MRO Delay Line

Metrology System & VME Hardware Design Description

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The Cambridge Delay Line Team

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Change Record

Revision	Date	Authors	Changes
0.1	2008-01-18	RCB and XS	First released version
1.0	2008-01-23	RCB and XS	Second version
1.1	2008-01-23	MF	Minor amendments plus adding VME parts to component list
1.2	2008-01-25	MF	Added section on stability
1.3	2008-01-28	MF	Included section on Datum facility + minor changes
1.4	2008-01-29	MF	Included acronyms, appendix C and other text changes

Objective

This document describes the design of the metrology system and associated VME hardware.

Scope

This document provides a description of the Cambridge test rig and MROI metrology system including the mechanical and optical components, the associated electronics in the VME chassis and the low latency link. The procedure of beam alignment for the 200m delay lines is proposed for reference. The metrology design is based on a Zygo 7712 water-cooled laser head and some corresponding Zygo optics components in this document. At the time of producing this document the Agilent 5517D laser head is being evaluated for possible use in MROI. Thus, some components for the final version of the MROI metrology system may be changed from Zygo to Agilent. For further information on the choice of laser head, please see the document AD04. For further information on the metrology system requirements, please see the document AD05.

Reference Documents

RD1 Results of the Risk Reduction Experiments (Rev 1.0 6th December 2005)

RD2 Top-level requirements INT-406-TSP-0002

Applicable Documents

AD01 VME Software Functional Description INT-406-VEN-0104

AD02 Shear Camera Software Function Description INT-406-VEN-0105

AD03 Trolley Electronics Design Description INT-406-VEN-0112

AD04 Metrology Laser Choice INT-406-VEN-0114

AD05 MRO Delay Line Derived Requirements INT-406-VEN-0107

AD06 Delay Line Pipes & Supports Design Description INT-406-VEN-0115

AD07 Metrology System to BCF INT-406-VEN-0012

AD08 Limits Design Description INT-406-VEN-0116

Acronyms and Abbreviations

BCA Beam Combining Area

BCF Beam Combining Facility

BRS Beam Relay System

DL Delay Line

DLA Delay Line Area

ICD Interface Control Document

ICS Interferometer Control System (now SCS)

MROI Magdelena Ridge Observatory Interferometer

MRAO Mullard Radio Astronomy Observatory

NMT New Mexico Tech

OPD Optical Path Delay

SCS Supervisory Control System

TBC To be confirmed

TBD To be determined

Contents

1 Introduction

This document describes the design of the test rig and MROI metrology system including the description of the VME electronics and the low latency link. The mechanical design of the MROI metrology, which is used for 200m delay lines, places more stringent requirements on the mechanical stability and thermal effects than the test rig. The supports of some critical optical components are made of stainless steel - the same material as the optical table, to eliminate “bimetallic” effect in thermal expansion. However, in order to get a shorter time of fabrication and cost saving, an aluminium prototype has been produced for preliminary tests at Cambridge.

It should be noted that the design described in this document is based on the Zygo 7712 laser head. An Agilent 5517D laser head, which is currently being evaluated, may replace the Zygo laser head in the final design (see AD04). Therefore, some relevant optical components may be changed accordingly together with some minor modifications on the mechanical components.

The procedure for aligning the metrology beams has been provided in this document although some parts of it are specific to the Zygo laser.

2 Test rig

A schematic layout of the optical system for the test rig is shown in Figure 1. The test rig includes a Zygo ZMI7702 laser head, a linear interferometer, two beam expanders, a shear camera and the VME measurement boards. The incoming laser beam is fed from the laser head via a mirror to the polarising beam splitter. The straight through beam is reflected by the retro reflector (the fixed reference) to the fibre optic receiver. The other beam is directed via a motorised mirror and then a manually adjusted mirror so as to produce a beam which is at the correct position and in the correct direction (when it leaves the beam expander) with respect to the science beam. After passing through the beam expander the beam is approximately 23mm diameter.

The returning beam from the cat’s eye passes through a second beam expander to reduce the beam to 6mm and, via two manual adjustment mirrors, is directed to the polarising beam splitter and hence to the fibre optic receiver. The separation between outgoing and reflected beams is 12.7mm.

After the returning signal is combined and phase compared with the reference signal, the relative change in OPD of the reflected beams causes phase shifts which are then accumulated in a counter. In addition a beam splitter splits the returning beam to project an image for the shear camera, see AD02. The brief specifications of the interferometer are:-

- Resolution 0.62nm (single pass, therefore 1.24nm OPD resolution)
- Velocity 5.1m/s
- Data Age Uncertainty +/-1.2nsec
- Data Rate 10MHz
- Data Format Parallel VME
- Electronics Format 6U VME
- Measurement Range +/-21.2m (extendable by software)

A 3D view of the components of the test rig is shown in Figure 2. The Galilean beam expanders are clamped onto the side walls of two aluminium brackets via their cylindrical lens adapters. The assembly of the interferometer and its adapter and the fibre optic pick-up are supported by an 'Ealing' bench. A 1 inch plate beam-splitter is mounted on a Comar prism table with an adjustable clamp arm to split off a small percentage of light for the shear camera. The camera housing is described in section 3.5.

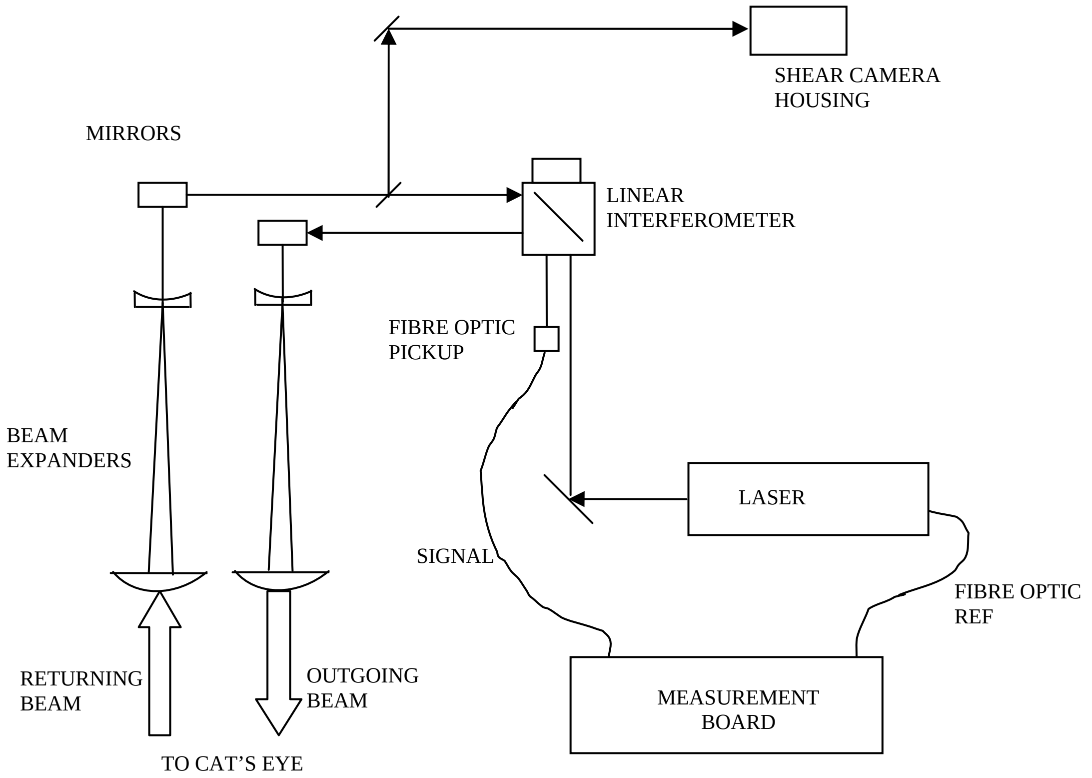

Figure 1 Schematic layout of the metrology system

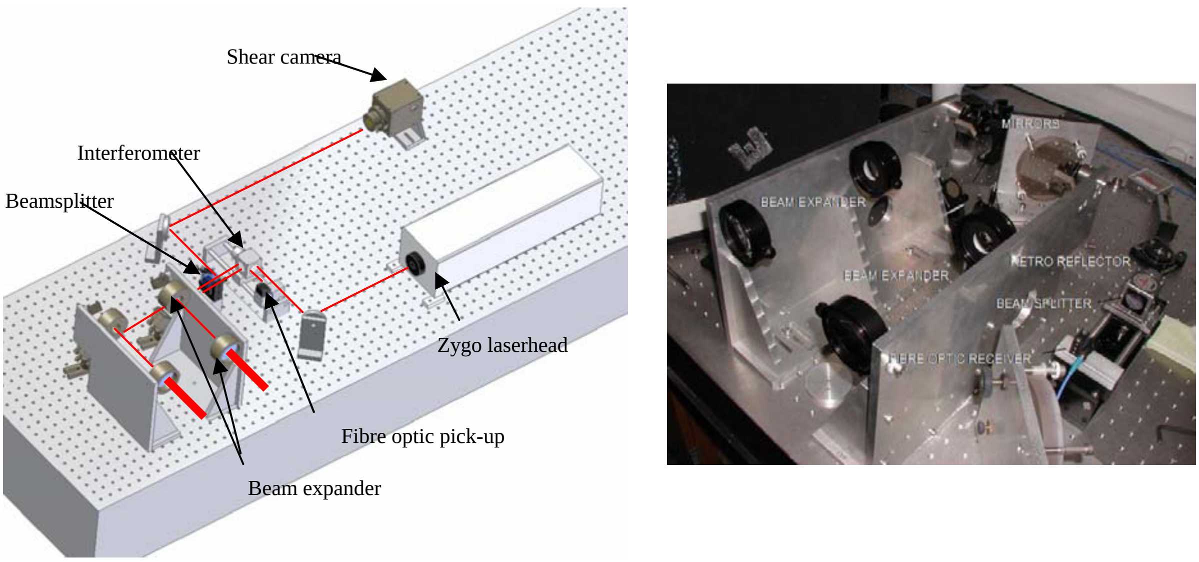

Figure 2 3-D view and a photograph of the metrology layout used for prototype testing

3 MROI metrology

The metrology layout, shown in Figure 3, is intended to be used for up to 10 delay lines though only some of them will be used in the first instance. Figure 4 presents the 3D views of the components in the layout, and Figure 5 shows the top and back views with some dimensions. The major concerns for the design of the mechanical components are mechanical stability and thermal expansion due to temperature variation. The critical optic supports should provide long term dimensional stability and relative high dynamic stiffness to the possible environmental disturbances.

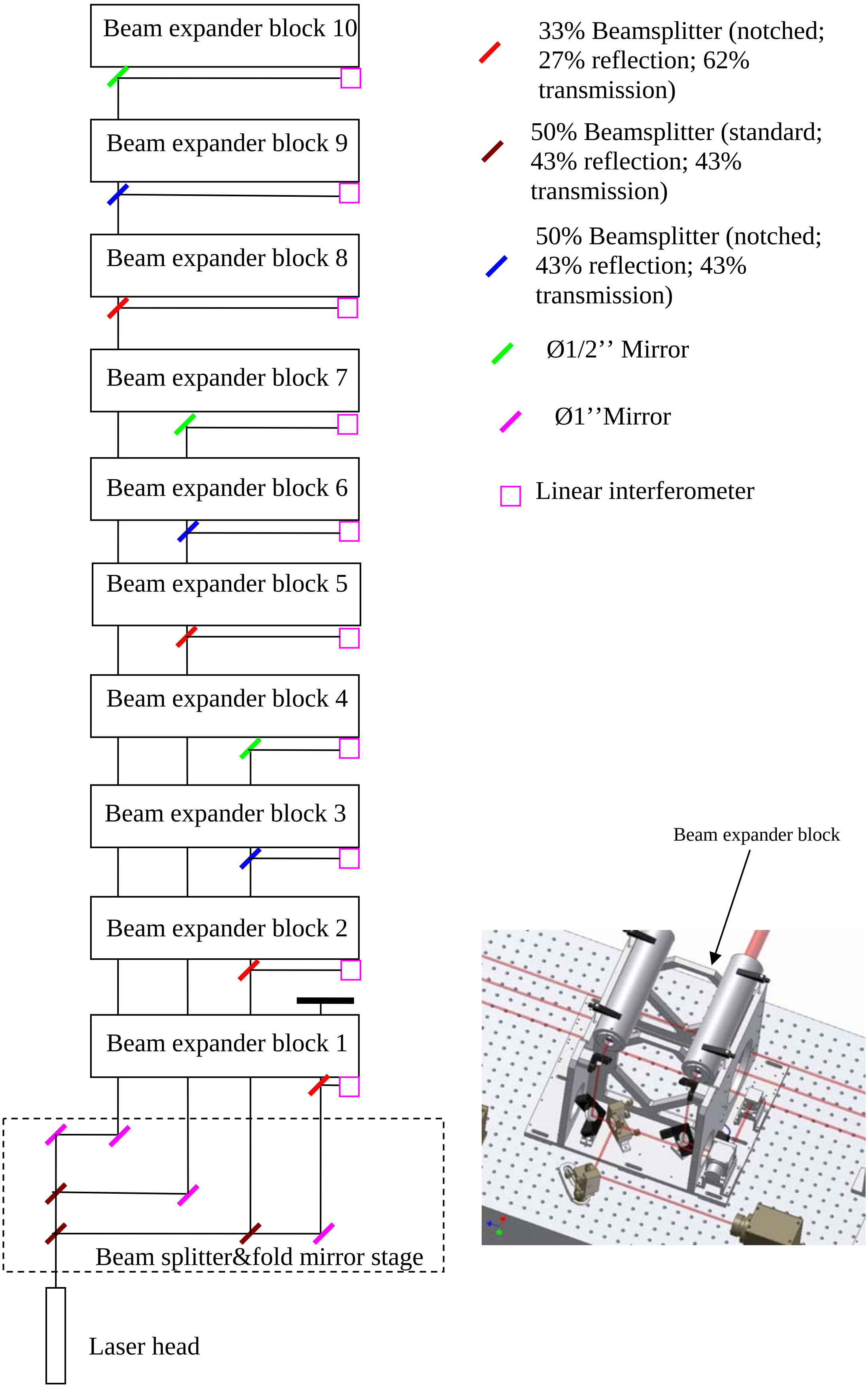

Figure 3 Schematic drawing of metrology layout for MRO

Stainless steel, the same material as the optical table, is specified for the major components to eliminate thermal distortion due to “bimetallic” effect. It should be noted that the system is installed in the inner BCA which is temperature controlled to ±0.1ºC by control of the air in the outer BCA.

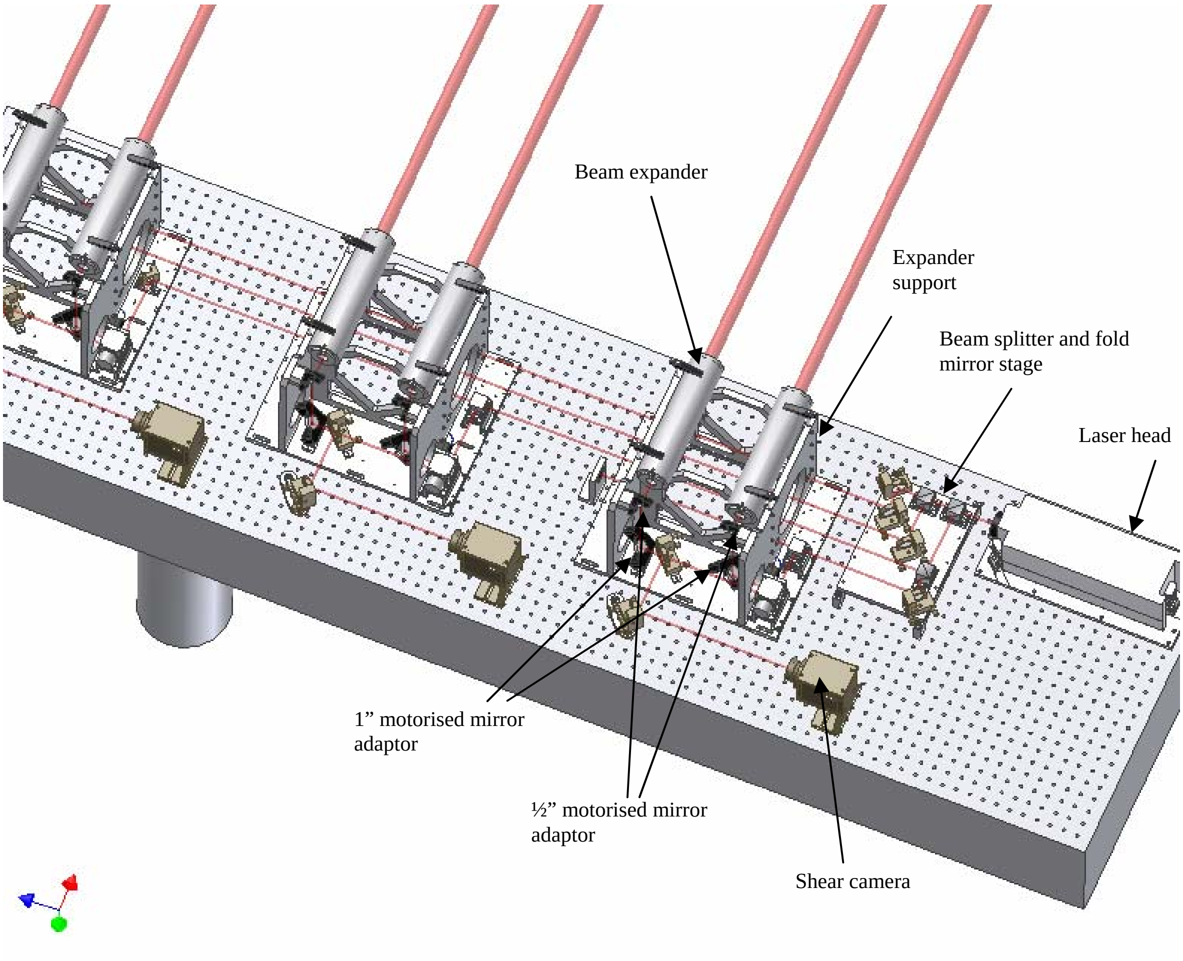

Figure 4 CAD drawings showing the MROI metrology system. (The three beam expander blocks represent three different cases, and are not drawn in the same position sequence as that in Figure 3)

3.1 The metrology block

The beam expanders, the interferometer, the motorised beam alignment mirrors and the beam-splitter for the shear camera are all mounted in a substantial stainless steel block shown in Figure 3 (the right picture). The block is composed of four vertical 12mm thick frames and a large symmetrical base plate jointed by M4 screws. Two beam expanders sit on the V grooves of the two web frames, and are clamped by four adjustable clamp arms. The large holes on the central webs allow the science beam go through to reach the beam combining area. There are holes on the side frames to let the metrology beams go through to the other metrology blocks. This feature allows the metrology blocks for multiple delay lines to be lined up on the optical table to save space. All the clamping holes on the large base plate are distributed symmetrically. This enables two kinds of blocks to be assembled, which allows the laser head to be located at either end of the optical table. Also this allows for the use of two lasers if it should be necessary. The stability of the opto-mechanical components for the launch beam is most important and this is addressed in section 6.

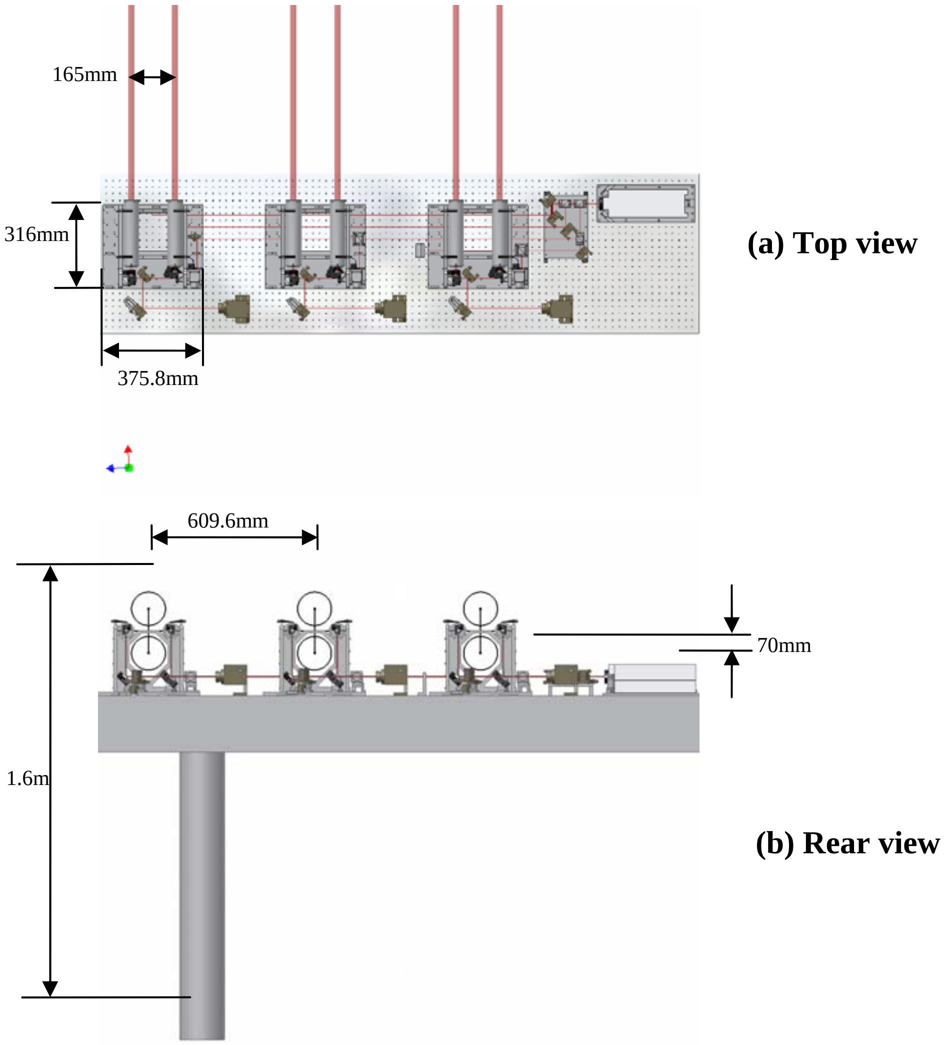

Figure 5 Plan and elevation views of the metrology layout for MROI

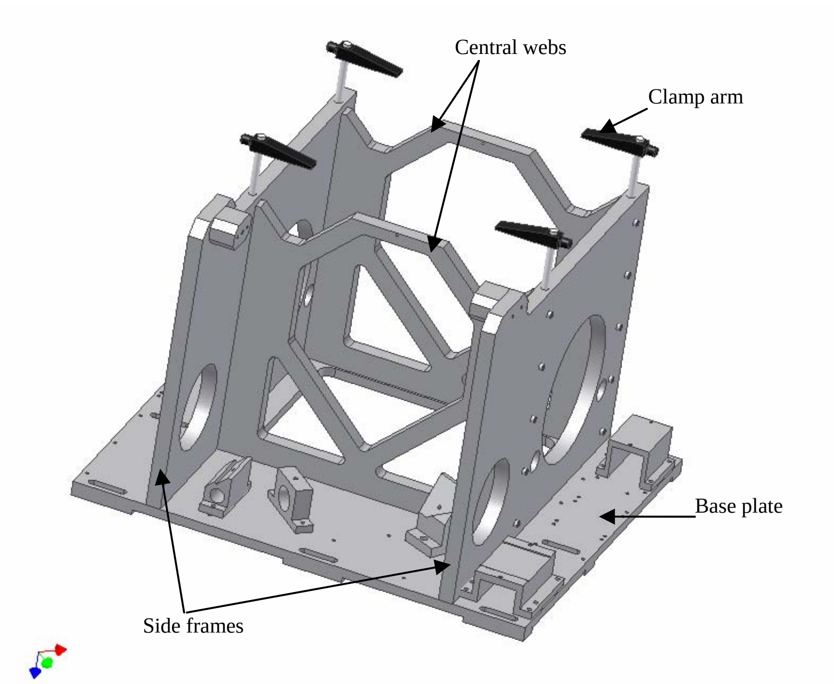

Figure 6 The metrology block. It is the main support for the optics for one delay line.

3.2 Beam expander

The concave and convex lenses are mounted in a precision-machined stainless steel tube to compose a beam expander shown in Figure 6. Two plastic spacers are put on both sides of each lens for separating the lens from the metal. The convex lens is mounted at one end of the tube with a threaded ring. The concave lens is mounted in a cylindrical stainless steel adaptor with a threaded ring. The outer surface of the adaptor has a close running fit with the internal surface of the tube at the other end. An M3 stainless hexagon socket set screw with 500 micron thread pitch is used for expander focus adjustment. The focus resolution requirement of 34µm is met by a 20º twist of the screw. Once the right focus is achieved, the M4 stainless hexagon socket set screw can be tightened up to fix the position of the concave lens.

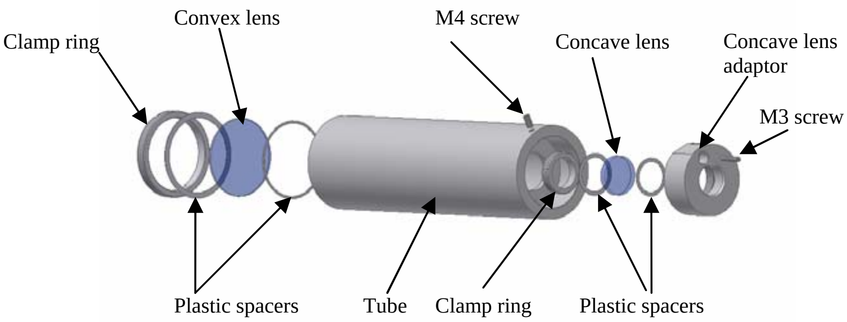

Figure 7 Exploded view of the beam expander

3.3 The beam-splitter stage

The laser, which is fed from the laser head, is split into four beams after going through a stage of beam-splitters and fold mirrors (see the rectangle enclosed by the dotted line in Figure 3). The stage, shown in Figure 8, is composed of a 10mm thick stainless steel top plate and two stainless steel legs. It supports three beam-splitters and four fold mirrors on the top. Four M6 screws are used for clamping the stage onto the optical table.

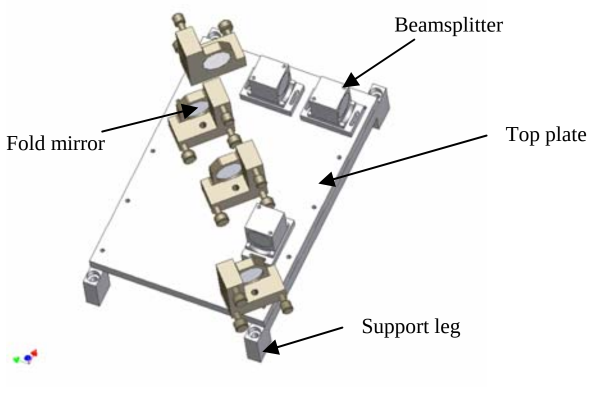

Figure 8 Beam-splitter and fold mirror stage.

3.4 Procedure of beam alignment

The following procedure is followed in aligning the metrology system to the delay line.

1. Install the optical table so that the holes are parallel to the delay line axes.
2. Set up an alignment target on the proposed metrology beam axis, referenced to the delay line axis, at the far end of the delay line
3. Mount and align the laser head so that the output beam is aligned to the table mounting holes.
4. Mount the beam splitter stage on the table and align the various beam splitters and fold mirrors so that the output beams are all aligned to the table mounting holes and in the correct position.
5. Mount the metrology block and align with the delay line.
6. Using the Zygo alignment mask on the interferometer block, adjust the first mirror so that the input beam enters the interferometer block at the correct place.
7. Remove interferometer block and check the input beam is also aligned with the optical table mounting holes.
8. Replace interferometer block and adjust the two motorised mirrors so that output beam to the delay line is at the centre of the first lens of the beam splitter. The expanded beam should now be close to the alignment target set up at the far end of the delay line. Make small adjustments of the top motorised mirror to align expanded beam with the target.
9. Move the interferometer block 12.7mm and repeat step 7 using the other two motorised mirrors and aligning the expanded beam with the second target at the far end of the delay line (165 mm from the first target) Move interferometer back to its correct position.
10. Insert trolley in delay line. The returned beam from the cat’s eye should be somewhere near the beam expander. Adjust the tip/tilt stage until the returned beam is at the centre of the beam expander (reducer).
11. Remove the fibre optic receiver from the metrology block. Align a target at the position of the beam from the retro-reflector (attached to the interferometer block). Place the target as far as practical from the interferometer block.
12. Slacken the screws holding the retro-reflector and insert a piece of paper to block the reflected beam.
13. Place modified Zygo alignment mask (2mm holes rather than 6mm) on the face of the interferometer block facing the returning beam. Repeatedly adjust the return beam motorised mirror mounts so that the return beam (now 2 mm) goes through the target hole and is aligned to the target setup in set 10.
14. Replace optic receiver, and remove the piece of paper and Zygo alignment mask. The top green LED on the measurement board should now be on. Connect a voltmeter to the test point on the measurement board and make small adjustments to the return beam motorised mirror mounts to maximise the voltmeter reading.
15. Adjust the beam splitter and mirror for the shear camera, so the beam is at the correct height and parallel to surface of optical table.
16. While observing the shear camera display, make final adjustments to the final mirror to centre the image.

3.5 Shear Camera Housing

An assembly view and an exploded view of the shear camera are shown in Figure 9. The beam passes into the camera housing via a laser line filter used to reject ambient light to improve the contrast ratio. The filter is mounted in a custom aluminium ring, which has fine-pitch thread for the connection with the commercial beam compressor. The compressor is clamped by a custom clamping ring which is mounted onto the front wall of the camera cage. The focus of the compressor can be adjusted by moving the beam compressor axially by loosening the M5 screw to produce the right size spot on the CCD surface. The shear camera which is supported by pillars is mounted to the back plate of the camera cage. Two slotting holes are on the base plate for clamping the camera housing onto the optical table. All the custom components are made of aluminium. For further information on the camera hardware and its implementation see AD02.

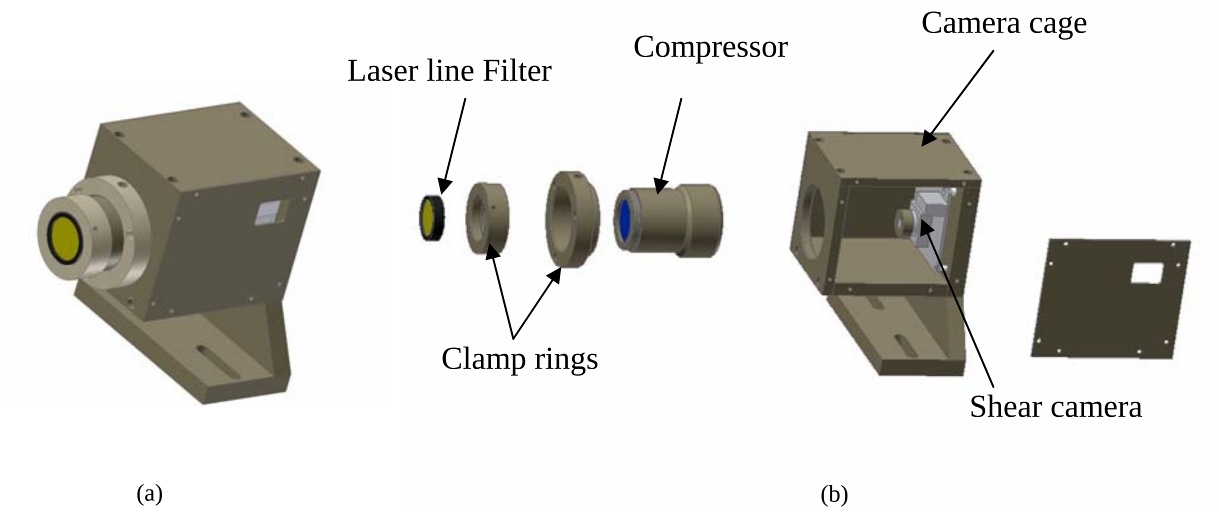

Figure 9 3D views of the shear camera

4 VME Chassis

The VME chassis contains a CPU, a timing board, up to 5 Zygo measurement boards, a DAC and PIO board and one custom made interface board. The chassis is a standard 6U chassis with a 10 slot VME backplane with 96 way connectors and a 200watt VME compatible power supply. Forced air cooling is necessary and 3 fans are mounted below the boards. The VME system is located in a rack in the outer BCA. See the ICD between the metrology system and the BCF (AD07).

4.1 CPU

This is a 1.6GHz Pentium M single board computer and has the standard architecture for an x86 processor with all the usual ports (Ethernet, USB, video, mouse, keyboard, parallel etc) together with a 6U storage unit with hard disk, floppy disk and CD reader. In addition it has a 'Universe' chip which interfaces VME bus signals to standard PCI bus signals. The manufacturer supplies software support for all the common operating systems including Linux and QNX.

4.2 Timing Board

Symmetricon TTM635VME

This is the timing board and has the following key features

- Time on demand with zero latency
- Synchronisation with time code input
- Synchronised programmable output clock 1,5,10MHz
- Programmable periodic output synchronous or asynchronous
- Time of day display

During development of the delay line the unit has been programmed to use a ‘free running’ mode using the on board crystal oscillator but in the system, it will be locked to an external time-code generated by a GPS timing receiver.

The unit is programmed to generate a synchronous periodic output at 5 KHz which is used to generate CPU interrupts and to sample the metrology measurement boards. It also provides a one second signal via a status register.

4.3 Measurement Board

Zygo ZMI 2002

The dual axis register based VME board is preferred over the four channel version because a board failure would not compromise so many delay lines. Also it would require three four-channel boards plus a spare to operate 10 delay lines and this is a more expensive option than five two-channel boards plus a spare. The board has front panel fibre optic inputs for the reference signal, from the laser head, and two inputs from the fibre optic receivers. Also on the front panel are monitoring points for alignment purposes. Other signals, including sampling requests, appear on the P2 connector of the VME bus. There are also various indicators for the state of the system. (loss of the reference signal, a measurement glitch, etc) all of which can be accessed via an error register. Programming is carried out by writing to various registers including resetting the counter (e.g. when the datum is reached) and turning off the overflow limit which would otherwise stop the counter from updating.

4.4 IP Carrier Board

TEWS Technologies TVME200

This is a four slot IP (industry packs) VME bus carrier board. The VME base address is set by switches. One board can be configured to handle ten delay lines using the following Industry packs.

4.4.1 Digital to Analogue IP Unit

Acromag IP220A.
This is 12 bit 8 channel DAC. Each output channel has its own DAC with a 11 μsec settling time and provides bipolar output -10v to +10v. Calibration coefficients are stored on board and outputs

can either be updated individually or simultaneously. The outputs via a 50 way ribbon cable are fed to the custom interface board. (Note: 2 packs would be needed but there is now a 16 channel version of this pack).

4.4.2 Parallel IO IP Unit

BVM IP PI/T
This unit uses two industry standard chips, Motorola 68230, which can be programmed for a variety of functions. It can provide up to 48 digital lines which can either be input or outputs and is used to monitor and control the datum switch. Ten delay lines can be controlled by this pack.

4.5 Custom Board

This board contains the following interface functions for each of ten delay lines (see the circuit diagram in Appendix C):

- Inversion of interrupt line to drive VME SYSFAIL signal (see AD01)
- Conversion of single ended analogue drive signal to a differential signal for sending 200m to the RF transmitter of the low latency link. This is implemented using an Analog Devices SSM2142 balanced line driver which is capable of driving very long cables.
- Provide power and a latch circuit for datum switch.

4.6 Datum facility

The requirement for the precision of the datum facility is set out in RD1. An intra-night repeatability better than 10µm rms and a night to night repeatability of 100µm rms is required. The datum facility is provided by a ‘nano-SPOT’ optical sensing switch mounted in the top of the delay line pipe close to the anchor which is a stable reference position. The switch (see Figure 10) is a commercially available combined light source and sensor with in-line conditioning electronics (Figure 11). The beam spot size is 1.5mm at 20mm distance and the sensing range is enhanced by using a reflective tape which is adhered to the trolley shell. The sensor, which is only 13.5mm x 13mm x 3mm in size, is mounted on the outside of the pipe so that it operates through a window, receiving a return beam when the trolley passes by on the inside. Arrangements for mounting the sensor are described in AD06.

Figure 10: The nano-SPOT sensor.

Figure 11: The nano-SPOT in-line amplifier.

The datum switch is interfaced to and powered by the custom board described in the previous section.

The state of the switch is interrogated by the VME system when the system is in datum seek mode and the VME system commands the following sequence of operations in order to seek the datum:

1. Reset the datum latch circuit

2. Slew at maximum speed towards datum

3. Stop the trolley when the datum switch activates and is latched

4. At this point the trolley will be past the datum switch

5. Reset the latch and drive slowly back until the datum latches again

6. Continue driving the trolley until clear of the datum switch

7. Drive very slowly towards datum until the switch operates

8. Reset metrology counter and change from slew mode to position hold mode (close cat's eye servo loop).

If the trolley is already past the datum when commanded to go to the datum then the trolley will drive into the pre-limit (see AD08). The workstation will then drive the trolley out beyond the datum by a direct slew command to the trolley micro and then command the VME to restart the above sequence.

5 Low Latency Link

To maintain a high servo bandwidth for the cat's eye, the delay between measuring the position with the metrology system, and applying a correction, must be kept to a minimum. Various methods were considered but of the commercially available units tested this one met the requirements.

The transmitter is an Applied Wireless T900AU and operates at 922MHz in the unlicensed wireless band (US) with a frequency response from DC to 20 KHz. By good fortune at this frequency the 16 inch delay line pipes acts as a circular waveguide giving low loss and, with a matched aerial, low standing waves

As mentioned above, the single ended output from the DAC is converted to a differential output with a single IC (Analogue Devices SSM2142) intended for audio application over long distances and transmitted via standard microphone cable 200m to the transmitter. Here it is converted back to a single ended signal, again in a single IC (analogue Devices SSM2143) attenuated and level shifted to modulate the transmitter.

The receiver on the trolley is the matching device from Applied Wireless R900AU and the 1v p-p output signal is amplified and level shifted for the cat's eye drive pre amplifier.

Circuit diagrams for these modules are given in the trolley electronics design description (AD03)

6 Metrology Stability

The pointing stability of the metrology beams is critical for such a long measurement length. Re-adjustment of the beams will be required on a periodic basis and the principal aim of the design of the metrology system is to minimise the pointing drift thereby maximising the time between re-alignment exercises.

6.1 Thermal considerations

6.1.1 Thermal environment

To minimise pointing drift the thermal environment in which the laser and the launch optics are situated should be controlled both in the sense of maintaining the same temperature and minimising thermal gradients. The diurnal variation in temperature of the inner BCA is specified to be no greater than ±0.1˚C. The temperature in the outer BCA is to be actively controlled throughout the year to approximately ±1˚C. The expectation is that this will lead to a variation in the inner BCA of the order of ±0.1˚C on a reasonably long time scale.

Facilities are provided in the inner BCA to remove heat from components mounted on the optical benches. This will help prevent the mixing of warm and cold air in light paths but will also help to maintain a constant temperature and minimise temperature differentials on the optical tables. The expectation is that temperature differentials on the metrology table will be better than ±0.1˚C. Even so, the metrology system assemblies are to be manufactured from stainless steel, with similar characteristics to the optical table on which they mount, and designed so as to minimise any distortion that may be introduced by thermally generated stresses.

6.1.2 Heat sources

Heat sources on the optical table are limited to the laser head and the shear cameras. The laser head dissipates approximately 25W and will be removed by enclosing the laser in a shell with a funnel to pass the warm air into the outer BCA through the ceiling.

The shear camera generates very little heat (approximately 1W) and so no special precaution is necessary other than to confine any warm air in a funnel until it is above the light paths across the metrology table should it prove necessary.

6.2 Stability requirements

The derived requirements for the metrology system are set out in AD05. This places specifications on the stability of opto-mechanical components and also presents an optical quality budget. The optical quality budget is met using standard commercially available opto-mechanical components and only the beam expanders/compressors need to be specially manufactured although they do incorporate catalogue lenses. The stability of opto-mechanical subassemblies and components is addressed through careful sub-assembly design, temperature control of the BCA and selection of precision components.

6.2.1 Laser stability

The pointing stability of the laser is dealt with in AD04. The mechanical stability of the laser mount is expected to be comparable to the inherent pointing stability of the laser provided that the heat generated by the laser is properly removed from the locality.

6.2.2 Beam feed angular stability

The beam from the laser to each metrology block is fed via three beam-splitters to the interferometer block and thence to the launch mirrors. The angular stability requirements placed on these are:

- Beam splitter system angular stability 0.45 arcsec RMS 2-axis over ±0.1ºC
- Interferometer angular stability 0.45arcsec RMS 2-axis over ±0.1ºC

The RMS angular stability in one axis for three mirrors is

$$\beta = \sqrt{(2\alpha_1)^2 + (2\alpha_2)^2 + (2\alpha_3)^2}\ ,$$

Where α_n is the stability in one axis for each mirror. Assuming the mirrors have identical stabilities:

$$\beta_2 = \sqrt{12}\alpha\ ,$$

where β_2 is the RMS output beam deviation and α is the single axis stability for each mirror.

Hence, $$\alpha = \frac{\beta_2}{2\sqrt{3}}$$

Therefore the 2-axis RMS angular stability required on the beam-splitters, assuming identical specifications for the three components, is:

$$\alpha = \frac{\beta_2}{2\sqrt{6}}\ ,$$

Therefore:

$$\alpha = \frac{0.45}{2\sqrt{6}} \quad = \quad 0.092\,\text{arcsec}$$

This stability can be met by the Newport 'Agilis' adjustable mirror mounts described in the next section but do not need the finesse of adjustment. Thorlabs KS1 ultra-stable kinematic mirror mounts are specified for the beam splitter stage and stability is likely to be better than the Agilis type once locked.

The interferometer angular stability is likely to be better than the stability of the Agilis adjustable mount.

6.2.3 Launch mirror adjuster stability

The beam adjustment mirrors on each metrology block are motorised for both the outward and return beams. Since these mirrors will be the adjustment mirrors for the beam direction into the delay line they require good adjustment sensitivity combined with adequate stability whilst being remotely controllable. The most sensitive requirements are for the outward beam and these are:

- Launch mirror adjustment resolution required is <1.8 arcsec.
- Launch mirror tilt stability required is 0.9 arcsec RMS over ±0.1ºC for the combination of two mirrors.

These specifications can be met by the Newport Agilis AG-M100N piezo motor driven optical mount.

The Newport Agilis mounts offer:

- Convenient hands-off remote adjustment
- Impressive 0.2 arc-s adjustment sensitivity
- Ultra-compact — ideal for space constrained setups and system integration
- Set-and-forget long-term stability
- Manual control and USB interface

The Specifications for the Agilis Mounts are:

Newport Agilis Mount	AG-M050N	AG-M100N
Optic Diameter	0.5 in (12.7 mm)	1.0 in (25.4mm)
Angular Range (°)	±2	±2
Adjustment Sensitivity (µrad)	2	1
Maximum Speed (°/s)	1.5	0.75
Stability (µrad/ºC)	7	4

A stability of 4µrad/ºC is equivalent to 0.83 arcsec/ºC or 0.083arcsec per 0.1ºC.

A stability of 7µrad/ºC is equivalent to 1.45 arcsec/ºC or 0.145arcsec per 0.1ºC.

The single axis tilt for the combination of two mirrors is:

$$\beta = \sqrt{(2\alpha_1)^2 + (2\alpha_2)^2}$$

where α is the tilt stability of a single axis of a mirror mount. Considering two orthogonal axes for beam deviation the RMS tilt stability is:

$$\beta_2 = \sqrt{2}\beta$$

The beam launch mirrors consist of one ½ inch type and one 1 inch type hence α_1 = 0.083” and α_2 = 0.145” and the beam stability becomes 0.472” RMS over 0.1˚C or ±0.472” over ±0.1˚C

For both axes this becomes 0.668 arcsec per 0.1ºC. This is better than the 0.9” RMS wave-front tilt requirement by a margin of 25%.

Appendix A. List of Metrology System Opto-mechanical Components

Component description	Vendor - Part Number	Quantity per DL
Laser head	Zygo ZMI 7712	1[1]
Linear interferometer	Zygo Part No: 6191-0135-01	1
Expander concave lens	Comar Part No: 63NQ25	2
Expander convex lens	Comar Part No: 250PQ50	2
Shear camera	Unibrain Fire-i BBW 1.3	1
Shear camera beam compressor	Opticron No:40940 2.5xUTA	1
Laser filter for shear camera	Thorlabs No: FL632.8-10	1
Beam splitter on the stage	Zygo No: 6191-0138-02	3[1]
Beam splitter mount on the stage	Zygo No: 6191-0445-01	3[1]
Ø1” Fold mirror on the stage	Thorlabs No: PF10-03-G01	4[1]
Ø1” Fold mirror adaptor on the stage	Thorlabs No: KS1	4[1]
Linear interferometer	Zygo No:6191-0135-01	1
Linear interferometer mount	Zygo No:6191-0446-01	1
Fibre optic pickup	Zygo No:8040-0104-01	1
Fibre optic adaptor plate	Zygo No:8040-1007-01	1
Motorised Ø1” mirror adaptor	Newport AG-M100	2
Motorised Ø1/2” mirror adaptor	Newport AG-M050	2
Ø1” mirror for the motorised adaptor	Thorlabs No: PF10-03-G01	2
Ø1/2” mirror for the motorised adaptor	Thorlabs No: PF05-03-G01	2
Beam splitter on the block[2]	Zygo No: 6191-0302-02	1
Beam splitter on the block[2]	Zygo No: 6191-0302-01	1
Beam splitter mount on the block[2]	Zygo No: 6191-0445-01	1
Ø1/2” mirror on the block[2]	Thorlabs No: PF05-03-G01	1
Ø1/2” mirror adaptor on the block[2]	Thorlabs KS05	1
Ø1” 50:50 broadband plate beamsplitter on the block (for the shear camera)	Thorlabs BSW07	1
Ø1” mirror adaptor on the block for the broadband plate beamsplitter	Thorlabs No:KS1	1
Fold mirror adaptor on the optical table for the shear camera	Thorlabs KS1	1
Ø1” fold mirror on the optical table for the shear camera	Thorlabs No: PF10-03-G01	1
Stainless steel post	Thorlabs TR30/M	1
Pedestal Style post holder	Thorlabs PH1E	1
Clamping fork	Thorlabs CF125	1
Beam expander assembly	Manufacture	2
The metrology block assembly	Manufacture	1
Shear camera housing assembly	Manufacture	1
The beamsplitter stage assembly	Manufacture	1[1]

Notes: 1 indicates that these components are not required for every delay line i.e. they provide for all delay lines.

2 Only available for some blocks.

Appendix B. List of Metrology System VME Components

Component description	**Vendor - Part Number**	**Quantity**
Ten-slot VME Crate including PSU + storage unit	To be recommended	1
CPU	Concurrent Technologies VP325/022-23U	1
Timing Board	Symmetricon TTM635VME	1
Measurement Board (2 channel)	Zygo ZMI 2002	1 per DL
IP Carrier Board	TEWS Technologies TVME200-10	1
Digital-to-Analogue IP Unit	Acromag IP220A-8 OR Acromag IP220A-16	2 1
Parallel I/O IP Unit	BVM IP PI/T	1
Custom Board	manufacture	1
Low latency link driver module	manufacture	1 per DL
Low latency link receiver module	manufacture	1 per DL
Datum sensor and amplifier module	STM Nanospot Sensor Sensor: RLF30RN-P-2:1M Amplifier: V91-BP/N-20	 1 per DL 1 per DL

Appendix C VME Custom Board Circuit Diagram

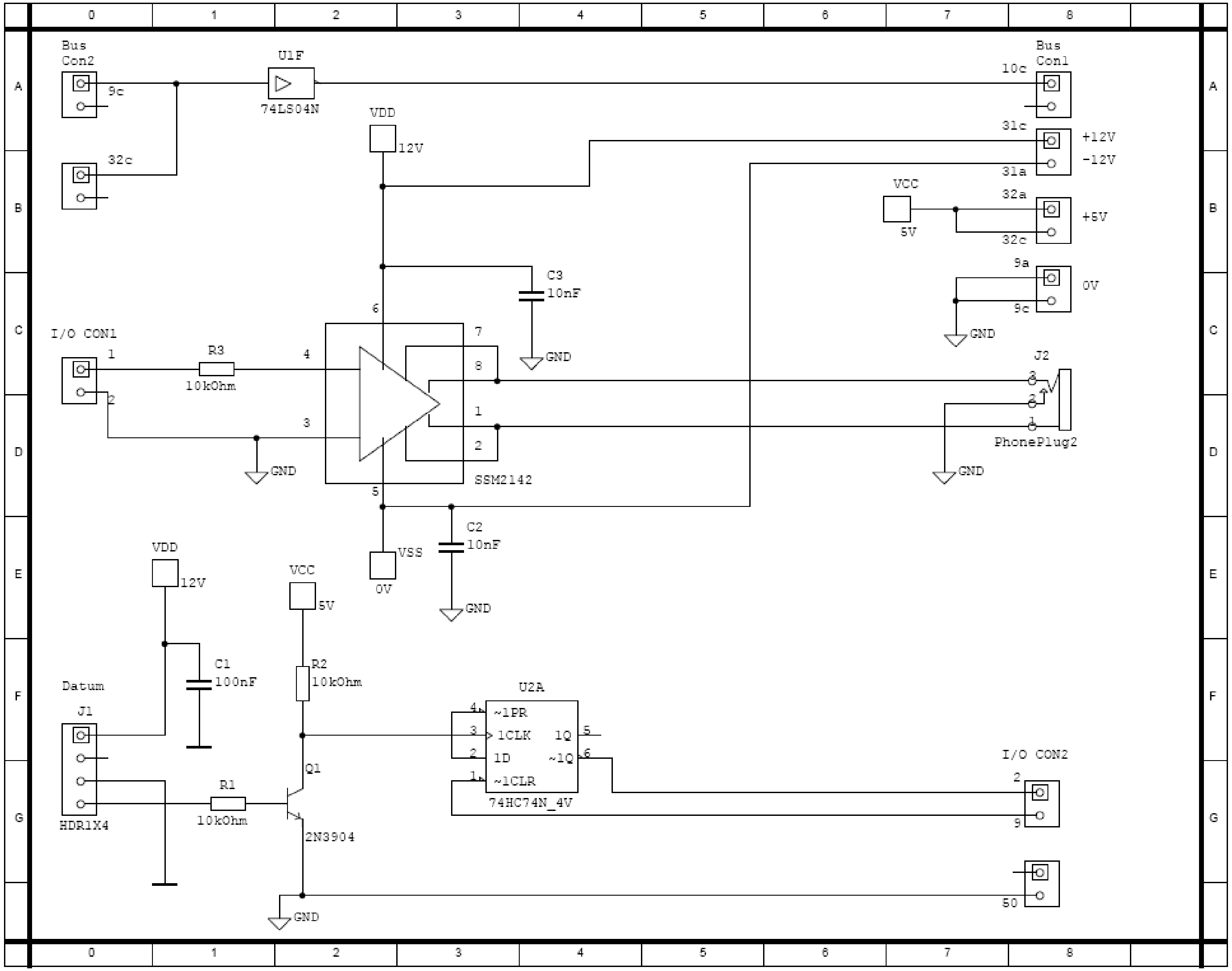

Figure 12: VME Custom Board