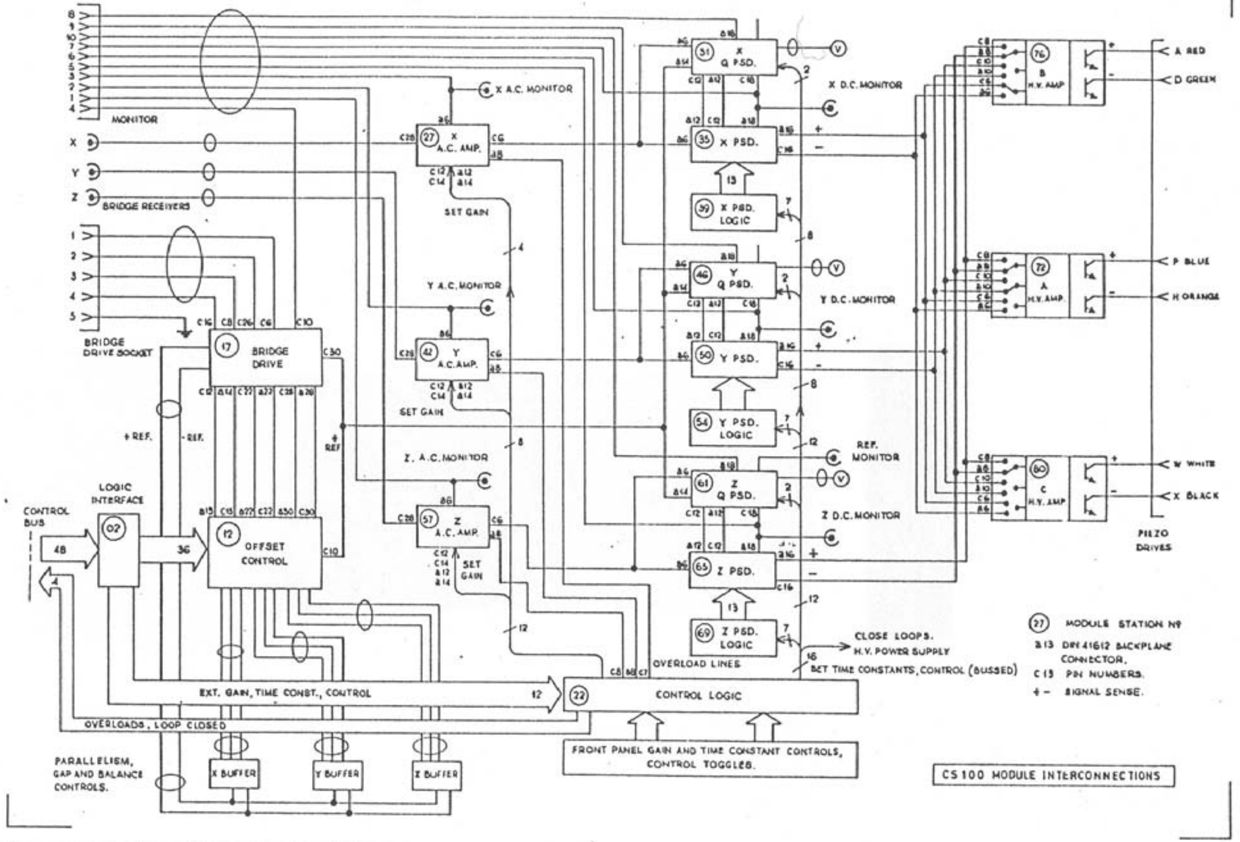
A2



CS100 MODULE INTERCONNECTIONS

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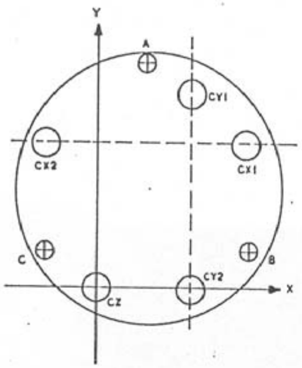
SYSTEM CS 100

DRG No 002

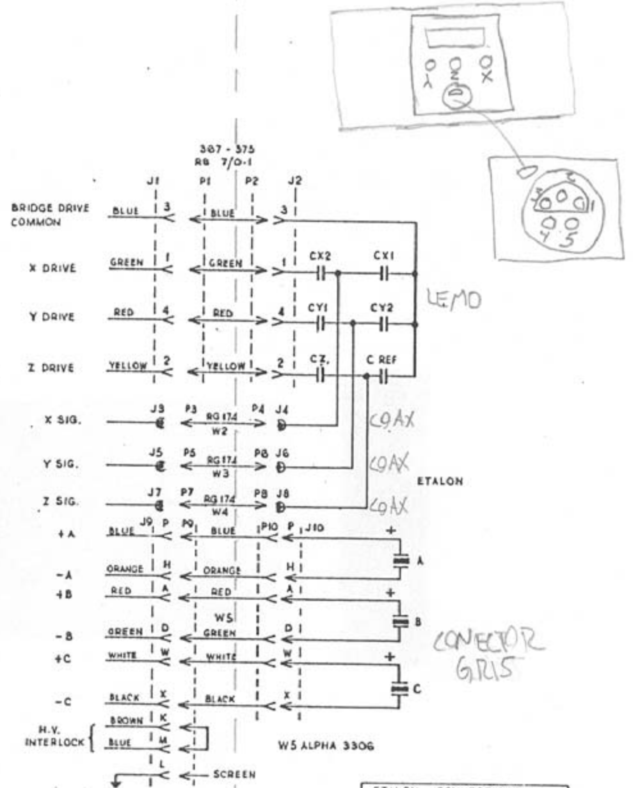
SCHEMATIC PLAN VIEW OF ETALON



+ Z MOTION → + j Z SIG.
+ Y MOTION → + j Y SIG.
+ X MOTION → − j X SIG.
REFERED TO BRIDGE DRIVE COMMON

COORDINATE TRANSFORMATION

A = −Y − Z
B = +X − Z
C = −Z



ETALON CONNECTIONS

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SYSTEM CS100

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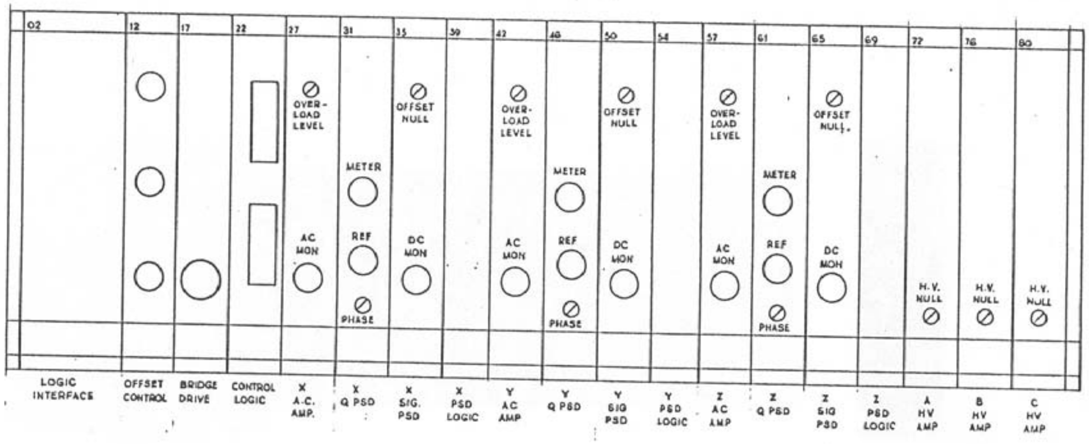

MODULE POSITIONS

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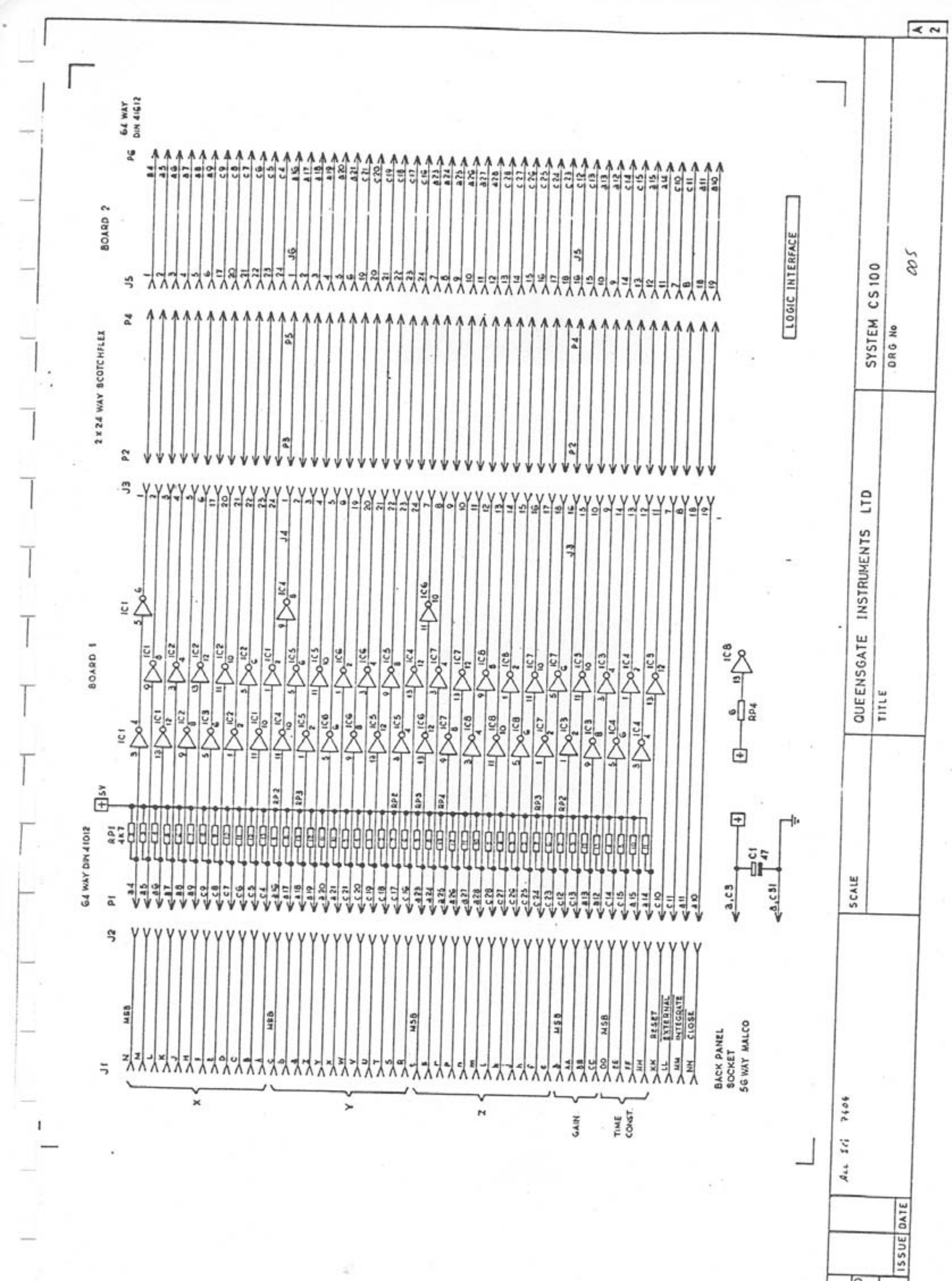
A 2



QUEENSGATE INSTRUMENTS LTD

TITLE

SYSTEM CS 100

DRG No 005

A 2

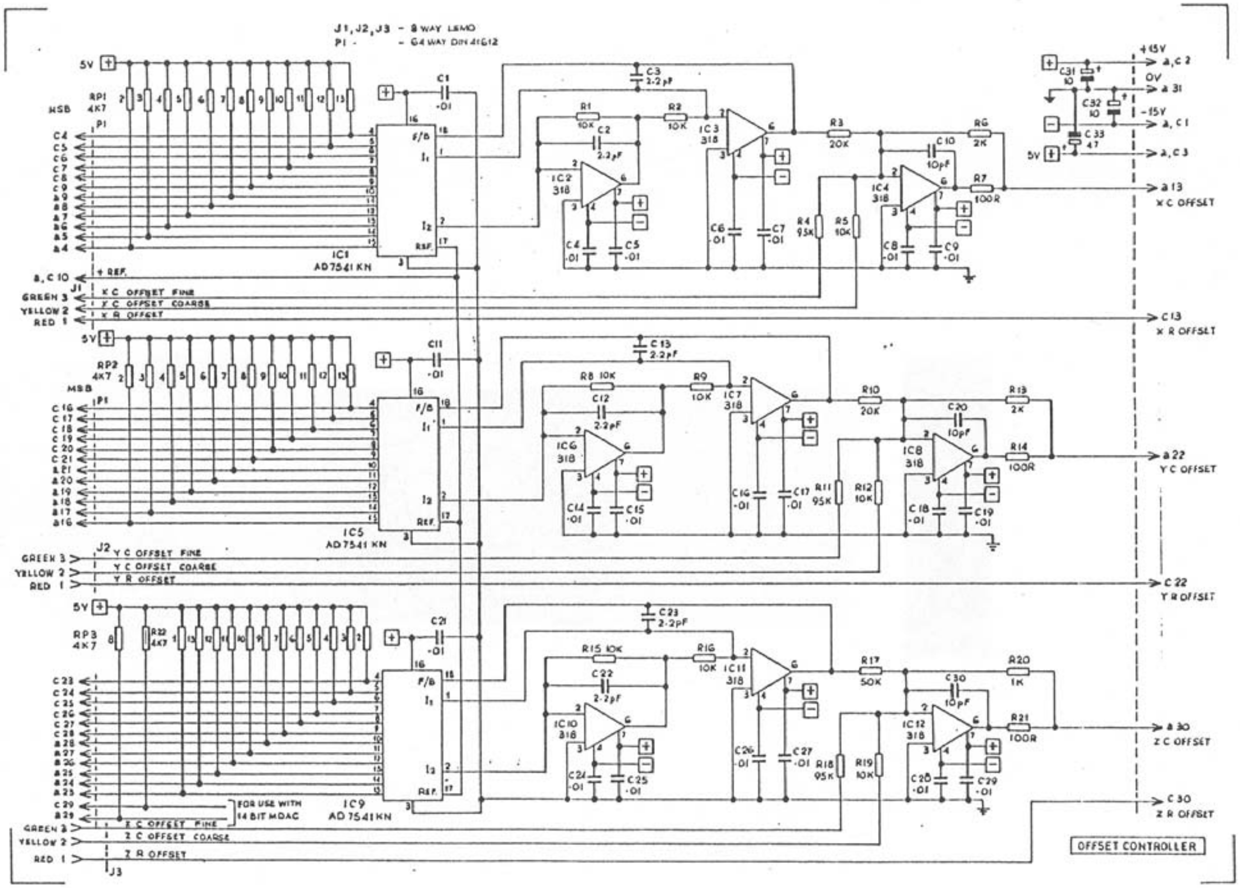
SCALE

DESIGNED

DRAWN

ISSUE DATE

Acc Sci 7404



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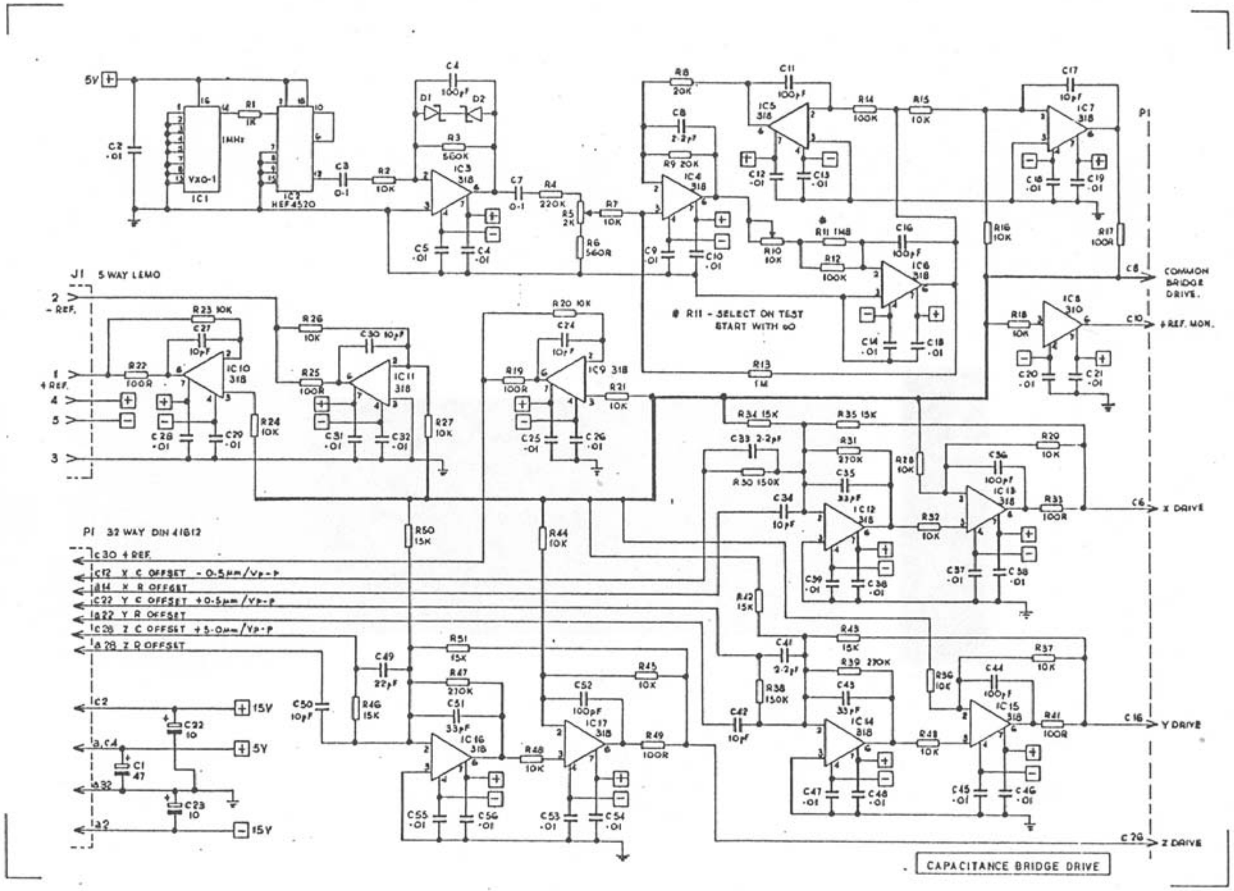
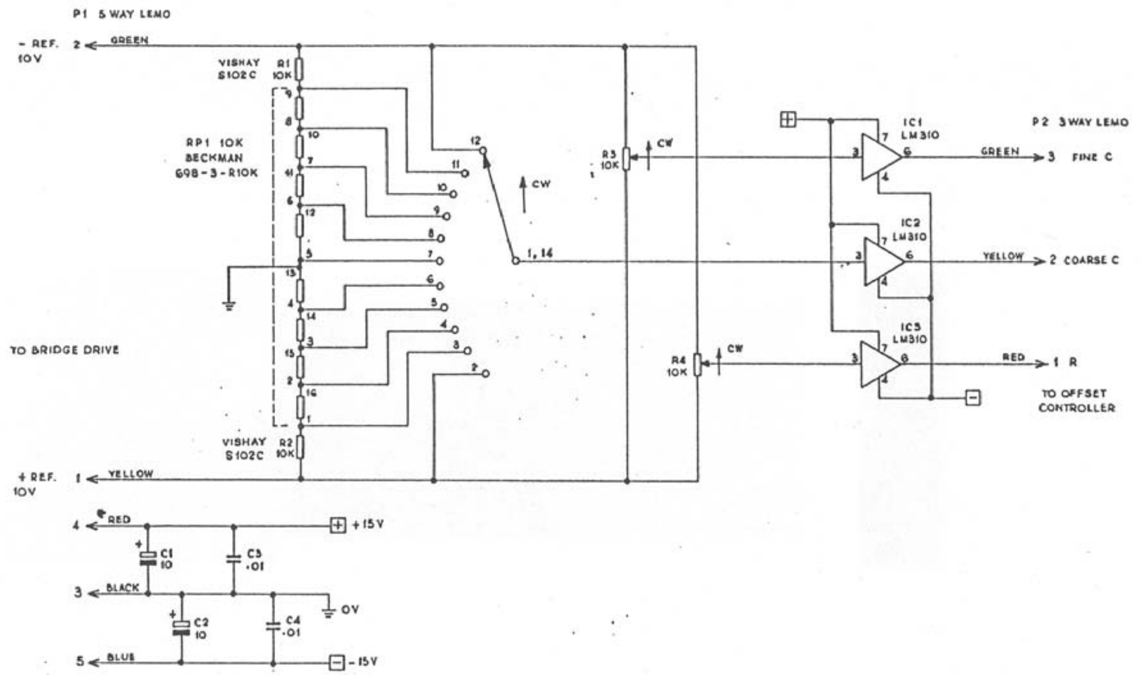


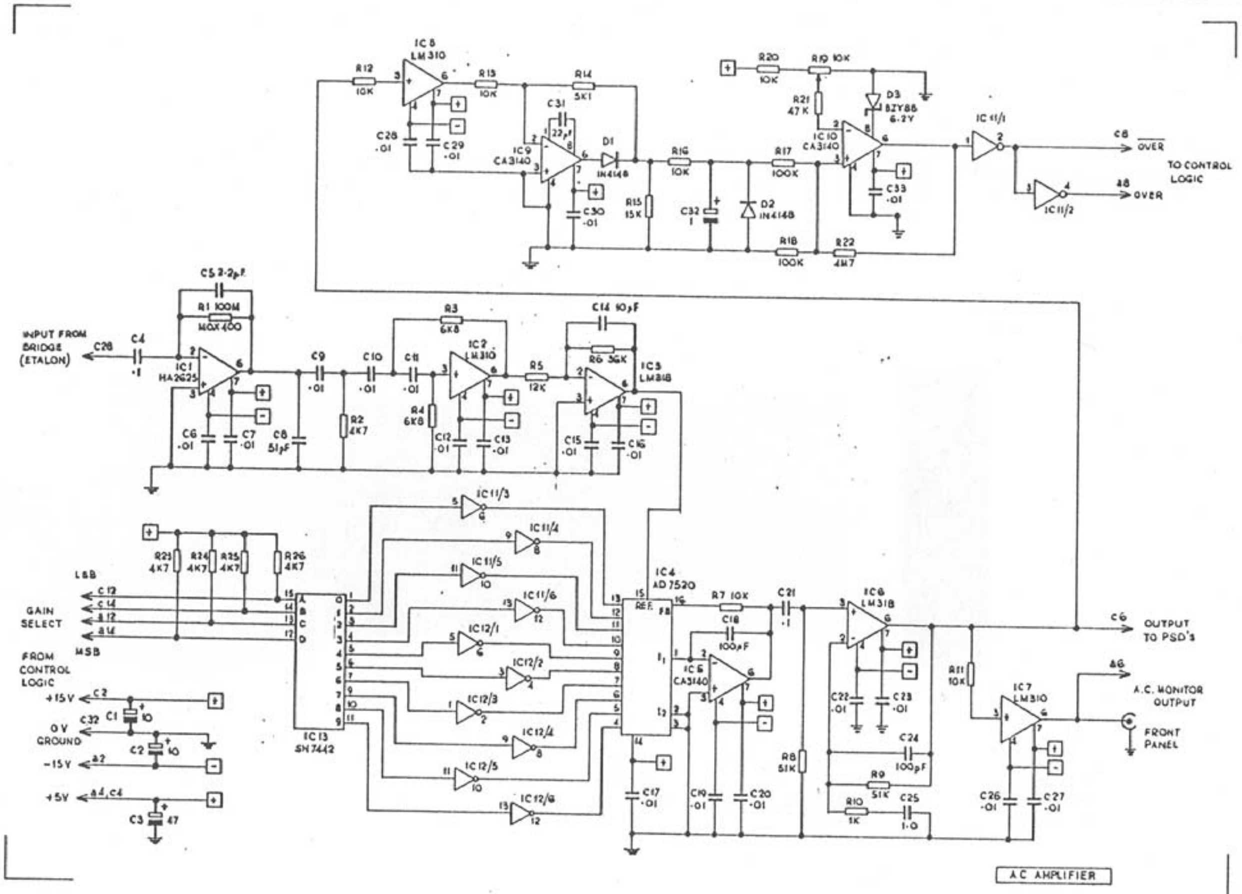
CAPACITANCE BRIDGE DRIVE

DESIGNED
DRAWN
ISSUE
DATE
SCALE
QUEENSGATE INSTRUMENTS LTD
TITLE
SYSTEM GS 100
DRG No 007
A2



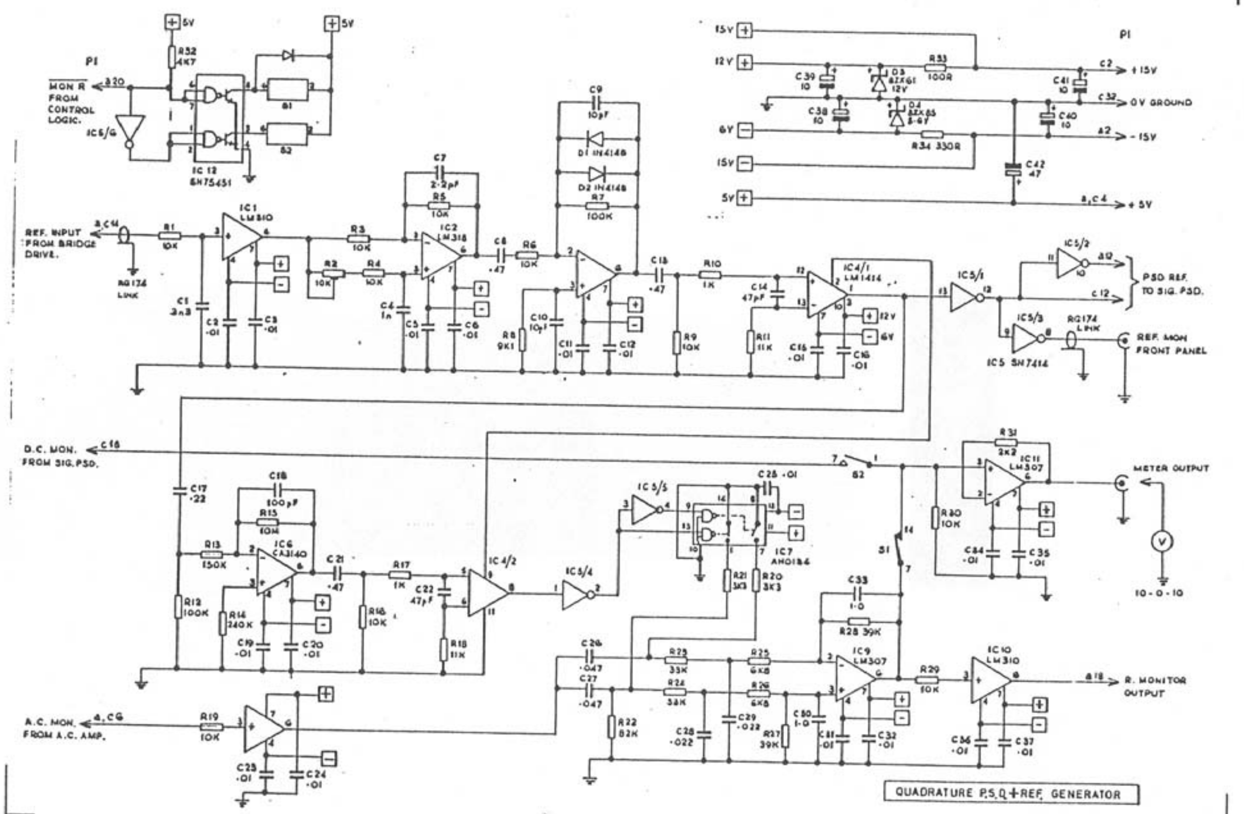
BUFFER

				SCALE	QUEENSGATE INSTRUMENTS LTD	SYSTEM CS 100	
DESIGNED					TITLE	DRG No 008	A
DRAWN	ISSUE	DATE					2



DESIGNED				SCALE	QUEENSGATE INSTRUMENTS LTD	SYSTEM CS100
DRAWN	ISSUE	DATE			TITLE	DRG No 009

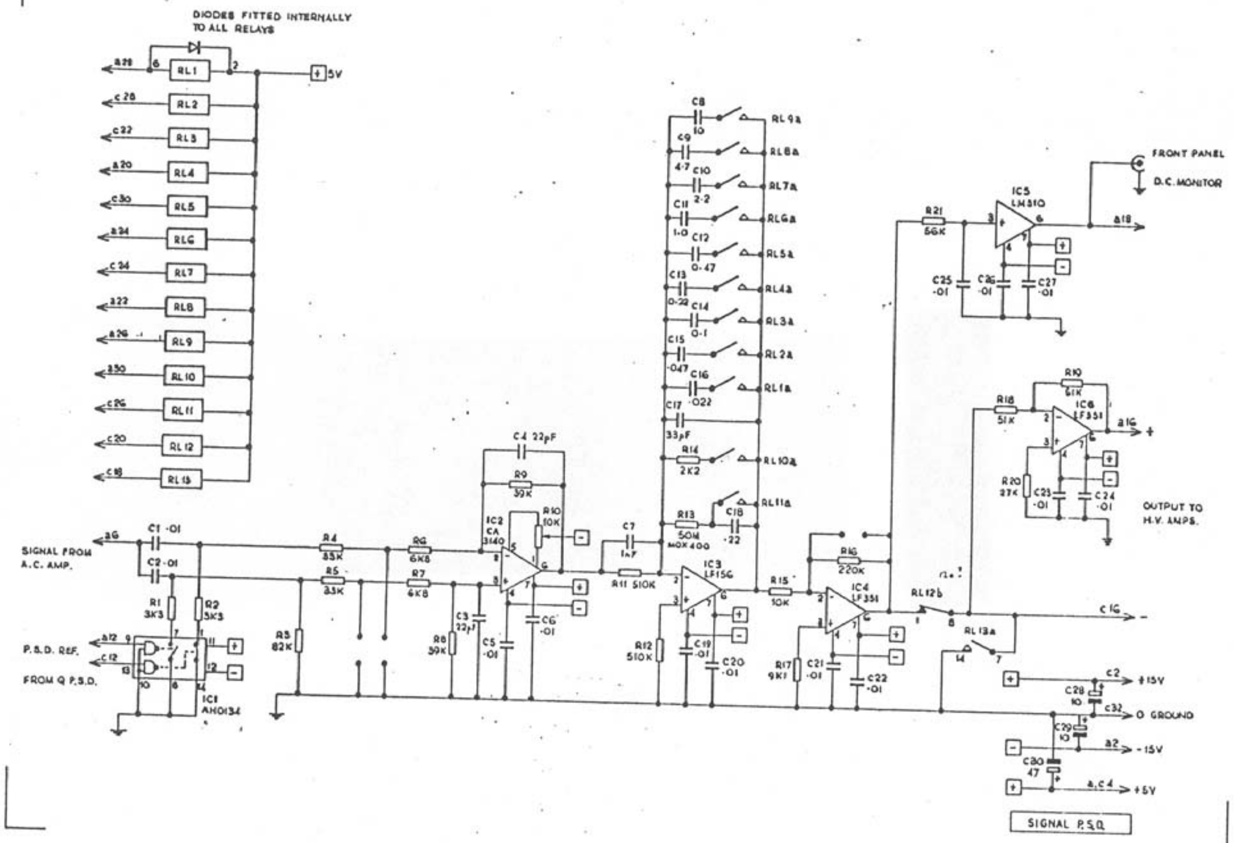
A
2



QUADRATURE P.S.D. + REF. GENERATOR

DESIGNED				SCALE	QUEENSGATE INSTRUMENTS LTD	SYSTEM CS 100
DRAWN					TITLE	DRG. No. 010
	ISSUE	DATE				

A 2



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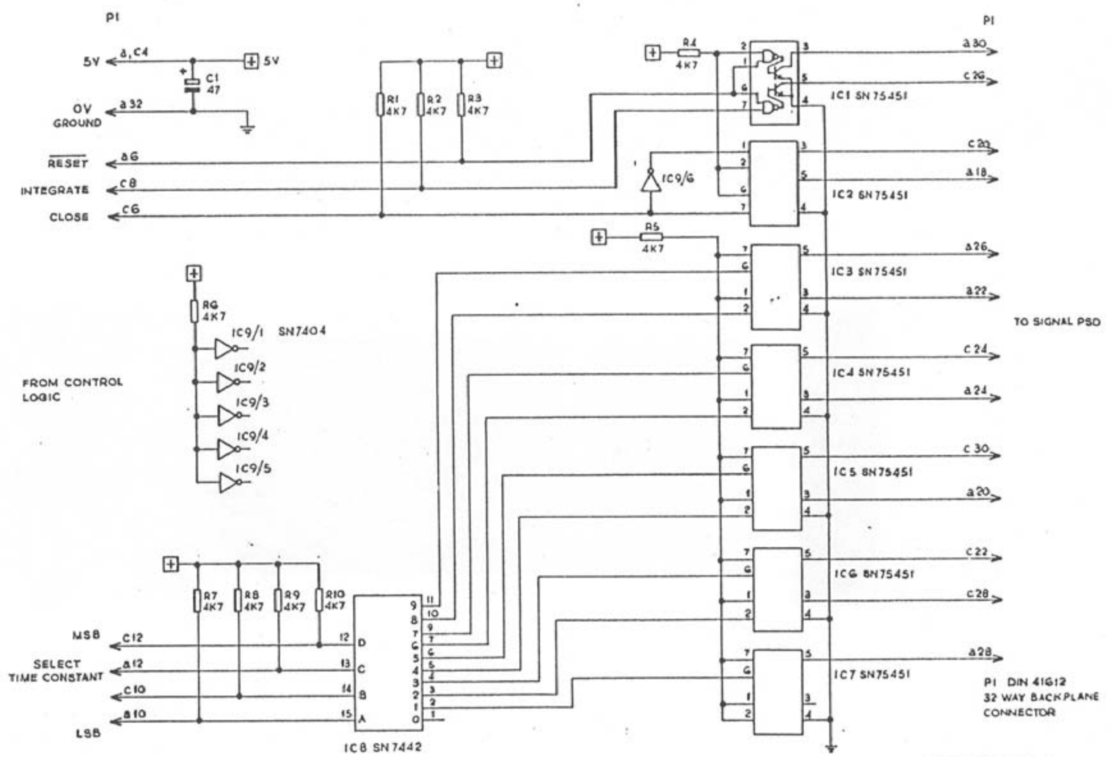
ISSUE
DATE
SCALE
QUEENSGATE INSTRUMENTS LTD
TITLE
SYSTEM CS 100
DRG No
011
A2



PSD LOGIC

DESIGNED
DRAWN ISSUE DATE

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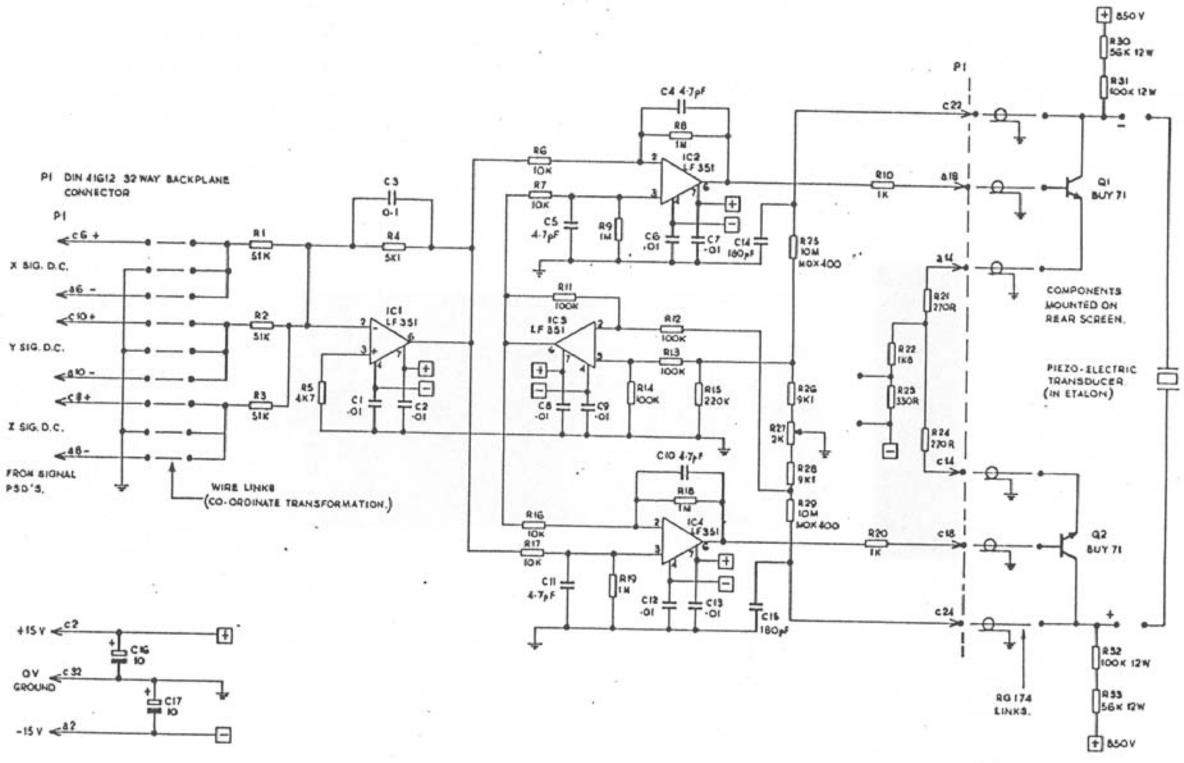
QUEENSGATE INSTRUMENTS LTD

TITLE

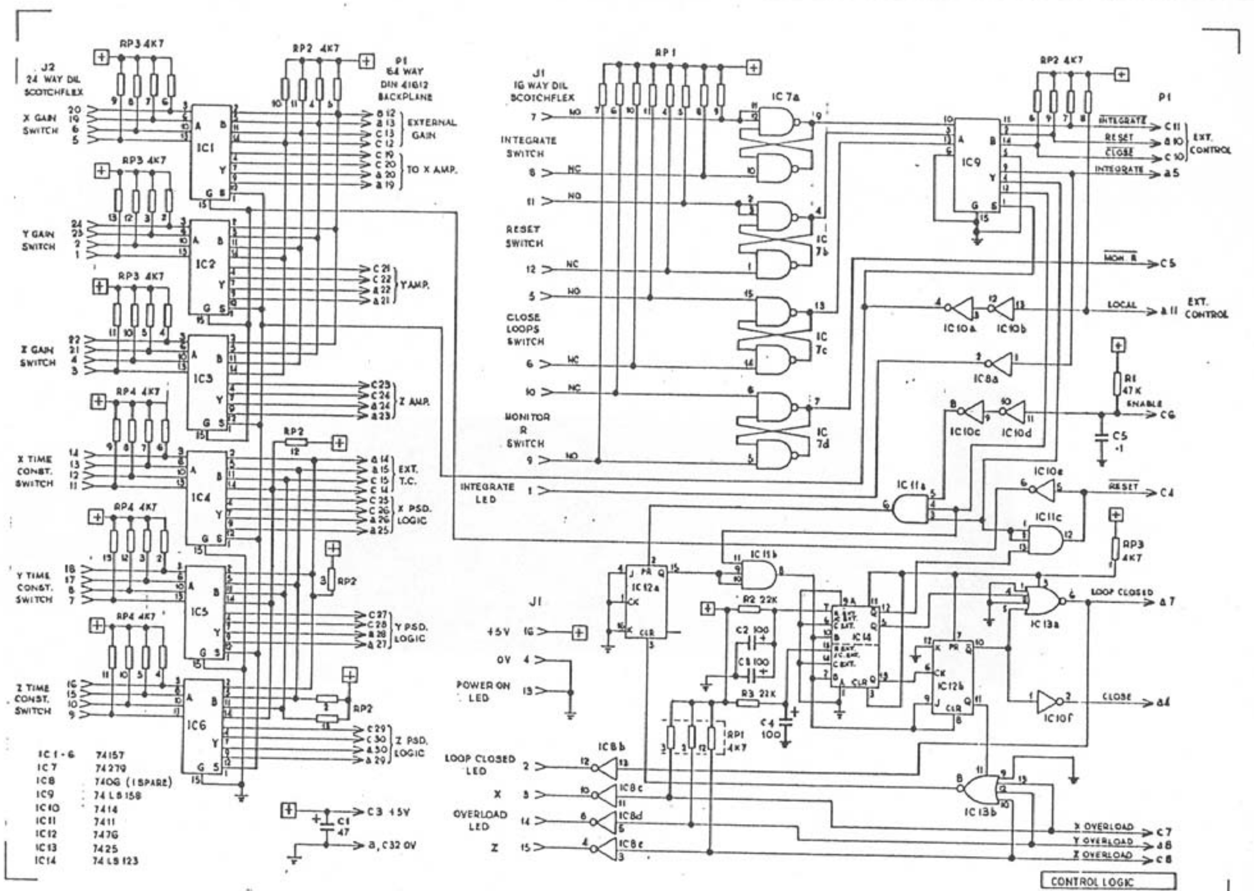
SYSTEM CS100

DRG No
012



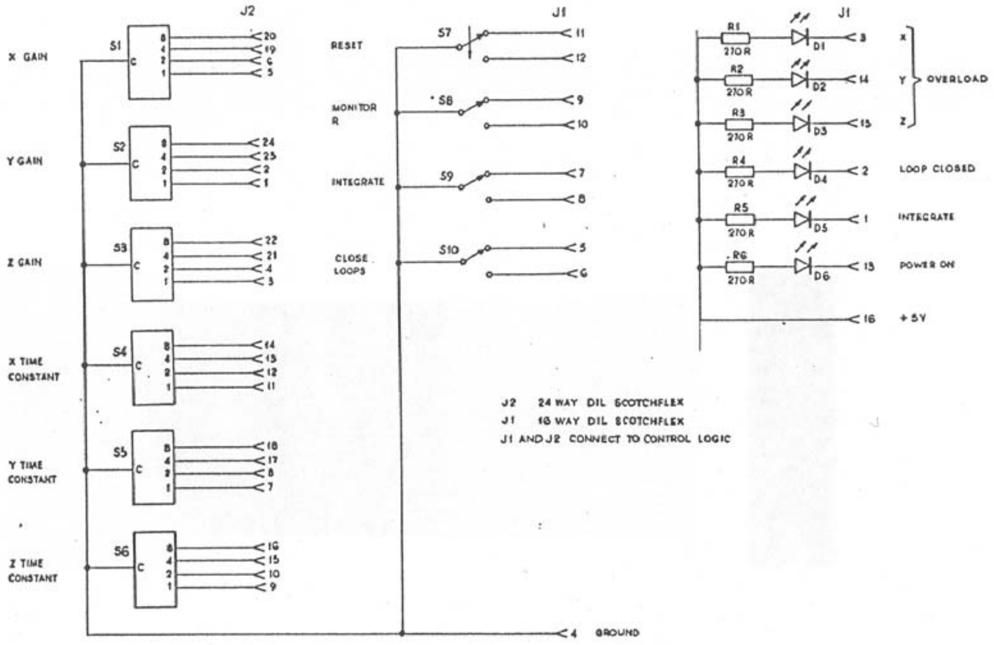
H V AMPLIFIER

DESIGNED				SCALE	QUEENSGATE INSTRUMENTS LTD	SYSTEM CS 100	
DRAWN					TITLE	DRG No 015	A 2
	ISSUE	DATE					



IC 1 - 6	74157
IC 7	74279
IC8	7406 (1 SPARE)
IC9	74 LS 158
IC10	7414
IC11	7411
IC12	7476
IC13	7425
IC14	74 LS 123

			SCALE	QUEENSGATE INSTRUMENTS LTD	SYSTEM CS 100	
IGNED				TITLE	DRG. No. 016	A 2
LWN	ISSUE	DATE				



J2 24 WAY DIL SCOTCHFLEX
J1 16 WAY DIL SCOTCHFLEX
J1 AND J2 CONNECT TO CONTROL LOGIC

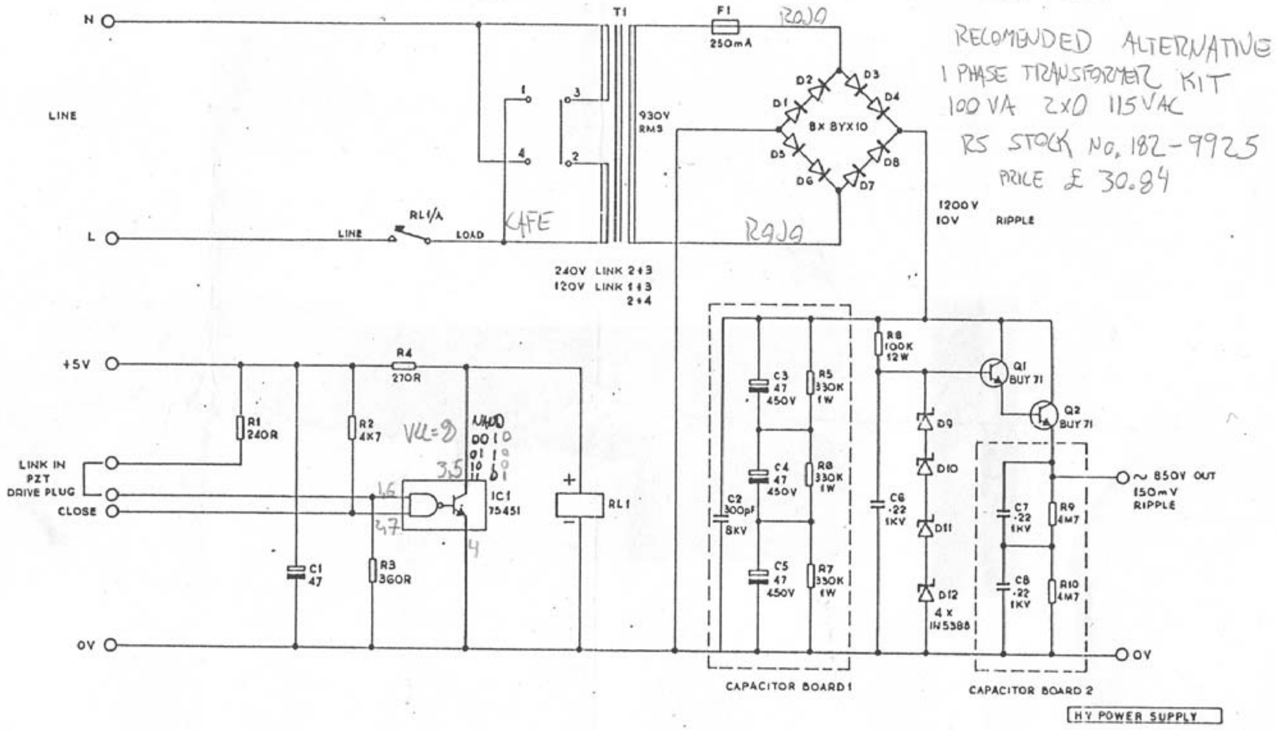
FRONT PANEL CARD

DESIGNED				SCALE	QUEENSGATE INSTRUMENTS LTD	SYSTEM
DRAWN	ISSUE	DATE			TITLE	DRG No 015

A 2

TRANSFORMADOR NEGRO PRIMARIO
TRANSFORMEX ROJO SECUNDARIO
120 - 1000 100VA

RS 100 VA TRANSFORMER STOCK No. 2@7-734 DISCONTINUED
MAX TOTAL SECUNDARY LOAD



RECOMENDED ALTERNATIVE
1 PHASE TRANSFORMER KIT
100 VA 2x0 115VAC
RS STOCK No. 182-9925
PRICE £ 30.84

DESIGNED
DRAWN
ISSUE DATE

SCALE

QUEENSGATE INSTRUMENTS LTD
TITLE

SYSTEM CS 100
DRG No 016

A
2