

WHT Marconi boards optimisation procedures

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Setting up and adjusting the Marconi Analogue Processing Boards (APB)

Introduction

The function of the APB is to take analogue rate demands from either the counter board (CTB) or manual input controls on the engineering console and process these with angular velocity inputs from the tacho generators to provide stable control of the telescope's axes and other drives. With the exception of some TTL logic for controlling relays the signal processing on this board is wholly analogue. An APB is used to control the motion of each telescope drive (including rotators) as well as the linear motion of the focus drive. Different moments of inertia (I) on each axis and the dynamic nature of azimuth axis (remember 'I' changes with telescope elevation) implies that each APB must be adjusted for optimum performance on the telescope whilst controlling the intended load. There is little advantage therefore of adjusting these boards off the telescope even if the necessary test fixtures were constructed, the only exception might be to isolate total failure of a component.

The range of loads APBs must accommodate means some fixed components must be selected before tuning the APB with the intended load. It might also be necessary to select some components on test if the necessary adjustment cannot be made using the range of the pot. It should be noted that this requirement has some bearing on the spares and maintenance philosophy that can be adopted by the operations group. The best situation would be to have pre-tuned APBs available as spares for each station. However, some relaxation ideal is possible without undue risk. In the author's experience nasmyth APBs can be interchanged without adjustment despite some possible difference in load, it should be noted that not all nasmyth loads are identical in any case e.g. changing between a derotator prism and Integral. In desperate times other changes could be contemplated with care but an inappropriate board substituted in the azimuth position is unlikely to operate at all telescope elevations.

Preparing and tuning an APB for a particular station

The component value table for all the APB's are listed in a separate document which can be found [here](#)

This procedure assumes that adjustments will be made on a board that either has not been used before or one that has an uncertain history. If an operational board is adjusted in an attempt to improve performance, but is subsequently discovered to have components with different values to those indicated in the table, reasonable engineering judgement must be exercised before substituting the 'nominal' value components the table.

Using the value table, configure an APB by inserting the appropriate fixed components for the particular station

Some Notes on differences between the first generation (old) APBoards, manufactured by Marconi, and the copies made RGO:

1. The circuitry around IC17, designed to introduce a test signal, has been eliminated on the RGO copies (new), and replaced by resistors and Switch 1.
2. R64 on the old boards has been renumbered R46 on the new boards. Resistor is in parallel with R49.
3. The link polarity for the tacho feedback has to be correct according to the table below:

Axis:	Old APB:	New APB:
Azimuth	1 - 3	1 - 2
Altitude	2 - 3	2 - 3
Cass turn table	1 - 3	1 - 2
Cass cable wrap	1 - 3	1 - 2
Focus drive	2 - 3	2 - 3
PF turn table	1 - 3	1 - 2

Nasmyth turn table	2 - 3	2 - 3
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With the appropriate fixed value components installed, the output offset voltages from IC1, 2, 4 and 10 must be reduced to zero and this adjustment is made with the APB in the crate on an extender card.

Marconi system preparation:

- Ensure telescope is in ENGINEERING mode.
- Ensure that ALL power amplifier circuit breakers are switched OFF
- Shut down the Marconi crate power supplies (both the 5V and +/-15V)
- Ensure the oil support is off (necessary for tacho amp adjustments)

Board preparation:

- Remove from the Marconi crate the APB for the axis/drive under test as well as the associated CTB
- Insert an extender card into the APB position and insert the board to be adjusted, leave the CTB slot empty
- Connect a meter able to resolve 0.02mV i.e. Keithley 2100 6 ½ digit DMM between IC1 pin 6, or use the leg of R2 closest to IC1, and analogue ground
- Using a 3 pin wire link, short PL1 28A/28C to PL2 5A the 0v analogue ground (the Schroff extender makes this easy but be sure to use the sockets that run to the board rather than the crate!)

Board adjustments (computer control):

- Switch on the Marconi crate power supplies (both the 5V and +/-15V)
- **NB: Check that the circuit breakers PU1 and PU2 haven't tripped, switching on the Power supplies.**
- Adjust pot VR1 until the DVM reads zero within +/- 0.02mV
- Carefully move the DVM connection from IC1 to IC2 pin 6, or from R2 to the junction of R8 and R9 legs closest to R10, leaving the other connection at analogue ground
- Adjust pot VR6 until the DVM reads zero within +/- 0.02mV

Board adjustments (tacho generator):

- Move the DVM connection from IC2 pin 6 (or R8 and R9), to TP4 leaving the other connection at analogue ground
- Adjust pot VR5 until the DVM reads zero within +/- 1mV

Board adjustments (summing amplifier):

- Move the DVM connection from TP4 to IC4 pin 6, or use the junction of R25 and C8 legs closest to R52, leaving the other connection at analogue ground
- Use another shorting link to take the junction to R23, R24, D7- and D8+ to analogue ground (PL2 5A)
- Adjust pot VR4 until the DVM reads zero within +/- 0.02mV

Crate restoration:

- Switch off the Marconi crate power supplies (both the 5V and +/-15V)
- Replace the CTB in the appropriate slot
- Remove all temporary shorting links added to the APB for zeroing the opamps
- If the APB has not been adjusted before or you are uncertain of its history set VR2 and VR3 to mid positions
- Switch back on the Marconi crate power supplies (both the 5V and +/-15V)
- **NB: Check that the circuit breakers PU1 and PU2 haven't tripped, switching on the Power supplies.**
- Start the TCS program running

WARNING:

During the subsequent parts of this set-up procedure the telescope drive being adjusted may oscillate or run out of control. It is important to ensure all personnel not involved with this activity are aware what may happen and are not close to moving machinery (nasmyth or prime rotators) or moving structures (altitude, azimuth axes or cassegrain rotator).

It is also important to be aware of the way the drive is behaving, and be in a position to use the emergency stops or other controls to quickly bring the system to the previously stable state (i.e. switching back to engineering).

In the early stages of adjustment it is not a good idea to have more power amplifiers on than are necessary for the test. Only when it is reasonably certain the drive being adjusted is stable should other drives be powered and slewing and tracking scenarios sent from the TCS.

Testing with manual control:

- Switch on the appropriate power amplifiers for the test
- Check that the drive being adjusted is not oscillating or drifting
- Turn the manual demand control to minimum (altitude and azimuth)
- Using the buttons and manual rate controls check that the drive can be moved in either direction. It should be noted that when performing this test on the azimuth or altitude axis it is very easy to trip the circuit breakers at the bottom of the Marconi rack by applying excessive acceleration. This should not necessarily be taken as indicating abnormal performance, simply that more care is needed when increasing the demand
- If the drive drifts away without any demand try increasing the tacho feedback, increase VR3

The next adjustment applied to all drives except nasmyth DS and CWS, cassegrain cable wrap drive and focus drive. These drives use motors with a mechanical antibacklash arrangement.

Table 2 Antibacklash Current

Altitude	Azimuth	Cassegrain Rotator	Prime
5.0 amp	5.0 amp	2.0 amp	1.5 amp

Board adjustments (setting up antibacklash torque):

- Ensure the TCS is running
- Switch the telescope from engineering to computer control and check the drive is stable (not oscillating)
- If oscillation is apparent check that the approximate antibacklash current is actually being applied (i.e. motor current meters are in opposite directions)
- If the drive is stable in computer control adjust the antibacklash current using VR2 to the optimum level for the drive given in table 2

At this level of adjustment it is possible to switch on other power amplifiers and enter slewing/tracking scenarios at the TCS and then use the encoder logging facility to produce plots of position error. Plots of position error at different tracking rates are helpful when adjusting the tacho feedback pot VR3 before proceeding to a full Frequency Response Analysis (FRA). The position error depends on tracking rate but at all usable rates the servo error should not have a large bias (i.e. sitting away from zero by $>0.2''$ RMS) or be cycling about zero by more than a good Point Spread Function (PSF) i.e. $>0.6''$ RMS. A bias away from zero suggests too much tacho feedback and excessive cycling about zero indicates the tacho feedback should be increased slightly. The TCS commands <RMS SERVO ON> followed by <RMS SERVO OFF> after a few minutes, provides a value of true RMS servo error over that interval, the use of this command is described in http://www.ing.iac.es/~eng/electronics/legacy/steve_magee/tcs/index.html

The 'Plot' program can also be used to check the performance of the focus drive since the focus position of both the rotary and linear encoders are written to a file during normal operation (whenever the TCS is running and a file is generated when the TCS is shutdown). Logging a deliberate change in focus position and plotting this error against time can show if the drive overshoots the demanded position.

Using the TCS 'Plot' facility to check servo performance

These tests are best performed at the telescope operator's console or with a laptop on the ING network. If a laptop or other PC is used a suitable X-terminal emulator such Hummingbird Exceed must be installed.

Generating an encoder file: -

- **Once the telescope is tracking steadily, type the command <log enc on> and accept the 15 min default**
- **After 2 min terminate the logging by typing <log enc off> and note the name of the file generated (e.g. DISK\$LOGS: [WHT.DATA.ENCODER]enc050507.dat;1)**

From the TO console:

- **Using the 'terminal' pull down menu establish a new LAT session with LPAS4**
- **Either of two accounts can be used for running PLOT, genuser or tcsmgr, the former is a captive account that can only be used for PLOT and another program called PAIRS. The latter is less restrictive and better if data needs to be exported to a PC to be analysed with other applications such as Excel or Matlab**
- **Enter the appropriate password**

The following should appear: -

GENUSER

Welcome to OpenVMS (TM) Alpha Operating System, Version V7.3-2

Username: genuser

Password: *****

Last interactive login on Monday, 16-MAY-2005 14:37:25.88

Last non-interactive login on Monday, 16-MAY-2005 14:37:30.68

1 failure since last successful login

Telescope General User Menu

Please enter an option -

PLOT - Run PLOT

PAIRS - Run the star pairs program

EXIT - Log out

Option>

TCSMGR

Welcome to OpenVMS (TM) Alpha Operating System, Version V7.3-2

Username: tcsmgr

Password: *****

\$ Welcome to the Telescope Control System Alphastation

Last interactive login on Monday, 16-MAY-2005 14:36:51.42

Last non-interactive login on Friday, 15-APR-2005 12:18:34.99

The X client is LPAS4

The X server is dhcporm-staff22.ing.iac.es a remote X terminal or computer connected via TCP/IP.

Encoder log directory DISK\$LOGS:[WHT.DATA.ENCODER]

Autoguider log directory DUA0:[INT.DATA.AUTOGUIDER]

16-MAY-2005 14:53:59

\$

- **In the genuser account type PLOT at the option prompt followed by <cd DISK\$LOGS: [WHT.DATA.ENCODER]>**
- **Type <dir> to list the files and ensure you are in the directory containing the file produced earlier**

In the tcsmgr account it is a good practice to first change to the DISK\$LOGS:[WHT.DATA.ENCODER] directory by typing `<set def DISK$LOGS:[WHT.DATA.ENCODER]>` before starting the program by typing PLOT at the \$ prompt. Instructions that follow are the same in either account from the PLOT> prompt. At the prompt it is always possible to `<help>` and list the available commands with definitions and examples.

To plot the file in the example enc050507.dat;1

- **At the PLOT> prompt, type `<data enc050507.dat;1>` and a record of available variables that can be plotted is listed.**

```
PLOT>data enc050412.dat;1
WHT          20050412
Encoder log file
Number of data fields = 32

Key 1      Key 2      Label
          UTC          Time
AZIMUTH    ABS          Azimuth Absolute
AZIMUTH    GEAR          Azimuth Gear
AZIMUTH    ROLL          Azimuth Roller
AZIMUTH    TAPE1        Azimuth Tape 1
AZIMUTH    TAPE2        Azimuth Tape 2
AZIMUTH    TAPE3        Azimuth Tape 3
AZIMUTH    TAPE4        Azimuth Tape 4
ALTITUDE   ABS          Elevation Absolute
ALTITUDE   GEAR          Elevation Gear
ALTITUDE   ROLL          Elevation Roller
FOCUS      ABS          Focus Absolute
DOME       ABS          Dome Absolute
AZIMUTH    POSERR       Azimuth pos error
ALTITUDE   POSERR       Altitude pos error
CASS       POSERR       Cassegrain pos error
FOCUS      POSERR       Focus pos error
DOME       POSERR       Dome pos error
AZIMUTH    VEL_DEM      Azimuth demand
ALTITUDE   VEL_DEM      Altitude demand
CASS       VEL_DEM      Cassegrain demand
DOME       VEL_DEM      Dome demand
FOCUS      VEL_DEM      Focus demand
CASS       ABS          Cassegrain Absolute
CASS       INC          Cass Incremental
          HORDIS1       Horiz Displacement 1
          HORDIS2       Horiz Displacement 2
          SECPOS1       Secondary Position 1
          SECPOS2       Secondary Position 2
          SECPOS3       Secondary Position 3
          AZMOTOR1      Az Drive Motor 1
          AZMOTOR2      Az Drive Motor 2
1200 records in the data file
PLOT>
```

When tuning APBs rather than investigating suspected telescope faults or poor tracking reports, plotting one of the four POSERR parameters against UTC are the most useful.

- **Type `<read 1 UTC>` to plot time along the x-axis**
- **Type `<read 2 AZIMUTH POSERR>` to plot azimuth position error up the y-axis**
- **Type `<dev xwin>` to define the plotting device as an xterminal window, there are other plotting options such as PS printers use `<help>` and `<device>` to see what is available**
- **Type `<lim>` to set plotting limits**
- **Type `<plot>` to plot the graph in an xwindow in this example**

An APB set up correctly should have a trace that appears symmetrical about zero and only cycles through zero with a small amplitude. Fig1 is an example of azimuth tracking with a large (-1.28") offset suggesting that the tacho feedback should be decreased. Fig2 illustrates good tracking, the servo error trace is symmetrical about zero and the RMS amplitude is much smaller than a typical PSF in fact even the highest peaks are between ~-0.2" and 0.2". Even with a

well set up APB the RMS error will not always be as small as this since the error is dependent on tracking rate, larger tracking rates will generally cause larger errors and some offset might also be noticeable at the highest rates. When tracking close to zenith but still below the usable altitude limit of $89^{\circ}.8$ the largest operational azimuth and rotator rate are reached and in these conditions the actual tracking errors should not still be less than $0.3''$ projected on the sky (i.e. when corrected for altitude).

The actual tracking error on the sky $ERROR_{SKY} = ERROR_{RMS} \cos(Altitude)$

Fig1

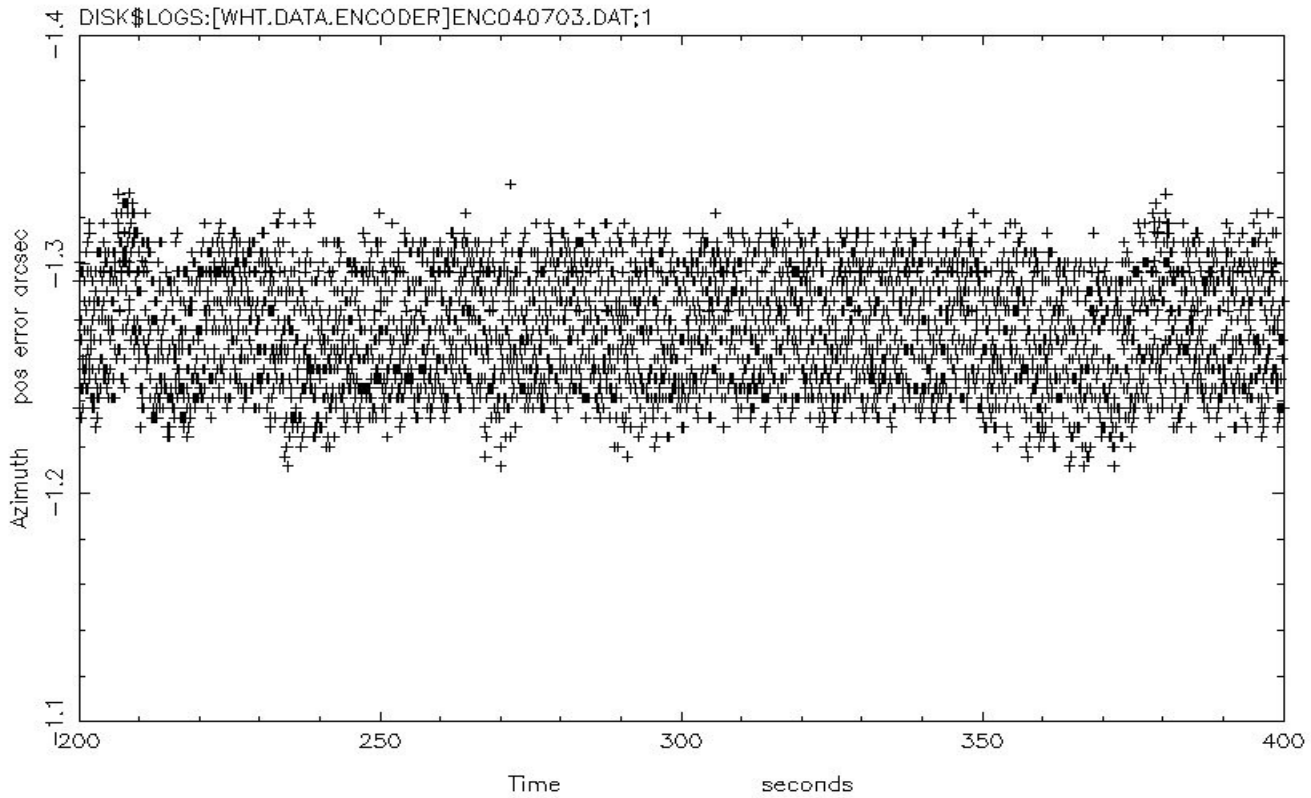
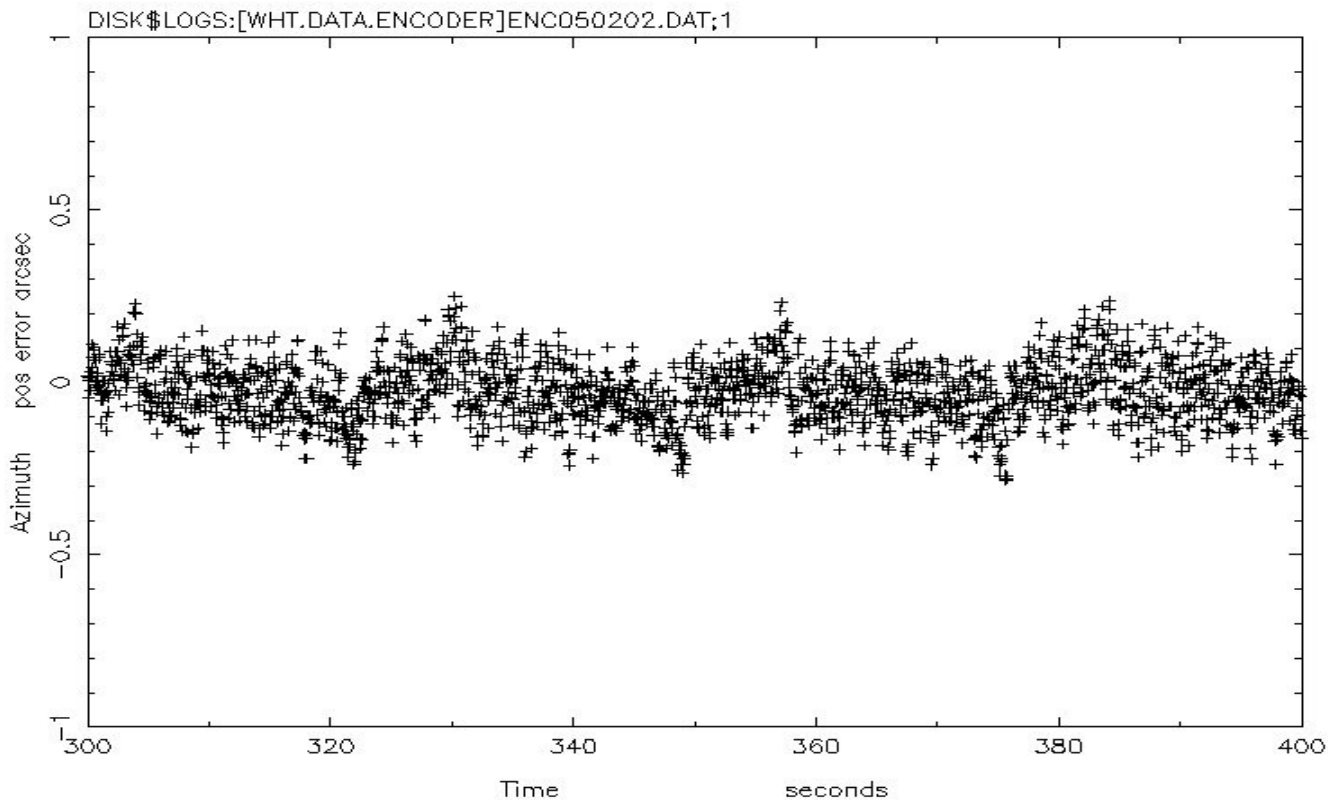


Fig2



This procedure is intended to be sufficient when preparing a new APB board for use as an operational spare. If the substituted board will remain in place after the faulty board is repaired then it is advisable to perform frequency response measurements on the drive and compare the results with previous measurements made with the original board. This ensures that the dominant resonant frequencies have not changed significantly as a result of the board substitution. It should also be remembered that any major changes to the rotating mass of the telescope might also alter the torsional resonance. The procedure for taking and analysing these measurements is given in detail in a document by Martin Fisher "WHT visit report May 2003_appendices". The part of the report describing the use of both the Solartron transfer function analyser and Siglab for making FRA measurements has been extracted and added as an appendix to this document.

Appendix 1

Frequency Response Analysis Measurements

Principle of measurement:

The purpose of measuring a system's Transfer Function (TF) is to determine its stability and optimise its performance. Measurements could be made open loop in order to determine the response in closed loop but this is not necessary when it is known that the closed loop system is stable. In fact it is more convenient to make closed loop measurements and plot them on the closed loop coordinates of the Nicholls chart. This is valid if the system is of second order or the dominant poles of the transfer function are sufficiently 'dominant'. It is then easy to estimate the compensation necessary to optimise the response. The general method for obtaining frequency response measurements using a TF analyser is to inject a disturbance signal, usually a sine wave, at a summing junction at some point in the circuit and then to measure the response at some point, usually just before the injection. The amplitude and phase of the injected and feedback signals are then compared or correlated to produce a transfer function. Usually the average of a number of measurements is made in order to improve the coherence.

Equipment needed:

Siglab

or

Solartron 1250 Transfer Function Analyser (TFA) plus an Oscilloscope and optionally a PC or printer with serial I/F. The setting up instructions for the Solartron FRA are shown below in detail.

Solartron System

Setting up:

The generator output of the TFA is connected to the injection point through a suitable resistor so as to preserve unity scaling of output/input signals. The generator output is also connected to channel 1 of the analyser section while the feedback signal is input to channel 2. Thus the analyser can be set to provide direct results by choosing to measure Ch2/Ch1. In order that non-linearities do not interfere with the measurement it is usual to bias the motion of the telescope with a constant offset demand and then modulate this with a signal whose amplitude does not exceed the bias. There are a number of ways of doing this but the preferred methods depend on the measurement to be performed and are described below.

Measurement of closed position loop:

Connections for this are shown in Fig A1. The TFA generator output is connected to the summing junction of the velocity loop at IC4 through a resistor equal to the sum of the resistors that connect the integrated position error to the same point. This ensures unity gain between the injected disturbance signal and the measured response at TP3, which is the position error. If this is not done then the change in gain must be taken into account. The generator signal is also connected to channel 1 and the response is connected to channel 2 so that the complex ratio of Ch2/Ch1 gives the system response directly. Note that the Ch2 inputs are inverted. This is because of the negative feedback connection of the position loop and in order to display the correct phase relationship it is necessary to re-invert the response signal. A scope is connected to the tachometer signal in order to monitor the behaviour of the drive and ensure that the drive does not reverse or saturate on application of the disturbance signal. For this test the bias is applied via the control computer since any bias applied by the generator would be counteracted by action of the closed loop servo trying to maintain position - a battle which bias cannot win! It is also necessary that the T/S is operating in computer mode so that anti-backlash torque is applied.

The drive can be set up to slew at a constant low velocity by changing the software velocity limit to a suitably low value and then commanding a slew to a position far enough away to allow time for the measurement to be made. The change to the velocity limit is made in the TCS using the Global Section editor "gsexam" and the procedure described later. With the drive slewing slowly the stimulus or disturbance can be applied in small increments until a desirable level is

reached. Note that the response will vary with frequency and a check must be made at each measurement to ensure the bias is not being overcome by a high signal level or that the response is so low as to cause coherence problems for the analyser. A suitable integration time should be chosen such that results are consistent. This depends on the S/N of the response and the linearity of the system under test. On the WHT integration over 10 cycles has been adequate. On the INT an integration of 100 cycles may be required although this is tedious at 0.1 Hz!

Warning: care must be taken not to over-excite the system under test as this can cause damage let alone produce meaningless results. The stimulus should be kept small. Care with entering the amplitude and frequency parameters is needed and a close watch kept on the tachometer voltage signal on the oscilloscope so as to avoid problems with resonances of the system.

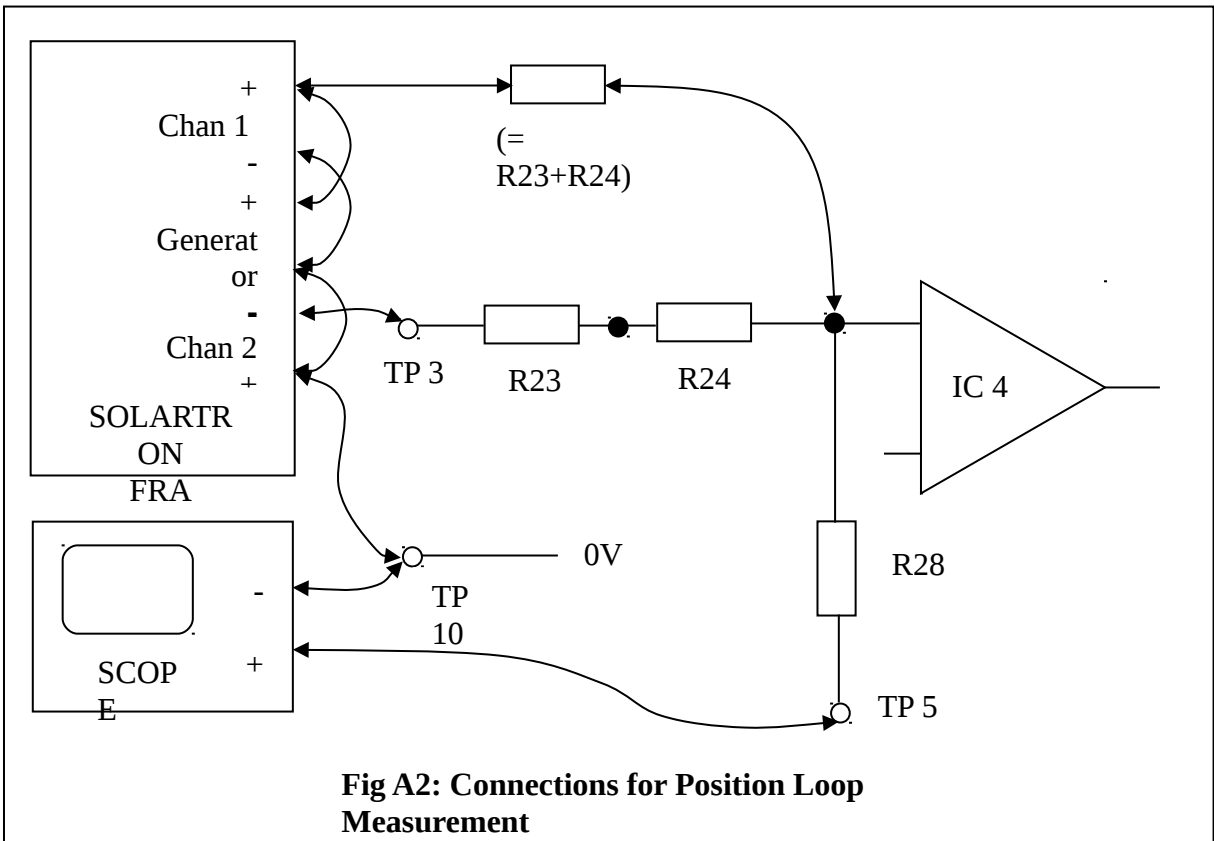
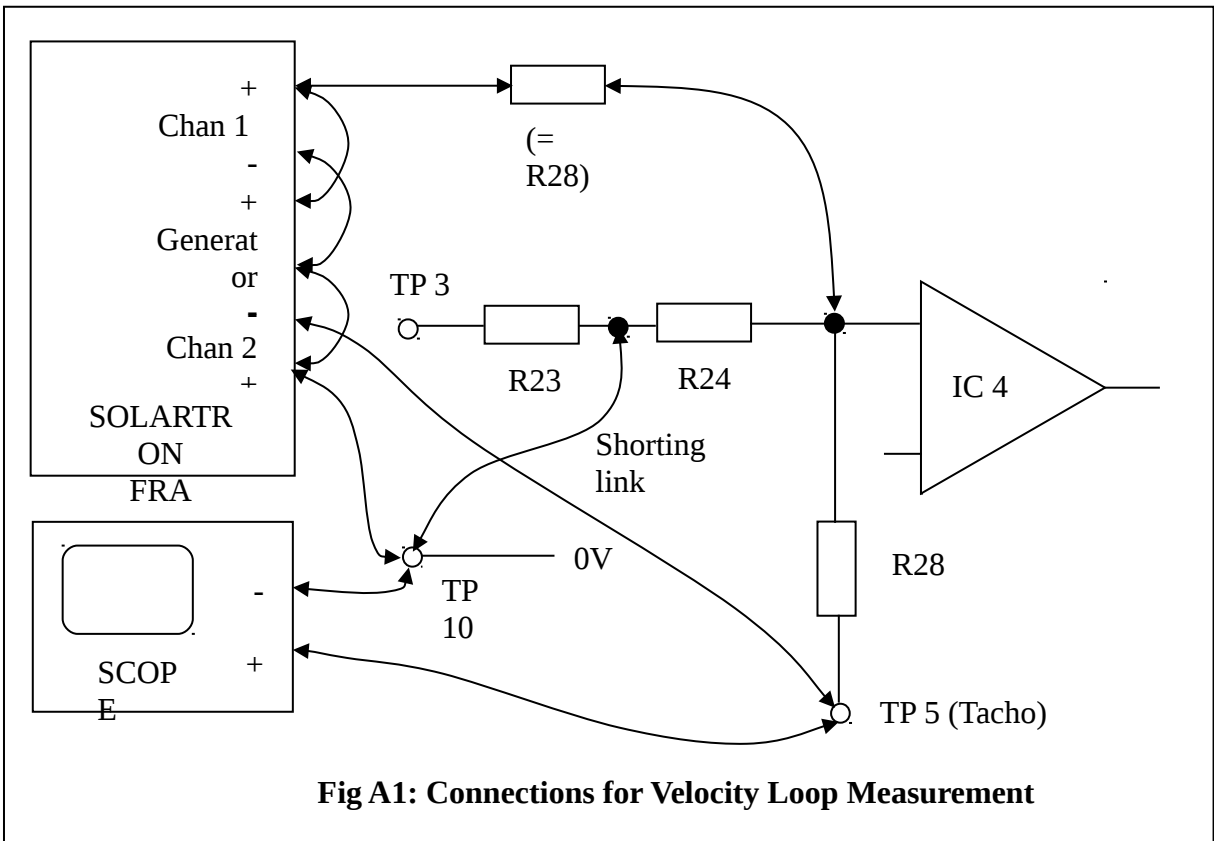
Connections for velocity loop measurement:

In this case signal injection is at the same point but via a resistor of the same value as the tachometer feedback resistor from TP5 (R28). The response signal is measured at the (TP5) and again the Ch2 connections are reversed. For this test, the position loop must be disabled for the measurements to be valid otherwise the position loop fights the velocity loop. The position loop is disabled without disabling the anti-backlash current by shorting the position error signal at the junction of R23 and R24 to ground. The velocity bias can now be applied using the TFA and increased until an appropriate rate is indicated by the tachometer output. The system is still in computer mode for the test even though the position loop is disabled. All the precautions mentioned above are still applicable.

Solartron FRA settings

Typical settings are shown in the table below:

FRA Section	Function	Setting
Generator	Waveform	SINE
	Carrier	NONE
	Modulation	OFF
	Bias	0
Analyser	∫ time	10 cycles
	Delay	0
	Harmonic	1
	Auto ∫	OFF
Sweep	not used unless response known	
Display	Source	CH2/CH1
	Coordinates	logR,θ
Function	Angle	DEGREES
	$\times \omega^n$	1
	Scale	1
	Limit	OFF
Data O/P	Display	ALL
	RS-423	ALL
	GPIB	OFF
	File	OFF



Some of the Marconi APB boards may have the necessary input resistors connected to the velocity loop summing junction, ready for leads to be attached. The RGO-style boards have the input resistors and the necessary links set by a switch to make set up for either measurement easy. The values of input resistors for each APB are shown in the table below. These resistors should always be checked to ensure the measurement is valid.

Analogue Process Board	R23	R24	R23+R24	R28
AZIMUTH	10k Ω	10k Ω	20kΩ	10kΩ

ALTITUDE	12k Ω	12k Ω	24k Ω	10k Ω
CASSEGRAIN ROTATOR	15k Ω	15k Ω	30k Ω	47k Ω
CASSEGRAIN CABLE WRAP	33k Ω	22k Ω	55k Ω	18k Ω
PRIME FOCUS ROTATOR	15k Ω	15k Ω	30k Ω	10k Ω
FOCUS DRIVE	15k Ω	18k Ω	33k Ω	10k Ω
NASMYTH DRIVE SIDE	15k Ω	15k Ω	30k Ω	10k Ω
NASMUTH CABLE WRAP SIDE	15k Ω	15k Ω	30k Ω	10k Ω

Applying the measurement bias

Note that the notes given in the Marconi instructions are incorrect and that the instructions given in this document should be used. For the velocity loop measurement the motion bias can be supplied by a DC offset injected with the test signal. This is available both on the Solartron FRA and on the Siglab virtual instrument panel. For the position loop measurement the axis motion bias can be supplied via the TCS by commanding a position reasonably far away from the current position. In order to give time for the test(s) to be conducted the velocity can be reduced by changing the velocity limit for that axis in the TCS parameter table called 'global section'. To change the parameter log on to LPAS4 as engineer and start 'gsexam'. The value of the required velocity limit for azimuth can be examined using this command at the DBG> prompt:

DBG> exa mec_ar_dat(1).limit.vel (carriage return)

This should return the value 1.745 D-02 which is 1°/s in radians. To change the value to 0.1°/s type:

DBG> dep mec_ar_dat(1).limit.vel = 1.745 D-03 (carriage return)

The number in brackets is the code for the telescope axis. For tests on rotators the appropriate focal station must be defined at the TCS user interface. The codes are given for all the axes in the table below. Note that the TCS does not have control of the Cassegrain cable wrap since it is slaved to the rotator.

Telescope axis	axis number
AZIMUTH	1
ALTITUDE	2
CASSEGRAIN ROTATOR	3
CASSEGRAIN CABLE WRAP	-
PRIME FOCUS ROTATOR	4
FOCUS DRIVE	7
NASMYTH DRIVE SIDE	6
NASMYTH CABLE WRAP SIDE	5

SIGLAB System

All the above information is valid for measurements undertaken using Siglab except for the differences noted below, the most important of which is the note about inverting leads:

The standard configuration for Siglab inputs is not differential. This means that input leads cannot be inverted unless the Siglab input reconfigured on the internal user IC header platforms. The LOW input is normally connected to ground through a 400 Ω resistor and this must be removed to allow input leads to be inverted. While this works reasonably well it should be remembered that common mode rejection is now reduced and sensitivity to offsets increased. There seems to be no means of inverting a signal channel within Siglab from the virtual instrument interface though it should be possible to modify the virtual instrument software to incorporate this. The best way to deal with this issue is not to invert the leads but accept that there is a 180° phase shift in the resulting transfer function. Then when analysing the results the phase shift can be removed. See analysis below.

The VNA virtual instrument in Siglab is used for obtaining transfer functions (or other representations) and within this instrument two excitation signals are available, Chirp and Random. Either may be used but there are advantages and disadvantages to take into account. The chirp excitation is better at overcoming non-linearities within the system under test but generates a harmonic signal, which sweeps through the selected frequency range. This harmonic signal may excite resonances, which result in high levels of response, requiring the excitation level to be reduced and decreasing sensitivity in other parts of the spectrum. The random excitation avoids the problems of harmonic response but generally takes longer to achieve good coherence. For drives with high stiction the level of random excitation may have

to be high to get a consistent response in which case harmonic excitation is likely to be the better option. Both methods should be tried unless the preferred method has already been established.

SIGLAB analysis

Once a Siglab test has been completed it should be saved to a *.vna* file but also exported to a text file by selecting 'export' and 'transfer function'. The text file contains headers, which describe the instrument setup and so are useful but may get in the way when importing them to Matlab. One way to deal with this is to edit the text file by placing a '%' at the start of each line to be ignored by Matlab. Some data lines at the start of the measurement also may need to be excluded because they contain spurious measurements at very low frequency. With the file in Matlab workspace the response can then be plotted as desired. To automate this process an m-file has been developed which loads the edited text file, allows the user to apply gain or phase modifications and prepares the data for plotting within the LTI viewer. It does this by converting the frequency response data into complex form, applying the inverse Nichols function to convert the closed loop response to an open loop response and then taking both these responses and converting them to a *system* so that it can be imported as such into the LTI viewer or directly plotted using standard control system toolbox plot commands. The m-file is called *clo2op.m* and is shown below. The script does not produce plots but prepares the data for plotting. It also includes a function for interpolating between data points which is useful when only a few points are available so in general one should use *olsys* as the import or plot data and only use *iolsys* if required. The Nichols plot requires open loop frequency response data since it uses those coordinates in its plot routine. The open and closed loop data is useful for Bode plots.

Typical set up appearance for the Siglab VNA instrument is also shown below in examples of both chirp and random excitation performed on the azimuth axis of the WHT for tube vertical and tube at 45° zenith distance. The instrument setup window is shown together with the resulting frequency response window for each case. Note the similarity of the response for chirp and random excitation but also the noisier high frequency response using chirp. Note also the different response between different tube elevations.

```

% clo2op.m  Converts measured T.F. data to a system for viewing using LTIVIEW.
% The mag and phase data is converted to open loop for plotting on the Nichols diagram
% Data is from a SIGLAB .vna file which has been edited by either removing the descriptor
% header or, better still, by commenting out the lines of the descriptor with '%'.
% For systems with sparse measurement points the gain phase and frequency points are
% interpolated by a factor of ten to provide a smoothed locus.
% Get data into workspace by entering the filename without the '.txt' e.g. whtaz_fra_16vna;
%

fn=input('Enter text filename: ','s'); % input the filename
fname=[fn '.txt']; % add the .txt extension for the load command
disp(['Loading ' fname]) % display the filename being loaded
load(fname); % load the filename
data=eval(fn); % assign contents of file to array 'data'
offset=input('Enter gain offset in dB: '); % input the offset
phaseshift=input('Enter phaseshift in deg: '); % input the phaseshift
w=data(:,1)*2*pi; % extract frequency (in Hertz) and convert to rad/sec
mag=10.^((data(:,2) + offset)/20); % extract magnitude (in dB) and convert to gain
phase=(data(:,3) + phaseshift)*2*pi/360; % extract phase (in deg) and convert to rads
x=mag.*exp(i*phase); % convert gain-phase to complex exponential form
h=x./(1-x); % use inverse Nichols mapping to get open loop coords
olsys=frd(h,w); % create open loop system
nmag=20*log10(abs(h)); % open loop gain in dB
nphase=unwrap(angle(h))*180/pi; % open loop phase in degrees
clsys=frd(x,w); % closed loop system

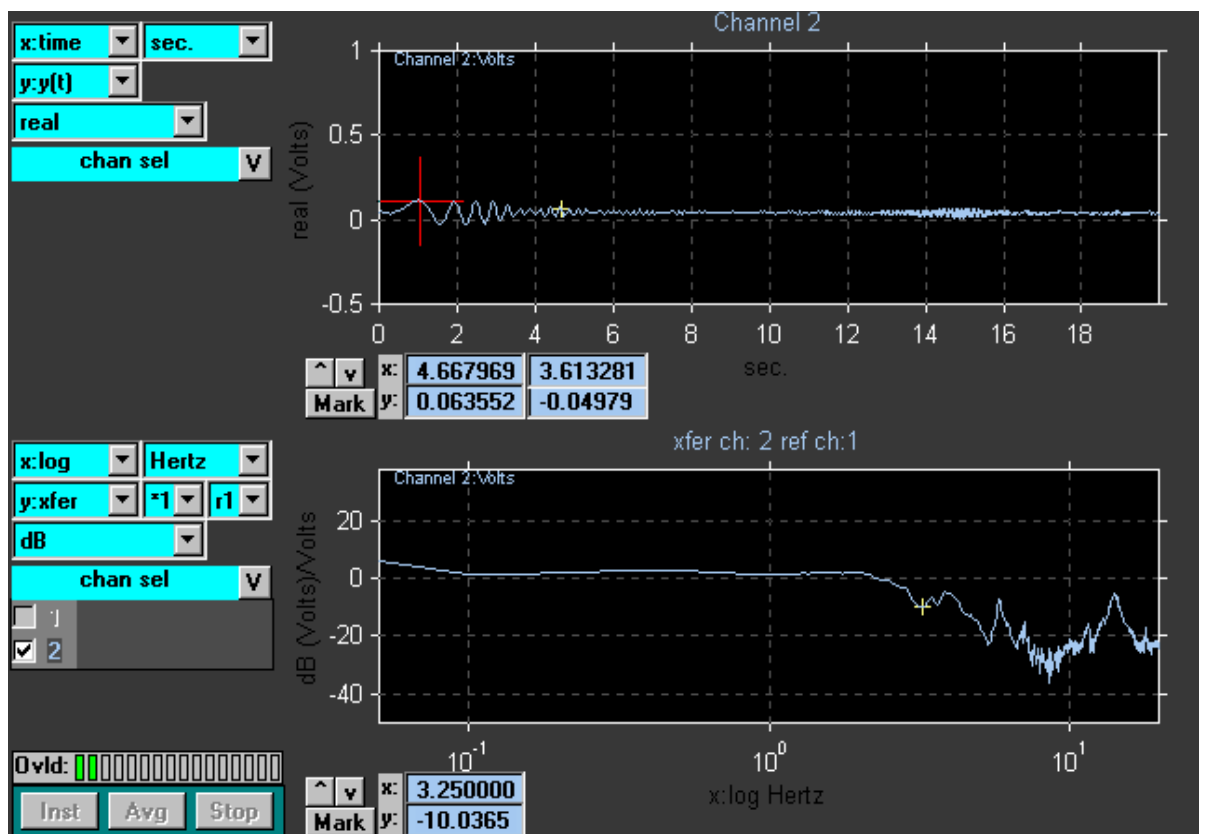
% Now interpolate data to produce a smoothed locus:
imag=interp(mag,10); % interpolate magnitude data
iphase=interp(phase,10); % interpolate phase data
iw=interp(w,10); % interpolate w data
ix=imag.*exp(i*iphase); % convert gain-phase to complex exponential form
ih=ix./(1-ix); % use inverse Nichols mapping to get open loop coords
ih(length(ih)-9:length(ih))=[]; % get rid of last nine superfluous points
iw(length(iw)-9:length(iw))=[];
iolsys=frd(ih,iw); % create open loop system

% Now produce vectors of the interpolated open loop response:
[response,frequency] = frdata(iolsys); % get the frequency response data
resp=squeeze(response); % reduce 3D array to single vector of complex response data
inmag=20*log10(abs(resp)); % magnitude in dB
inphase=unwrap(angle(resp))*180/pi; % phase in degrees

```

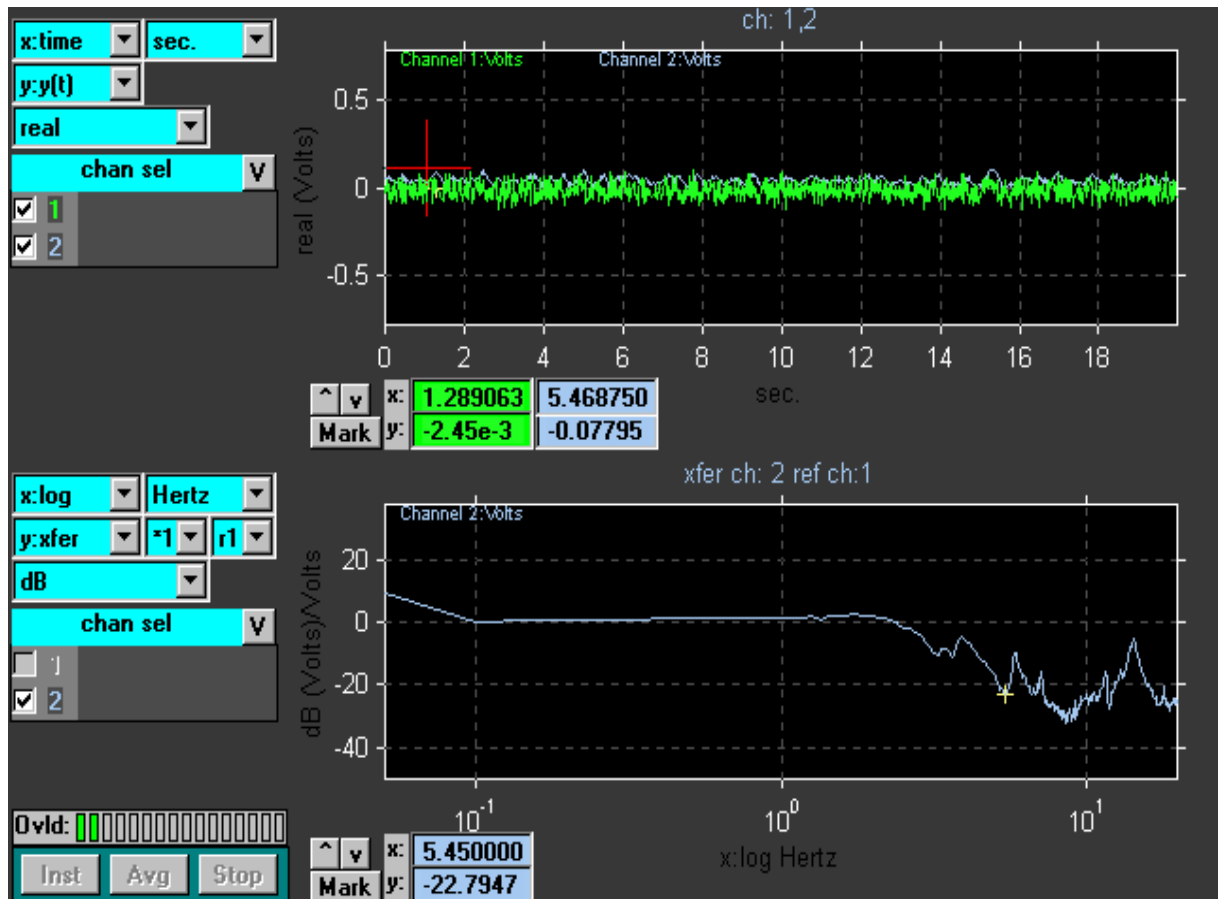
The following azimuth axis frequency response with tube vertical was obtained using the Siglab Virtual Network Analyser (vna) mode with "chirp" excitation.

CHANNEL SETUP		FREQUENCY RNG	
Ch1	On	BW=20.0Hz	
0.63V	DC	AA Filters On	
Input Offset -2.5 0.000 2.5		Record Length 64 1024 8192	
Channel Label Channel 1		Zoom Off	
EU Off	1 0dB	dF=0.050Hz.	
PROCESSING		EXCITATION	
Add	Zp	Chirp	Off
Stop at Count 1 10 1000		Output RMS 0 0.050 2.5	
OvldRej = Off		Output Offset -10 0.000 10	
No Overlap			



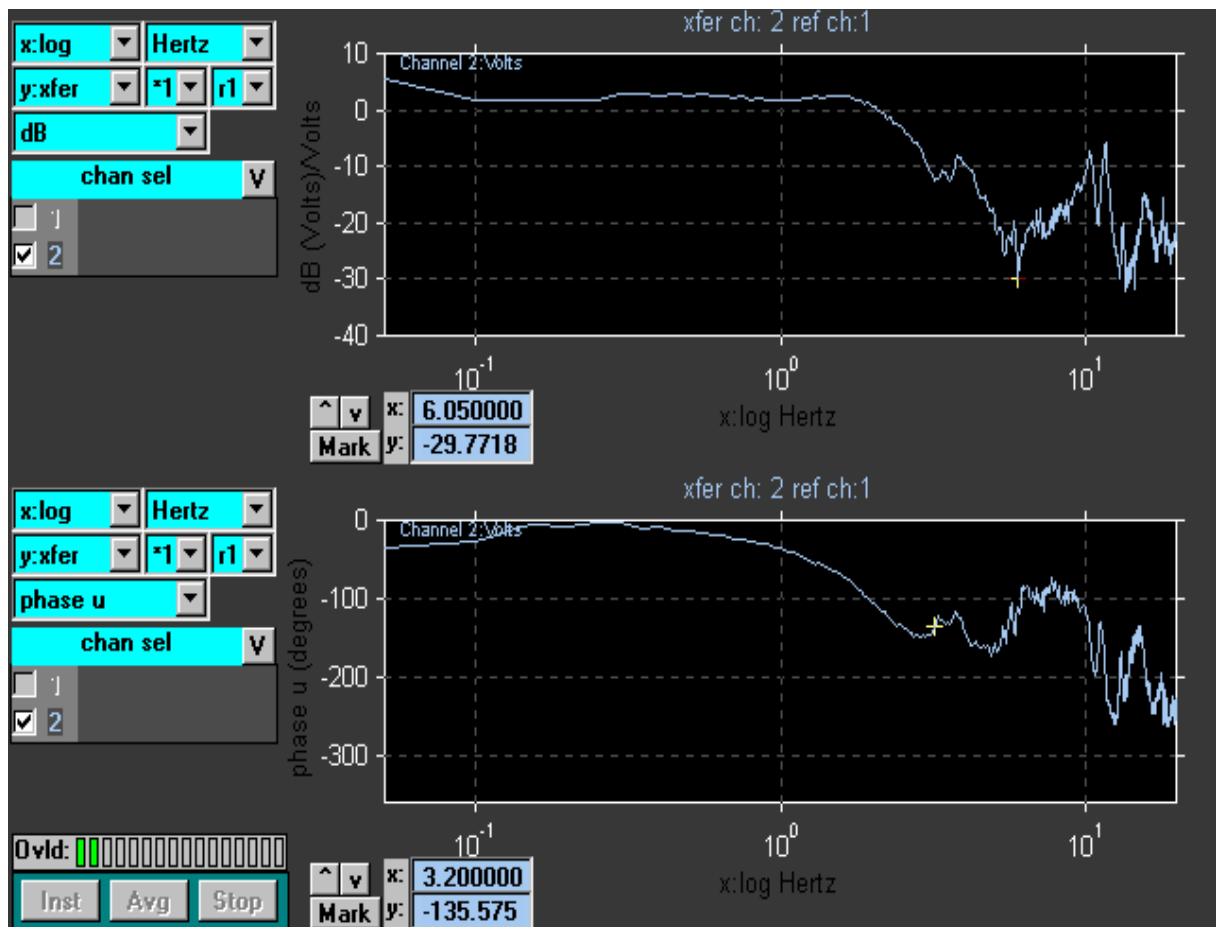
The following azimuth axis frequency response with tube vertical was obtained using the Siglab Virtual Network Analyser (vna) mode with "random" excitation.

CHANNEL SETUP		FREQUENCY RNG	
Ch1	On	BW=20.0Hz	
0.63V	DC	AA Filters On	
Input Offset		Record Length	
-2.5	0.000	64	1024
Channel Label		Zoom Off	
Channel 1			
EU Off	1	0dB	dF=0.050Hz.
PROCESSING		EXCITATION	
Add	Zp	Rand	Off
Stop at Count		Output RMS	
1	10	0	0.050
OvldRej = Off		Output Offset	
No Overlap		-10	0.000



The following azimuth axis frequency response with tube at 45° Z.D. was obtained using Siglab's Virtual Network Analyser (vna) mode with "chirp" excitation.

CHANNEL SETUP		FREQUENCY RNG	
Ch1	On	BW=20.0Hz	
0.63V	DC	AA Filters On	
Input Offset -2.5 0.000 2.5		Record Length 64 1024 8192	
Channel Label Channel 1		Zoom Off	
EU Off 1	0dB	dF=0.050Hz.	
PROCESSING		EXCITATION	
Add	Zp	Chirp	Off
Stop at Count 1 10 1000		Output RMS 0 0.050 2.5	
OvldRej = Off		Output Offset -10 0.000 10	
No Overlap			



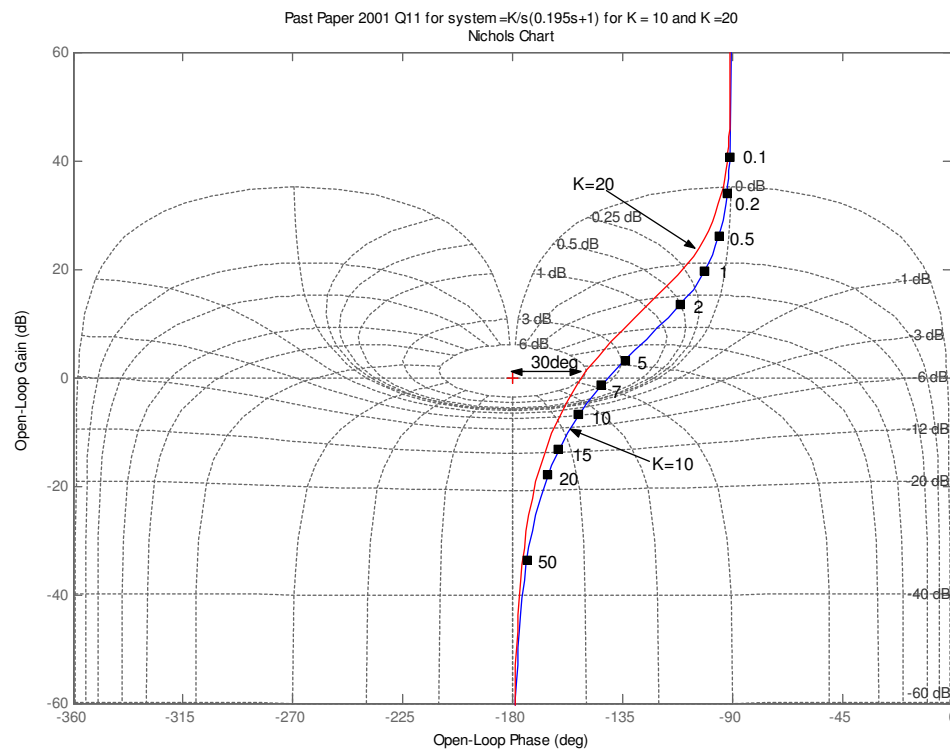
Tuning:

Should this ever need to be re-done then the basic points are covered below. It is not a procedure that can be automatically followed, one has to understand both the theory and practice of control systems to be able to analyse and assess the system under test and be on the lookout for indications of problems which are not of a tuning nature e.g. non-linearities, regular disturbances such as torque ripple or significant high-order terms which should not be ignored.

The Marconi system is a nested loop control system. The velocity loop should be tuned first to give good response over a wide bandwidth. The higher the loop gain and bandwidth in the velocity loop the better will be the disturbance rejection provided there is no saturation introduced in the loop. However this loop will affect the characteristics of the outer rate or digital loop and too much gain will cause problems for stability. Increasing the velocity loop gain will introduce phase lead into the rate or position loop but also increase the high frequency gain. A compromise needs to be found which provides the best disturbance rejection properties with the optimum bandwidth and stability properties of the position loop.

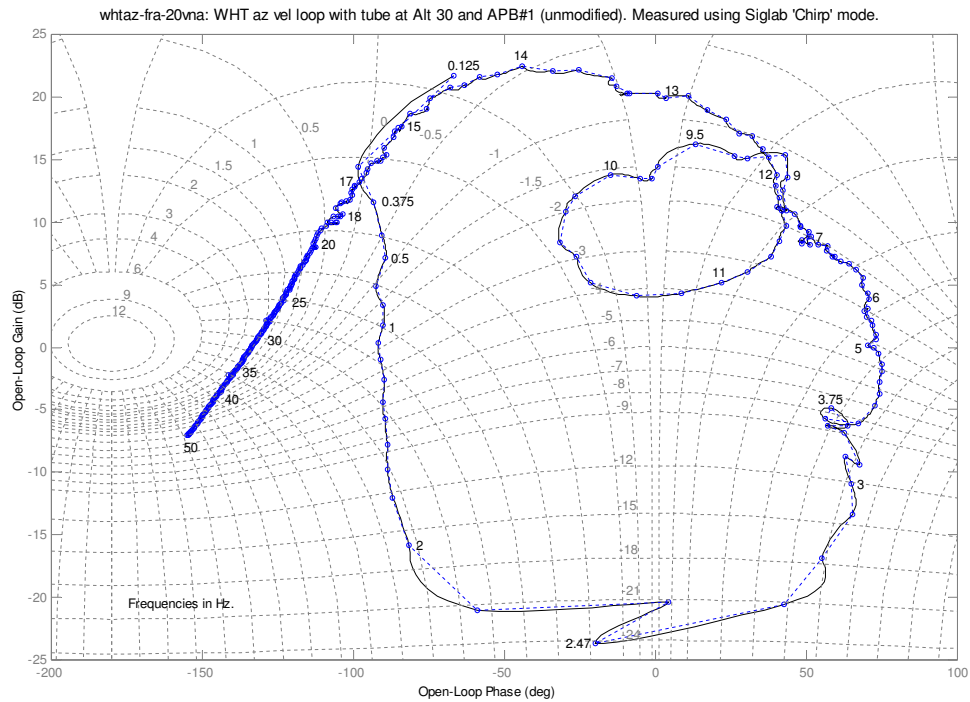
Designing compensation is best done using the Nichols plot though it can also be done using Bode plots. The Marconi handbook describes the calculation of components to produce desired gain and phase properties and the site tuning report contains the Nichols charts and component values for the axes which were set up after the telescope was installed in 1987.

As a brief explanation of Nichols plot compensation, here is the general characteristic for a second order, type I system represented in Nichols form; note that for each locus the open loop phase starts at -90° at low frequency and progresses to -180° at high frequency. A desirable aim for many control systems is to reach a closed loop response which peaks at 3 dB at the highest frequency possible, thus the locus of the response is required to be tangential to the 3dB closed loop contour. In the diagram below the red locus cuts through the 6 dB contour giving a phase margin of only 30° that is generally regarded as insufficient for a stable control system. This system would exhibit substantial overshoot to a step response. To improve it a simple reduction in loop gain from 20 to 10 produces the blue locus, which is tangential to the 3 dB contour and increases the phase margin to about 50° , which is acceptable. However the alternative, which would preserve the loop gain, would be to introduce some phase advance between 2 Hz and 10 Hz such that the locus is pulled to the right.

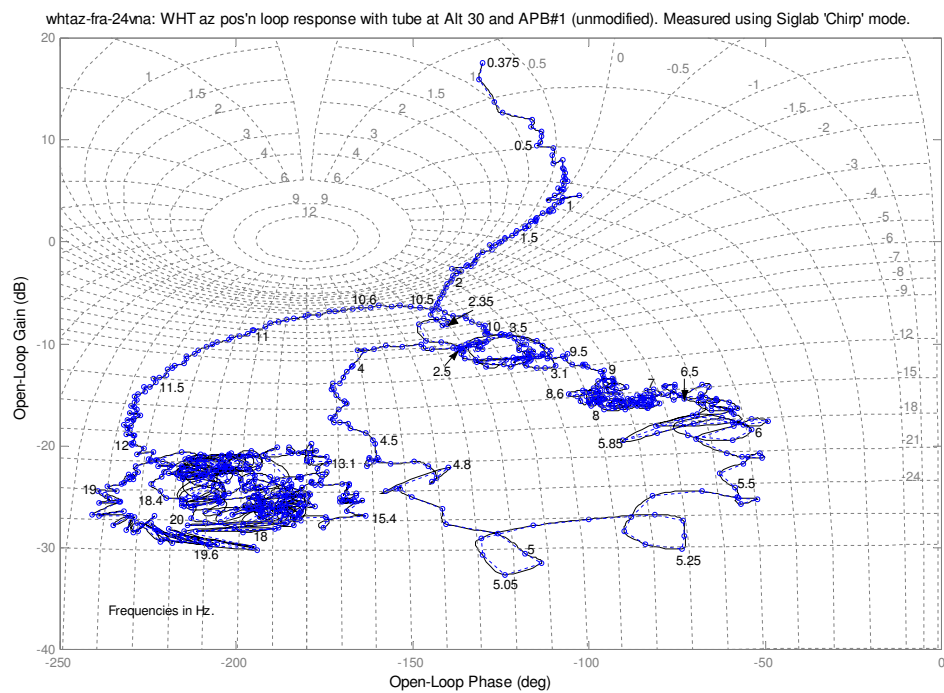


Most systems are not second order and many contain resonances so that the Nichols plot is not so simple but the basic aims are still valid, i.e. to have a reasonable gain and phase margin for the open loop system and to avoid exciting resonances. A reasonable gain margin is 8dB to 12 dB and a reasonable phase margin is 45° to 80° but it depends very much on the system what is acceptable. Some overshoot is desirable since it usually provides the best response and settling time so closed loop peak gains of 1dB to 3dB are common.

An example of the WHT Azimuth velocity loop and rate (or position) loop is shown below. The loops are caused by structural resonances. In the velocity loop response the large loop is caused by the locked rotor resonance due to the drive chain and the smaller loop is the structural resonance of the tube (top end) since the telescope is at an altitude of 30° and so the tube inertia is significant. The locus is tangential to the 2 dB contour, the phase margin is about 50° and the -3 dB bandwidth is almost 50 Hz. Since there is no integrator in the velocity loop the low frequency phase will start at 0° and the frequency phase will, in principle, be asymptotic to -180° so that the gain margin is infinite.



The position loop response shown below has low frequency phase starting at -180° since there are two integrators in the rate loop, the analogue integrator and the counter, which acts also as an integrator. The high frequency phase will continue well past -180° because of all the structural resonances evident down stream of the azimuth position encoder. The locus is sucked to the right at around 1 Hz by the combined action of phase advance in the lead-lag network on the APB and also the effect of the velocity loop. Otherwise the locus moves around the 1 dB contour, enters into multiple resonance loops and emerges to sweep around the -2 dB contour at about 10.6 Hz. This produces a gain margin of about 7 dB which improves as the telescope moves towards zenith. The phase margin is about 70° which is more than adequate but will get smaller as the telescope moves to zenith. This illustrates the importance of testing azimuth at two representative elevations of the tube, zenith and, usually, altitude 30° .



Tuning of the servomechanisms should always take into account significant operating conditions but one must also be aware that faults with the mechanism under control can affect the outcome of frequency response tests. It is important not to retune a servo mechanism unless it is established that no faults are present. However, a change in parameters may occur which may lead to poorer performance or decreased stability margins. Changes in inertia are not likely to occur unless a significant modification is made or a significant change to instrumentation is introduced. The most likely

change to be encountered is an increase or decrease in friction and the effect depends very much on the type and location of the friction. A change in static friction may introduce limit cycles in systems. A change in viscous friction can change the damping and hence make a system more or less stable. Another thing to beware off is the addition of a small inertia through a large gear ratio or change in friction of a small device like an encoder which also couples through a large gear ratio.

Initial problems may be identified through tracking tests, looking for evidence of encoder malfunction or of 'new' frequencies being introduced which increase with velocity and therefore indicate gearing, motor or encoder problems. Frequencies which don't shift with velocity may be structural resonances or may be due to closed loop peak response excitation produced by a shift in frequency response locus due to parameter changes. Simple tests can help to distinguish between these problems and are worth carrying out and analysing before committing to frequency response analysis.