Ulf Jonsson
Daniel Malm

The Making of an Actively Stabilised External Grating Cavity Semiconductor Laser

SP
Swedish National Testing and Research Institute
Weight & Measures
SP REPORT 1996:03

Abstract

The Making of an Actively Stabilised External Grating Cavity Semiconductor Laser

Teoretisk och praktisk realisation av en aktivt stabiliserad extern gitter kavitets halvledarlaser

The design and construction of a grating cavity semiconductor laser is reported. Full details of the optical, mechanical and electrical layouts are given. Care has been taken to reduce negative effects of thermal expansion, and the laser has been designed to fit into a commercial vacuum chamber. Measurements and results include the amplitude noise of the laser with and without modulation; the photo-detector response; and the optical output power as a function of the laser diode injection current.

Key words: Frequency, stability, control, laser, semiconductor, grating, cavity, reference, standard

Sveriges Provnings- och Forskningsinstitut
SP Rapport 1996:03
ISBN 91-7848-607-6
ISSN 0284-5172
Borås 1996

Swedish National Testing and Research Institute
SP Report 1996:03

Postal address:
Box 857, S-501 15 BORÅS,
Sweden
Telephone + 46 33 16 50 00
Telex 36252 Testing S
Telefax + 46 33 13 55 02

Contents

Acknowledgements

The development and construction of the 1550 nm grating cavity diode laser described in this report was performed by Daniel Malm and Ulf Jonsson, Chalmers University of Technology (CTH), as a diploma work at the Swedish National Testing and Research Institute (SP), Borås, Sweden.

Useful discussions on theory and practical problems concerning grating cavity lasers have taken place with several specialists; in particular Dr. Leslie Pendrill, Weights and Measures, SP; Dr. Leif Liedquist, Electrotechnology and Physics, SP; Johan Åman, CTH and Dr. Stellan Jacobsson, Department of Microwave Technology, who also was the examiner.

The authors are grateful to the mechanical workshop at SP, especially Mr. Wilson, in making the laser assembly; Anders Ohlson, Cencema AB, Alingsås for supporting the mechanical drawings; other personnel at SP and Radians Innova, Göteborg, for the provision of laser diodes.

1 Introduction

The aim of this diploma work was to construct and build a system to be used as a calibrating source for optical wavelength. The task consisted of making a fibre-adapted laser with a good coherence length, and included the optical, mechanical and electrical construction of a frequency stabilised external grating cavity laser. The laser system is to be used at a wavelength of 1550 nm. Light of this wavelength experiences the least amount of dispersion and attenuation in optical fibres. It is therefore important to be able to have a stable lasing source when transmitting information in single-mode fibre optic communication systems. Also, when the information transfer capacity is to be optimised using multimode fibre technology it is of great interest to be able to identify each mode with high accuracy (higher accuracy results in a greater number of possible transmitting modes which in turn brings about a larger information transfer capacity).

2 Grating cavity laser

2.1 Theory

2.1.1 General aspects of the external grating cavity laser

There are many different kinds of lasers, with different kinds of lasing media which can be gas, liquid, crystal or semiconductor. Light amplification is accomplished through stimulated emission which occurs by "pumping" the lasing medium until a condition known as population inversion is achieved. This state is reached in a semiconductor by injecting electrons into the material so that the lower states of the conduction band are filled while corresponding states of the valence band are empty.

The external grating cavity laser basically consists of a laser diode with one side anti-reflection coated (to avoid secondary cavity effects), the external cavity (air) and a grating (used as the second mirror). This configuration enables an initially multimode laser with a large spectral width (several GHz) to become basically a single mode laser (with a spectral width of a few kHz) through the suppression of side-modes. It is also possible to tune the lasing wavelength by changing the grating position, varying the injection current and/or the temperature. Such a laser has (ideally) a narrow line-width (due to the relatively long cavity).

The grating is either rotated, translated or swept (a combination of rotation and translation), depending on desired wavelength, mode and modulation. Apart from the grating position (the length of the cavity and the side mode suppression (depending on the grating angle, Bragg's law)), the lasing frequency also depends on the gain spectrum of the lasing media, the injection current and the temperature (which brings about changes in cavity length and indices of refraction). The laser is also easily affected by acoustic disturbances.

2.1.2 Frequency Stabilisation

Frequency stabilisation is obtained by controlling the above mentioned frequency and mode selective parameters. By using a mechanical construction with little thermal expansion (and hopefully later acoustic shielding) and by implementing a feedback system it is possible to stabilise a reproducible centre frequency with little frequency drift.

2.1.2.1 Frequency Reference Cell

In order to control the lasing frequency using electrical feedback it is necessary to use some kind of frequency reference. In this work an acetylene gas cell is used [Mogren 1994]. The applicable attribute used is that electronic transitions in a molecule only occur between discrete energy-levels. The desired absolute frequency reference is obtained by measuring the absorption due to an optical transition at a well-defined frequency. Figure 2.1 (a) shows a typical atomic or molecular spectral profile with ν_r being the reference frequency.

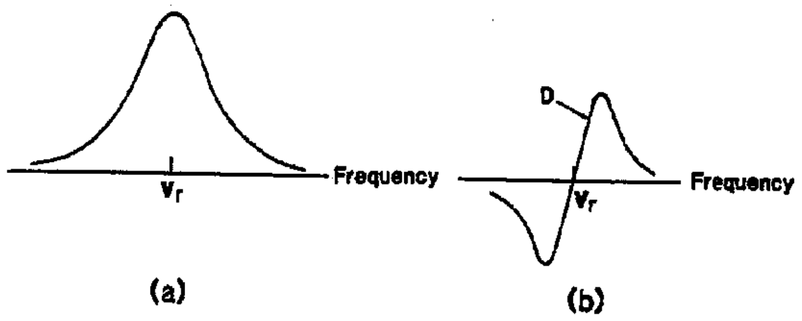


Figure 2.1 (a) Typical atomic or molecular spectral profile
(b) Derivative of spectral profile

2.1.2.2 Lock-in Amplifier

A lock-in amplifier is used to improve the signal-to-noise ratio. Input parameters are a reference modulation signal and the modulated laser signal (electrically converted). The output is a dc-signal proportional to the product of the optical output intensity and the modulation signal.

2.1.2.3 Laser Modulation

To receive a signal from the gas cell which can be used by the lock-in amplifier the frequency must be modulated. This is done either with the laser diode injection current or with changing the position of the grating (a few GHz/mA or approximately 0,22 GHz/V sweep mode).

By modulating the frequency $\Delta\nu$ a signal ΔI is received which is proportional to the first derivative of the absorption. (see figure 2.1(b)). The same kind of figure is obtained as the output from the lock-in amplifier when the lasing wavelength is modulated. This "error-signal" is then passed on to the control unit and the frequency can be stabilised by using negative feedback. Based on the experience of others, we decided to use 100 kHz current modulation and 1 kHz grating modulation.

2.2 Principles of Design and Construction

Figure 2.2 shows the laser system set-up with the different modules connected. When modulating the laser frequency only one of the two possible parameters are varied, i.e. only the injection current or the grating position. The user can choose to control the frequency with either the current or the grating position or both. Bear in mind that with fast modulation there is no use of slow controlling.

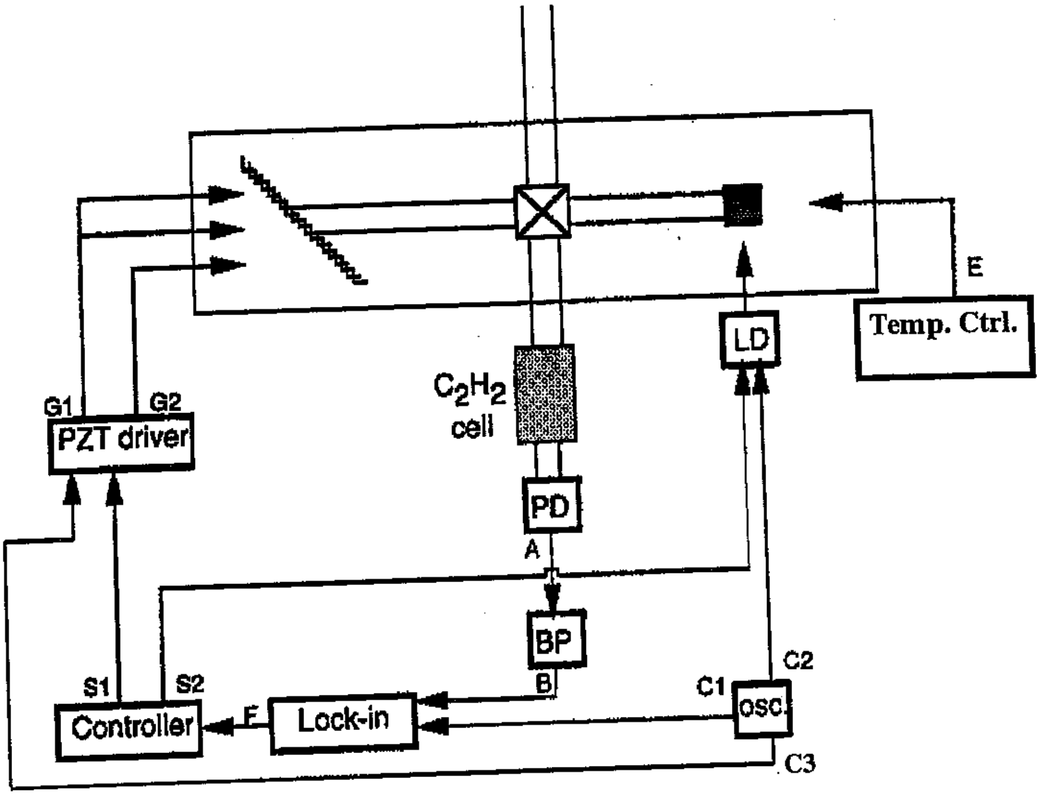


Figure 2.2 Laser system set-up

2.3 History

Numerous studies have been devoted to the long-term frequency stabilisation of semiconductor lasers using an atomic line as a reference frequency. This section describes some of the most important steps in the development of a stabilised 1,5 µm semiconductor laser during the last six years.

Frequency stabilisation of laser diodes using vibrational-rotational absorption $^{13}C_2H_2$, NH_3 and C_2HD molecules is of vital importance for the exploitation of optical frequency - division multiplexing coherent transmission systems and high resolution optical measurement applications. In particular in the 1,5 µm wavelength region, ideally at the 1,55 µm wavelength of importance for present optical transmission system, is required.

In 1989, some Japanese scientists [S. Sudo, Y. Sakai, H. Yasaka *et al.*] succeeded to stabilise a 1,55 µm DFB laser diode by using vibrational-rotational absorption $^{13}C_2H_2$ molecules within 2 MHz peak/peak at 1,54949 µm (i.e. the line closest to 1,55µm) and the frequency fluctuation was calculated to be about $7 \cdot 10^{-10}$ for an averaging time of $0,05 < t < 100$ s. After investigation of the absorption characteristics of C_2H_2 in the region 1,51 to 1,55 µm it was found that C_2H_2 has many strong lines up to 1,54 µm, but rather weak at 1,55 µm. On the other hand, it was found that $^{13}C_2H_2$ has many strong lines in the whole region 1,52 to 1,55 µm and whose shape is similar to that of C_2H_2 absorption lines.

The experimental set-up consisted of the DFB laser, the $^{13}C_2H_2$ gas cell, a Ge PIN photodiode and a feedback system equipped with a lock-in amplifier. The laser frequency was modulated at 10 kHz by adding a small-amplitude sinusoidal current to the injection current. The DFB laser was kept at a constant value to within an accuracy of 0,01 °C by using a electric cooling system. The stability of the laser frequency was estimated by tracing the error signal measured with respect to the zero point of the curve obtained by the first derivative of the absorption curve. The peak/peak frequency fluctuation in the free-running condition was estimated to be about 200 MHz. With the feedback loop closed, it never exceeded 2 MHz for the response time of 0,05 s. Finally the spectral width was evaluated to be 25 MHz.

A year later, French scientists [M. de Labacheliere, C. Latrasse *et al.*] presented a study of a packaged long-term stabilised 1,5 µm extended cavity semiconductor laser, on a NH_3 absorption line. The laser was simultaneously highly coherent (60 kHz line-width) and had a 10^{-10} long-term stability. This device could be useful for coherent optical communications.

They used a classical set-up using a diffraction grating. The laser diode, a buried heterostructure InGaAsP 1,5 µm, was AR-coated with a low residual reflectivity on one of the diode facets. They found out that a 1200 l/mm grating and an 8 mm focal length collimating objective were suitable, giving a single frequency. However, the design was sensitive to acoustical and mechanical perturbations which broadens the optical spectrum for longer observation times. This led to a 1 MHz practical line-width for 1 s observation time. They noted that no precise temperature stabilisation was required to maintain oscillation in the desired wavelength region. Because of the high sensitivity of the laser frequency to the PZT driving voltage (0-125 V), they found that the laser line-width was practically limited by the voltage noise on the PZT drive.

They also found out that the best way to obtain a high stability consists in locking the laser to the top of the reference line. However, such a locking method requires a large laser frequency modulation to detect the maximum of the wide absorption line used in their experiments. The best way to improve the results would be to detect narrower saturated absorption lines. They estimated that the laser should stay at the desired frequency within a few megahertz for very long observation times.

In 1993, the same group presented a new report [Latrasse C, de Labachelerie M 1994] demonstrating a stabilised 1,5 µm laser for space applications. They now chose the isotropic acetylene $^{13}C_2H_2$ as the reference molecule and locked the laser to the top of the reference line. The modulation frequency was determined by the future use of the laser and also the volume of the device had to be reduced, therefore they decided to modulate the injection current at several megahertz. Moreover, this method was interesting because it allows a sensitive and fast detection of the absorption or dispersion features. Small lenses were used to collimate the beam through the cell and focus it in the detector. Special efforts were devoted to minimising parasitic Fabry-Perot effects in the optical path: anti-reflection coatings of the absorption cell windows and lenses, tilting of the cell and so on.

To measure the frequency stability, they separately stabilised two DFB lasers on the same absorption line to obtain a beat signal. The peak/peak frequency fluctuation in the free-running condition was about 240 MHz, whereas it decreased to 3 MHz when the servo loop was in use. The improvement of the frequency stability under locked conditions was clearly shown, but one problem was random-walk frequency noise of the error signal. It appeared that this problem was caused by some electromagnetic leakage from the local oscillator. The measured stability was better than $2 \cdot 10^{-10}$ for observation times between 0,3 and 300 s. For longer sampling times, the Allan variance is limited by electronic offsets. Some standard r.f. isolation improvements in the electronic circuits would help.

A more recent report, received in July 1994, describes the co-operation between the Japanese and the French scientist groups [Nakaqawa K, de Labachelerie M *et al.* 1995] demonstrating a frequency-difference measurement of acetylene (C_2H_2) absorption lines at 1,5 µm with an optical comb generator. The frequency difference between two lasers locked to saturated absorption dips of C_2H_2 ro-vibrational lines could be measured up to approximately 1 THz with a 10^{-9} accuracy and a table of more than a hundred optical frequency references. The experimental set-up consisted of two AR-coated 1,5 µm diode laser in a grating feedback extended cavity configuration, with a tuning range of 1,50 - 1,58 µm and a typical output power of 5 mW. The beam is divided by a splitter; one part is introduced into the external Fabry-Perot build-up cavity absorption cell filled with C_2H_2 gas and the other is used for the heterodyne frequency measurement. They used current modulation when locking the laser. The output from one laser is fed to the frequency comb generator made of LiN_6O_3 electro-optic phase modulator and is mixed with the beam coming from the other laser and is then detected. The beat signal was 40 dB higher than the noise level.

Problems occurring during the experiments were for example the inaccurate modulation frequency because this error is to be multiplied by the side-band order. Another problem is pressure shifts of absorption lines, coarsely estimated to be less than 200 kHz /Torr, which can be neglected for the present precision but should be carefully evaluated for higher precision in future measurements.

3.2.3 Piezo driver

Of necessity, the piezo driver unit needs to have little noise and low drift. The making of such a unit had a high priority in this project. One critical parameter was how large the operational amplifier's feedback capacitors could be (see figures 3.3b and c). This depends on the modulation-frequency, and how high an amplitude is needed for proper grating-modulation. Our solution is a compromise between amplitude and frequency requirements. In order to ensure low drift it was decided to use precision resistors in the design. Since this circuit consists of so many components, it was necessary to use two lab-cards which were screwed on to the same panel (PZLV=piezo low voltage, PZHV=piezo high voltage). The noise output was less then 1 mV peak to peak. Switch 1 is a redundancy switch in case the switch at the oscillator module is not turned off. Potentiometers 1 and 2 enable manual sweeping mode (coarse and fine adjustments). Potentiometers 3 to 5 controls the three different piezo ceramics. With potentiometer 6 it is possible to translate the grating, i.e. the change in length is the same for all of the piezo elements.

The piezo configuration is show in figure 3. 3.a. (view from behind). To calculate the ratio of voltage to be turned on between the horizontal and centre piezos vs. the vertical one see [Johansson 1992].

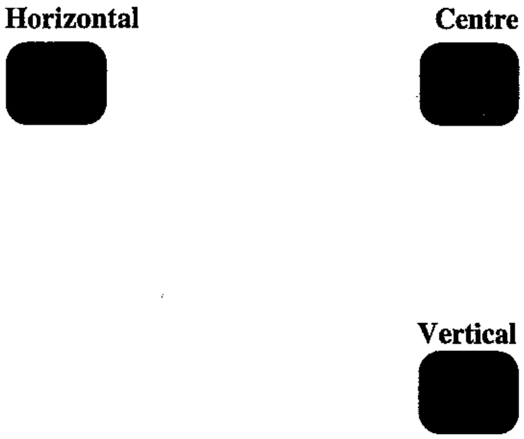


Figure 3.3a PZT configuration

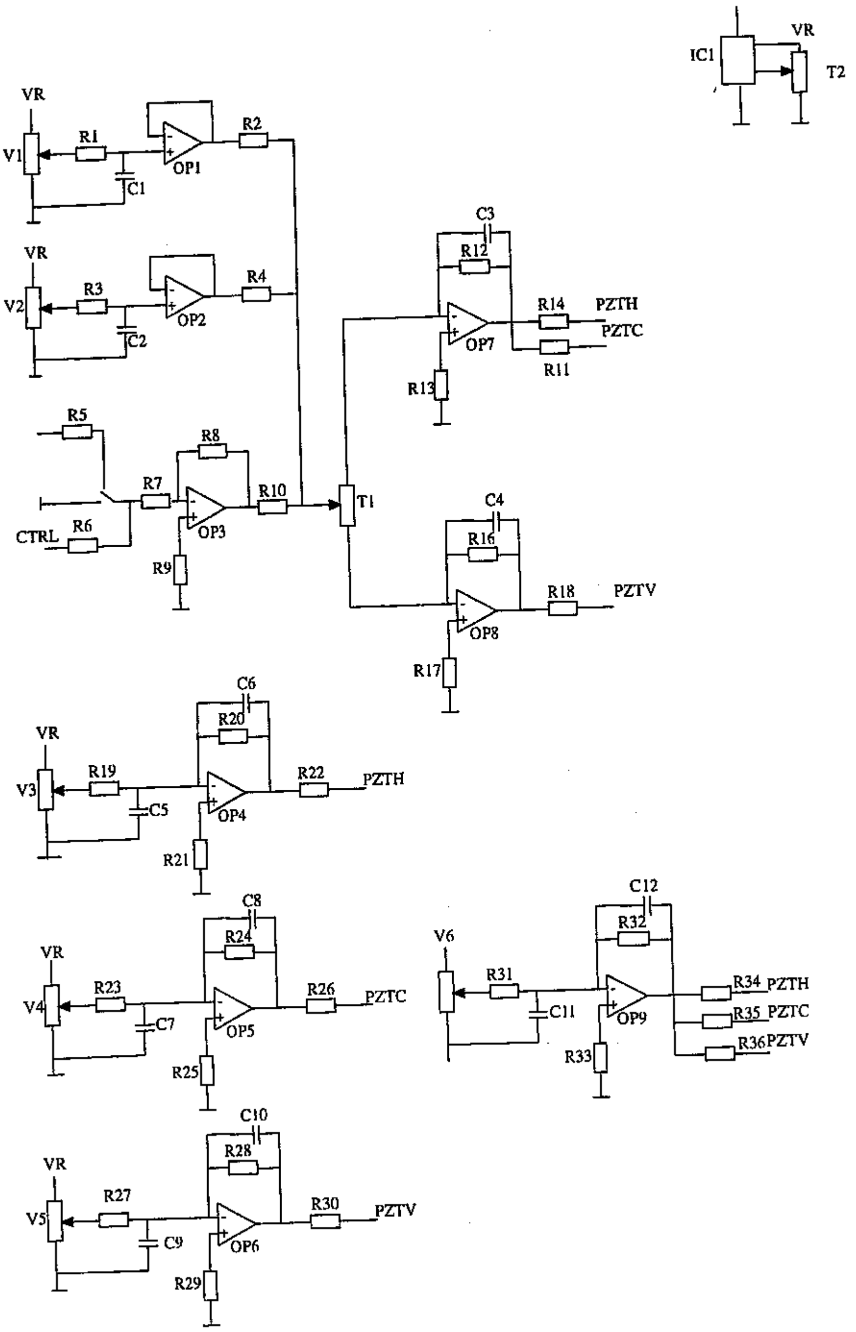


Figure 3.3b Low voltage PZT circuit

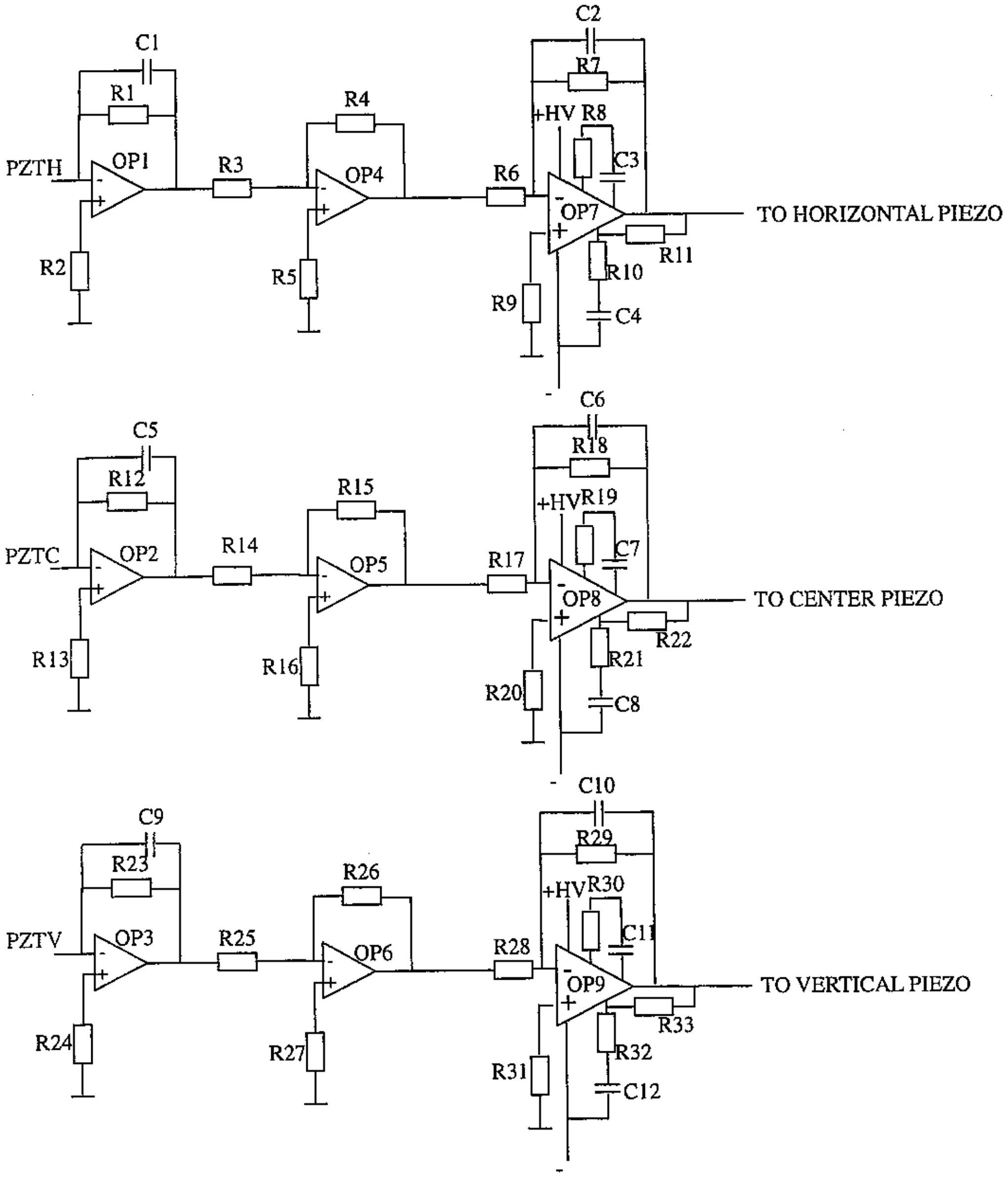


Figure 3.3c High-voltage PZT circuit

3.2.4 Control Unit

The error signal coming from the Lock-in amplifier (I1) is fed to a double PI-PD control circuit. Depending on if the grating or the current is to be modulated, the signal to be controlled goes through a PI- or a PD stage. The 'P' stands for proportional gain and the proportional term will multiply this signal by its gain. The control unit and the output stage have a total gain range of -100 dB to +26 dB. The 'I' stands for integrator. The integrator will charge to a voltage until the error signal is zero. The charging rate is determined by the integrator time constant which can be altered by adjusting T1G and T3G. If it is necessary to "limit" the integration procedure, this can be done by adjusting T2G and T4G. The time constant is calculated by : 1/(T2GxC1G) and 1/(T4GxC2G). The 'D' stands for differentiator. The differentiator adds more gain when the error signal varies quickly. This has the effect of eliminating overshoot and dampens ringing. When the control unit is to be used together with grating modulation, the switch S2G must first be in the no integration mode (INT 0) and the gain factor turned to zero. After switching the PI-unit on (S1G) and the first integrator is switched on (INT 1), the gain can be adjusted (V1G). After some time, also the second integrator can be activated (INT 2) and the gain is once more adjusted, making sure to exclude the possibility of self-resonance in the loop.

When modulating the injection current the PD-unit shall be used. The circuit consists of two differentiators and the time constant is set by T13 and C1S (T3S and C2S) and can be calculated in the same way as in the integration step.

The connection procedure is done in a similar way as the PI-unit. To facilitate signal inversion (SKG and SKS), both the PI- and the PD stages have an inverter (OP3 and OP7). The OP-amplifier used in this application is an high accuracy low offset drift amplifier where the offset is taken care of by the capacitors Coff. The outputs O1G and O1S are connected to the output stage where the signals can either be amplified or dampened (-20 dB , 0 dB , -20dB). The switches OM1G and OM1S must not be operated when the control unit is in use.

Short description of operation;
the module is divided into two parts: the grating control (top) and the (injection) current control (bottom).
top:

- Gain potentiometer - Adjusting the proportional gain
- PI-on/off - PI-control on or off.
- INT 0 1 2 - How many integrators are in use.
- -20 dB 0dB -20 dB - Output stage , coarse gain adjustment
- output BNC - Possibility to connect output signal to an oscilloscope.

bottom:
similar, except the DIFF 0 1 2 - How many differentiators are in use.

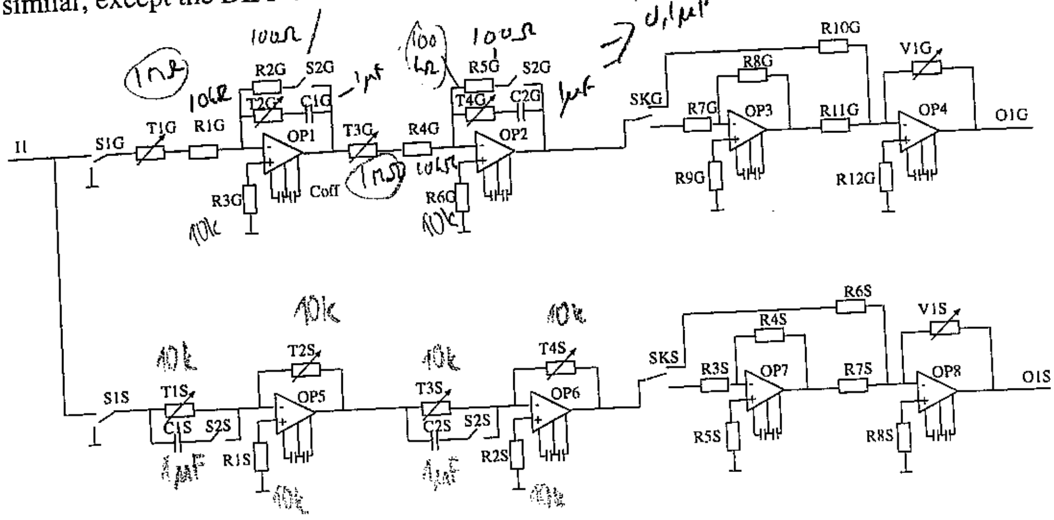


Figure 3.4 Control unit

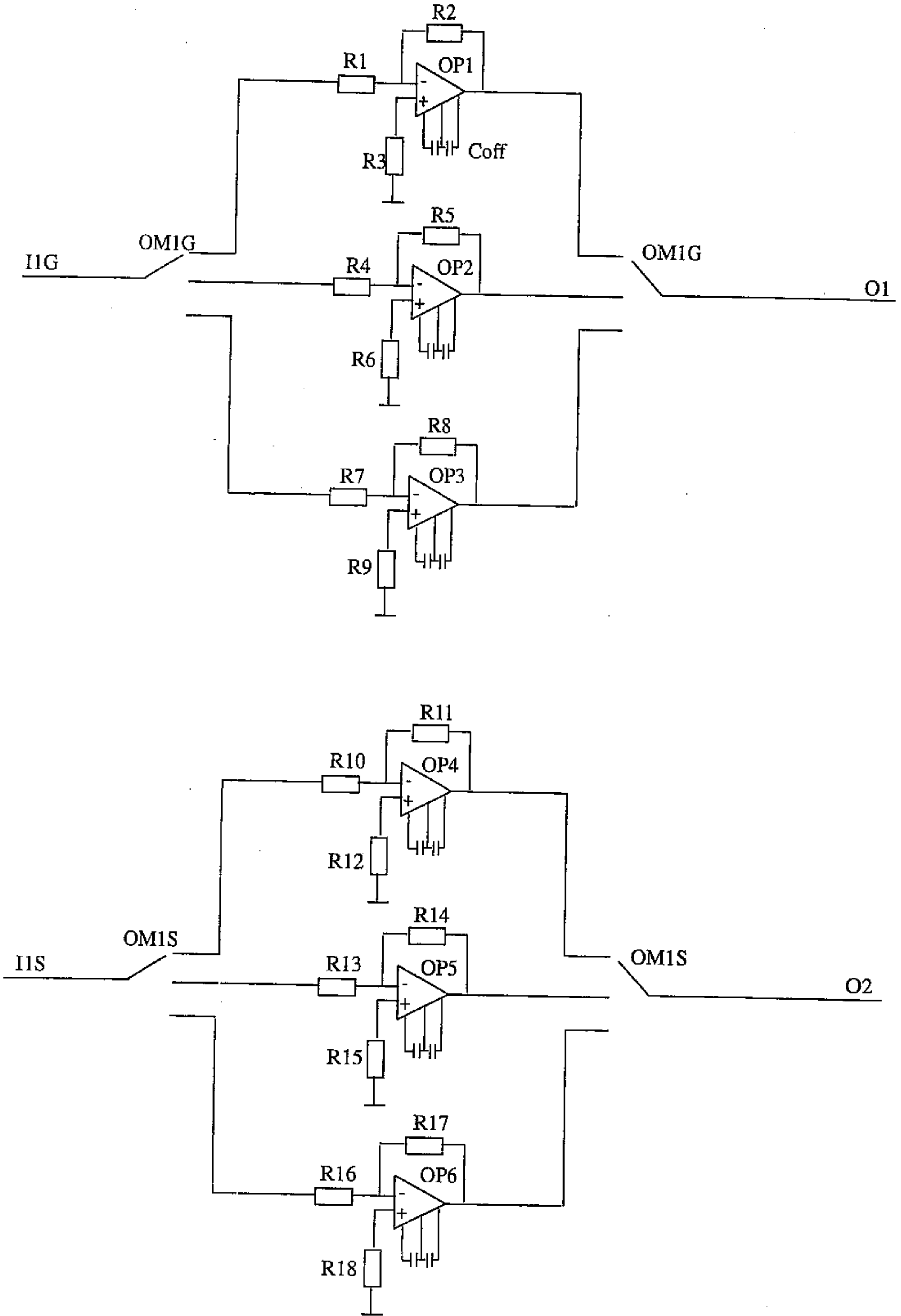


Figure 3.5 Output stage

3.2.5 Laser Diode Driver

The commercial LDD100 from Wavelength Electronics is used to supply the injection current to the laser diode. The possible modulation and control signals are added together in OP2 (figure 3.6), after which we added an inverter in order to feed the LDD with the proper voltage to pin three. The display UP-5135 is supplied by Elfa. OP1 is a voltage follower which is needed since it is not possible to feed the display directly from pin 2.

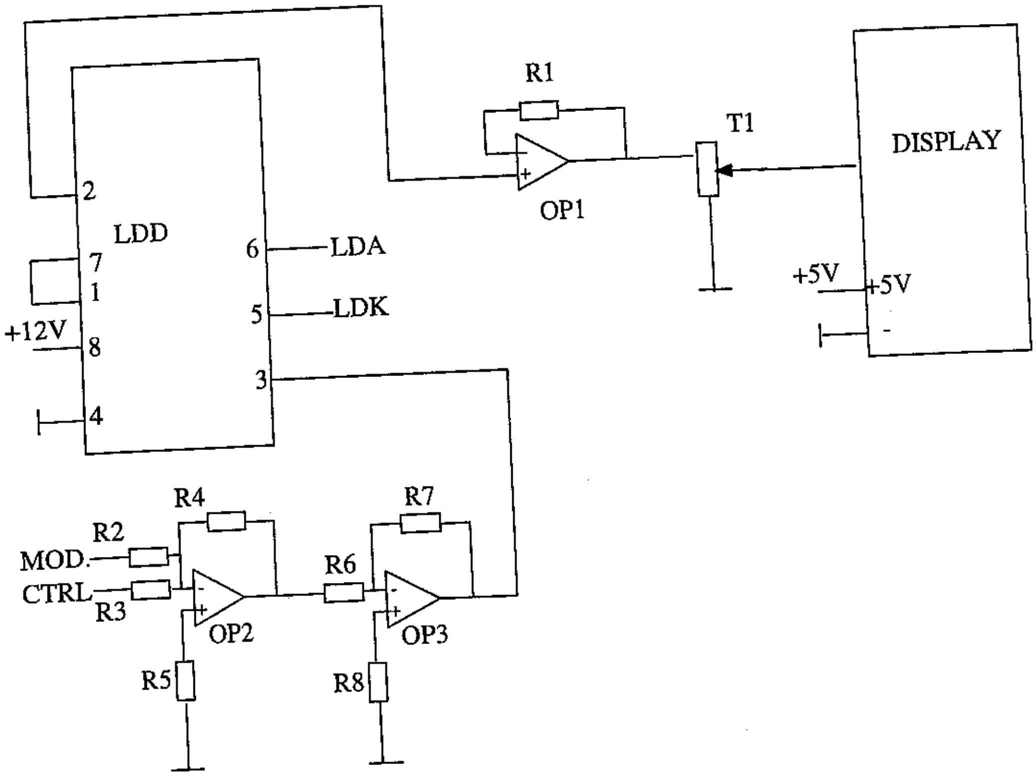


Figure 3.6 Laser diode driver circuit

3.2.6 Temperature Controller

To maintain oscillation in the desired wavelength range it is required to stabilise the temperature of the semiconductor laser chip. Therefore, a commercial temperature controller FPT-2000 was purchased from AG Electro-Optics, U.K. The controller is designed to operate with a peltier element and a few different temperature sensors, where in this case, the PTC sensor AD 590 was chosen. FPT-2000 features;

- Full PID-control.
- Multiple protection strategies:
  - sensor open or shorted detection
  - TE-cooler current limit
  - TE-cooler open circuit detection
  - FPT over temperature detection
- Fully adjustable current limit
- Long term stability, 24 hr , < 0,005 °C

The controller has a warm-up time of 1 hour to rated accuracy. The required external resistor when using an AD 590 is mounted on the Temperature control module together with the display circuits and some OP-amplifiers. Several monitoring outputs are available on the FPT-2000 and three of them can be displayed on the panel:
The current through the TE-cooler (CM), temperature set-point (TS) and the measured temperature (TM).

To be able to display degrees centigrade, the TS and TM monitoring signals are amplified and offset trimmed to obtain the transfer function 10mV/°C.
(i.e. 2,73 V <=> 0°C)

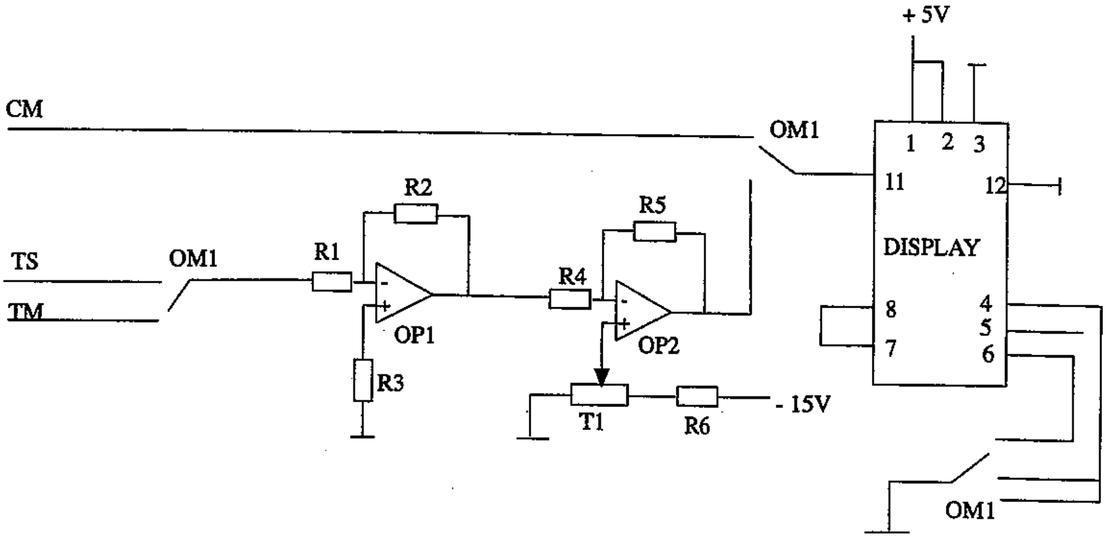
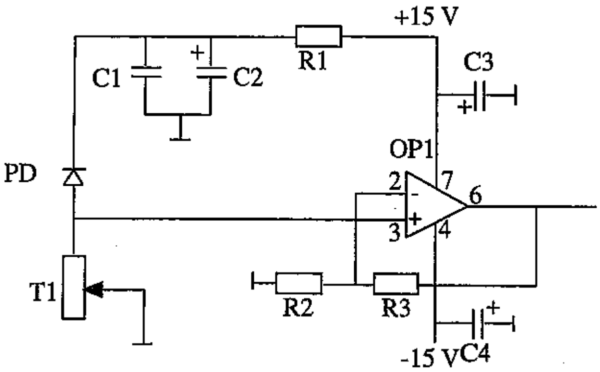


Figure 3.7 Temperature control module showing the displaying circuit

3.2.7 Photo Detector

In order to detect the optical signal after the gas absorption cell a photo detector has been made. It consists of a Hamamatsu InGaAs-pin photo-diode (with a peak sensibility for 1550 nm) and an amplifying circuit. The choice of components are shown in figure 3.8 (for values see appendix I). The whole photo-detector is finally enclosed in a shielded box and is connected with a shielded cable.



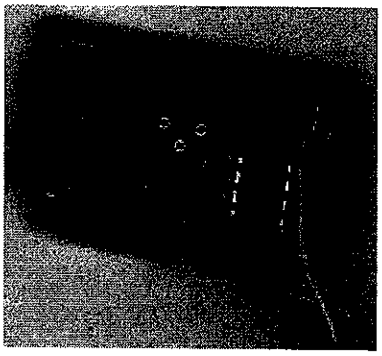


Figure 3.8 Photo-detector circuit

3.2.8 Laser Diode

For producing light at a wavelength of approximately 1550 nm, a semiconductor laser diode was used. It is anti-reflection treated on one side and has a threshold current of about 20 mA. The lasing wavelength is tuned through variations in temperature, through change in the external grating position and through change in the laser diode drive current (a few GHz/mA). The chip was supplied by Radians Innova.

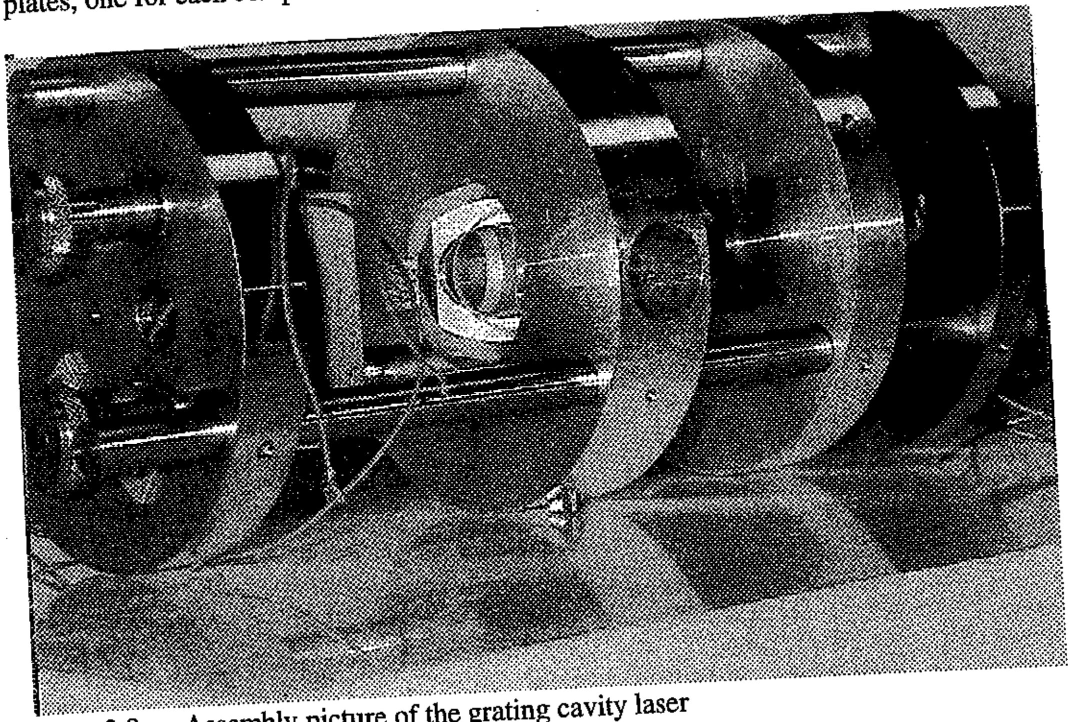
3.3 Mechanical Construction

3.3.1 The overall mechanical design

By a careful choice of material and design of the parts forming the cavity laser, it is possible to improve the frequency stability due to temperature changes and acoustic interference.

The important factors concerning temperature are cavity length changes, thermal change in grating constant and symmetry of rotation of all the parts defining the laser.

To make the operation of the laser easier, the main frame consists of five plates, one for each component, mounted with three Invar bars. See figure 3.9.



Figur 3.9 Assembly picture of the grating cavity laser (half-wave plate holder not mounted)

The outer dimensions of the plates were determined with the intention of using a commercial vacuum chamber to avoid acoustic interference. The chamber (Ø102 mm) could be purchased from Leybold AG. Delivery time: 4 weeks, price 12 925 SEK. Each plate have a symmetric shape so that any temperature shifts should have no possibility to interfere in x or y axis.

The expansion of the PZT-actuators, length 18mm and expansion coefficient $1{,}4\cdot10^{-6}$, compensate the expansion of the Invar bars, length 200mm and expansion coefficient $0{,}8\cdot10^{-6}$, resulting in a length expansion of 135 nm/K, corresponding to a thermal frequency shift of 130 MHz/°C. Another factor influencing the stability is thermal change in grating constant. Assuming the grating thermal expansion coefficient to be in the order of optical glass, the change in diffracted wavelength can be calculated to be about (grating constant $d=8{,}33\cdot10^{-6}$) -12,36 pm/K, which in terms of frequency at a wavelength of 1,55 µm; $\Delta\nu=c\,\Delta\lambda/\lambda^2 = -1{,}54$ GHz/°C. However, assuming the grating thermal expansion coefficient to be on the order of glass is not a good approximation and the calculated frequency change $\Delta\nu$ is not a real frequency shift but will result in a mode-hop if the temperature change is too large. The thermal frequency shift will be dominated by the length expansion mentioned above.

3.3.2 Diode laser mount

When designing the mount for the diode laser there are some requirements to consider. First of all, to ensure good stability the holder which is made of copper is thermally and electrically insulated from other parts of the construction to prevent interference, such as electromagnetic radiation, heat gradients etc. The copper plate is temperature stabilised by a thermoelectric cooler (peltier, using an aluminium plate as a heat-sink) and is designed to be as small as possible. It is then attached to a bigger holder by three plastic screws and a plastic film (~ 0,1mm thick) is used to insulate the copper plate.

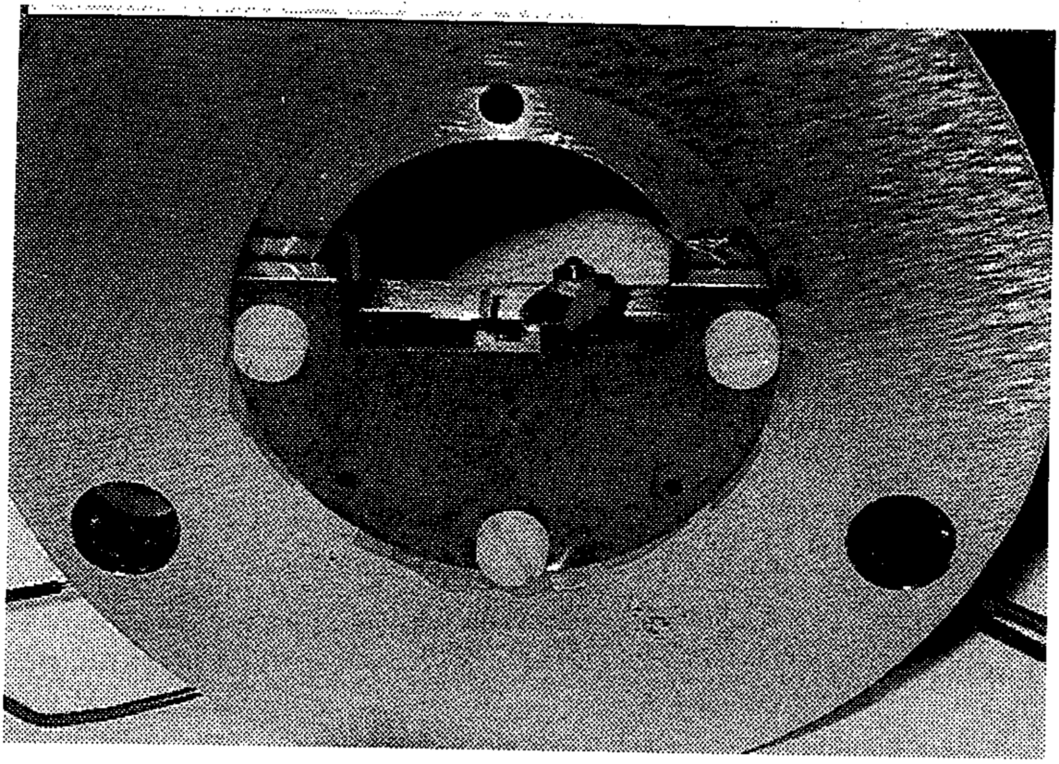


Figure 3.10 Diode laser mount - front view

To make sure that the copper plate is in the right position, two small holes exists to make it possible adjusting the location of the holder. The diode is placed within a tenth of a millimetre and is fixed with a metal clamp and a pin.

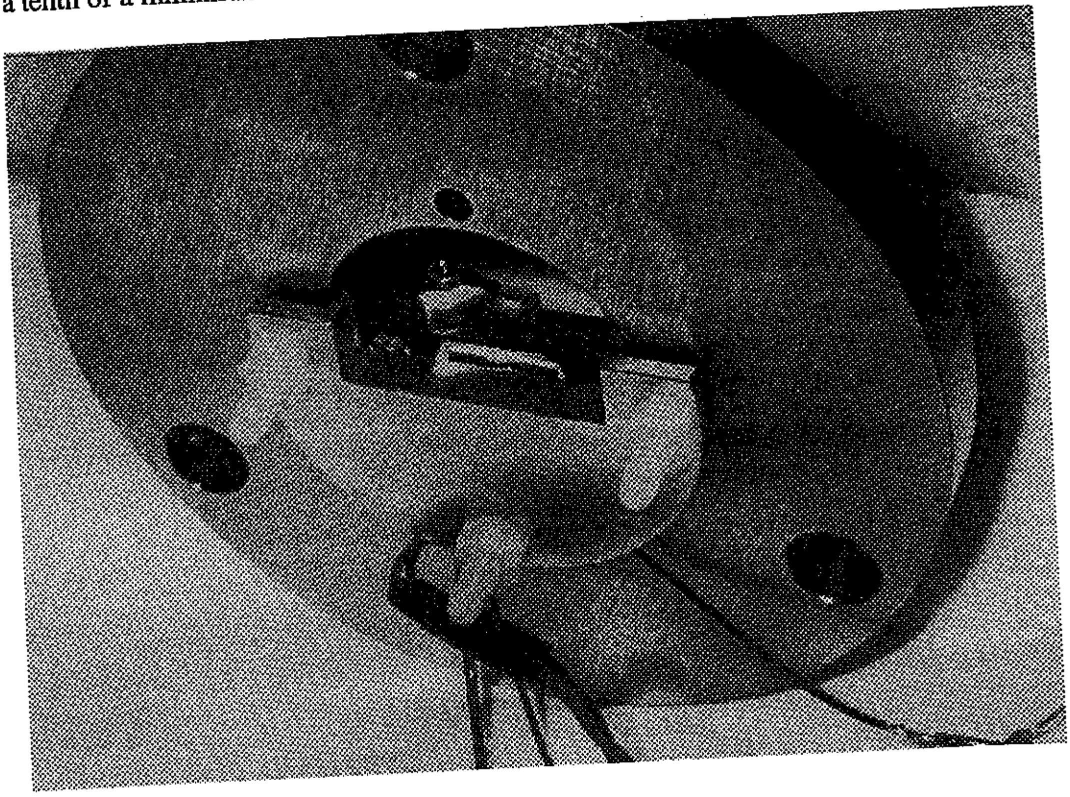


Figure 3.11 Diode laser mount - back view

The heat-sink has no contact with other surfaces except the peltier element which is clamped between the aluminium and the copper plate. Also, the plate is one of the electrical connections for the diode laser (see machine drawing - diode laser mount - in appendix II). A milled slot in the copper plate is used for attaching the temperature sensor.

3.3.3 Collimating lens mount

An aluminium plate holds the lens in position (x-y axis) and the distance to the diode can be adjusted by a, for the occasion, manufactured precision collimating lens screw, purchased from Finland.

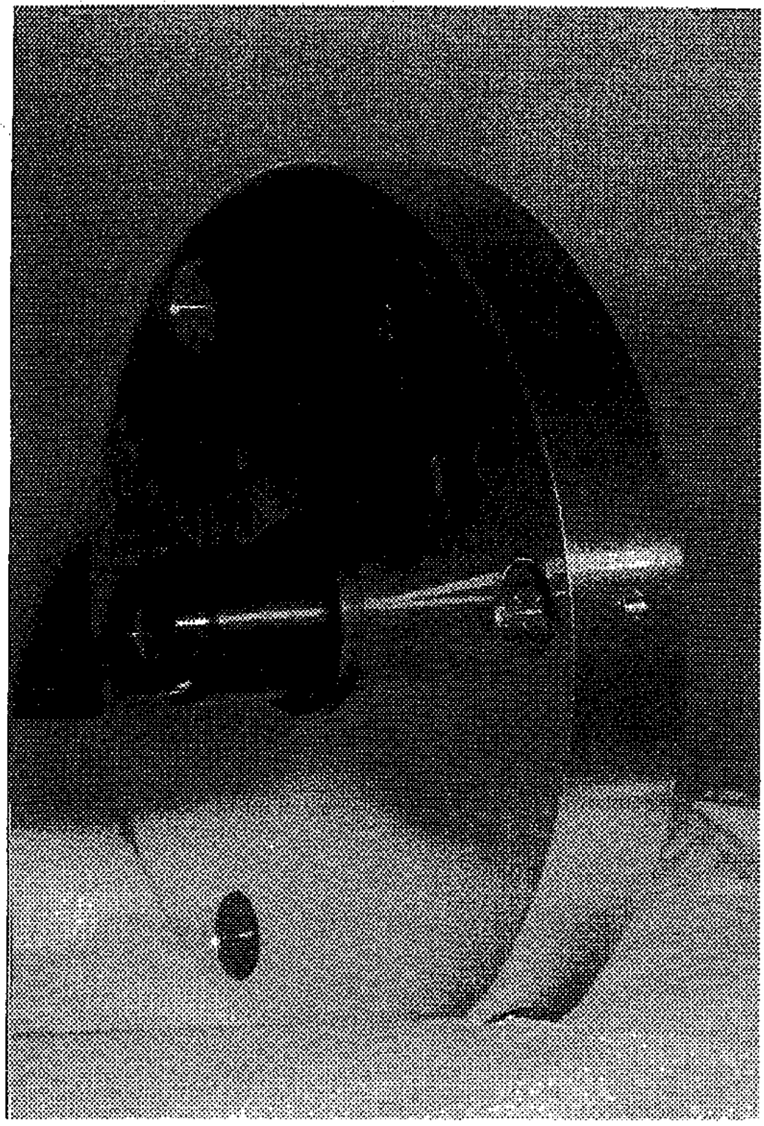


Figure 3.12 Collimating lens mount

3.3.4 Beam-splitter mount

A plate glass beam-splitter is glued to the holder which is held in the bigger mount made of aluminium. The laser beam is coupled out through holes in two directions.

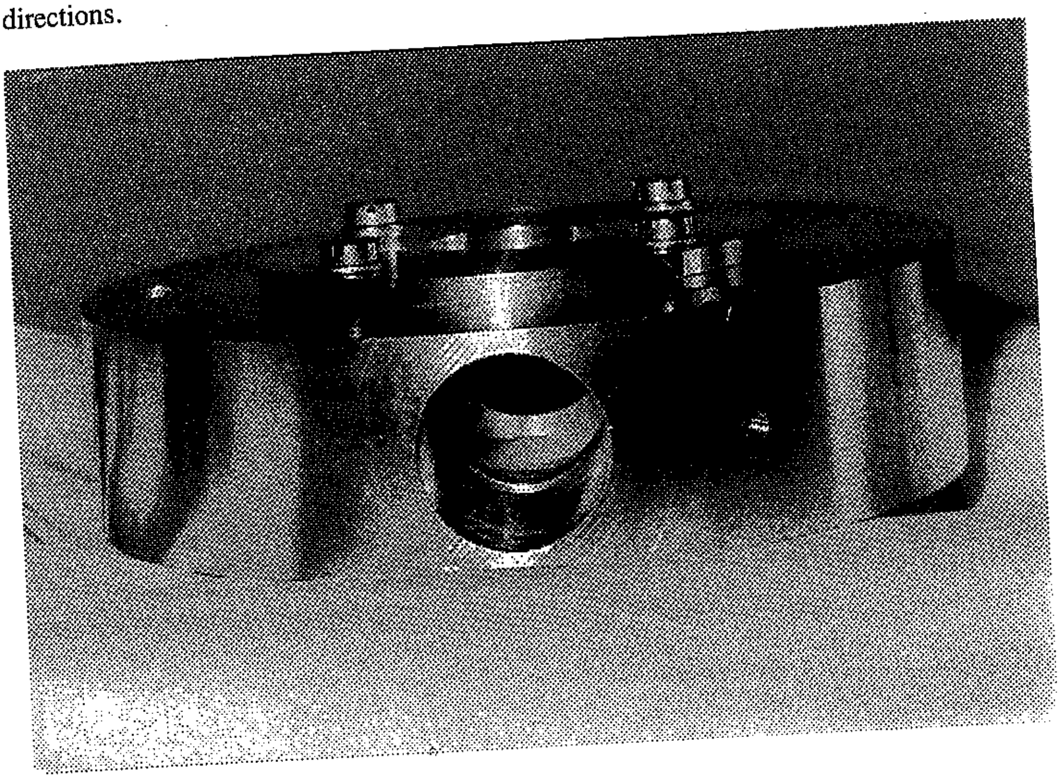


Figure 3.13 Beam-splitter mount

3.3.5 Half-wave plate mount

The plate is glued to the holder. It is fixed with a small angle to prevent direct reflection from the plate back to the diode laser.

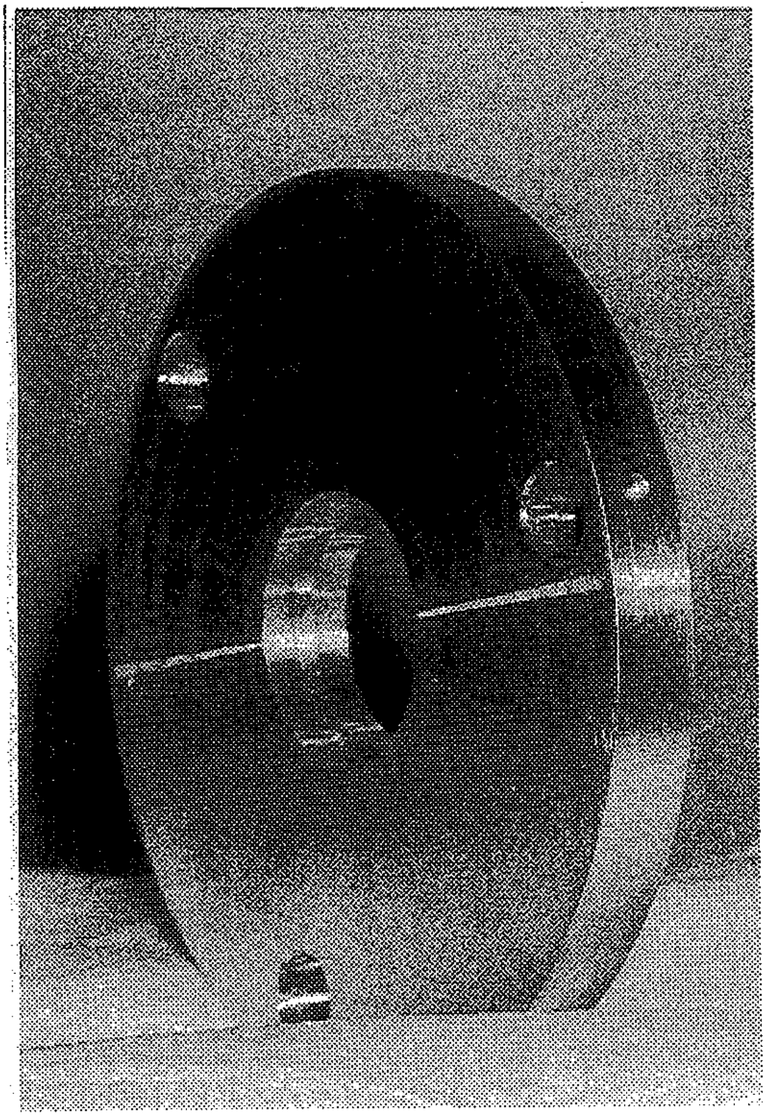


Figure 3.14 Half-wave plate mount

3.3.6 Grating mount

With respect to the optical axis it should be possible to adjust the location and the angle of the grating. The coarse adjustments are altered by three Invar screws (M10 x 0,35) and the fine adjustments by three piezoelectric actuators, which are placed inside metal tubes to ensure that no side forces affect them. All parts of the grating mount are made in Invar except; the three tubes, four metal springs, spring pins and insex screws clamped on the head of the adjustments screws, making it possible to adjust more exactly. To get a satisfying characteristic of resonance (see section 4) of the holder, rather strong springs were chosen (30 N and 85 N). It is easy to achieve a very low resonance amplitude by adjusting the modulation frequency. To assure an easy way of changing the grating angle by changing the grating wedge, a milled slot is made in the grating mount I and II (figure 3.15). The angle can be calculated using the grating equation; $m\lambda = 2d\cdot\sin\theta$ ($m = -1$, $d = 8,33\mu m$, $\lambda = 1,55\mu m$) giving $\theta = 68°$.

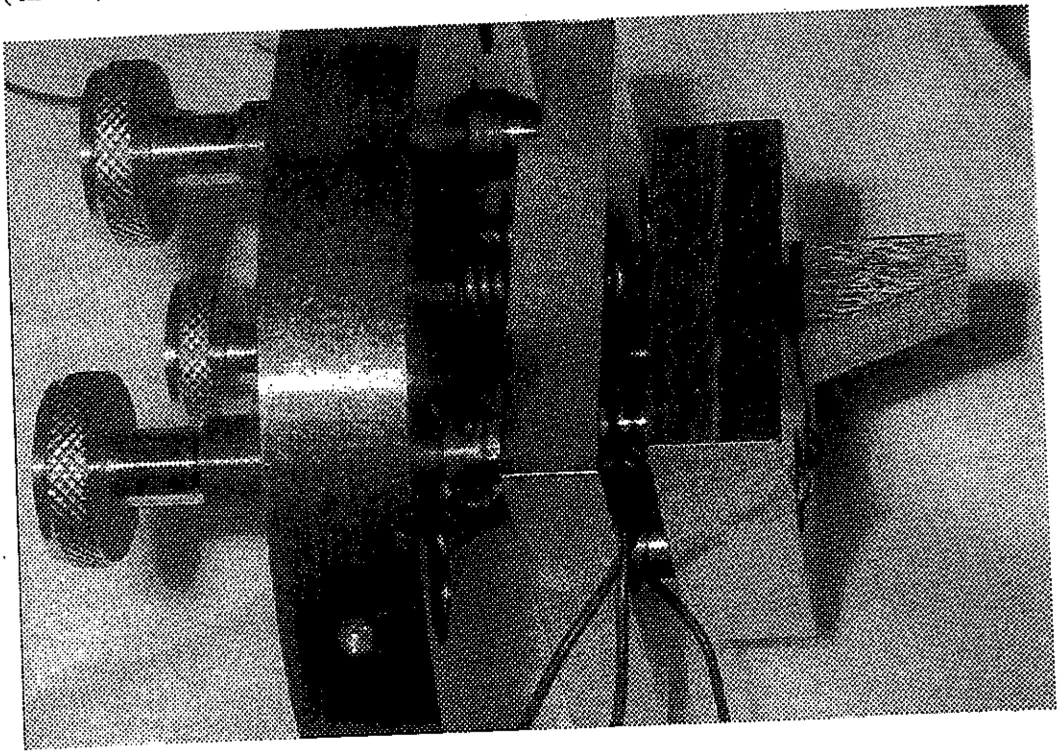


Figure 3.15 Grating mount

3.4 Optical design

3.4.1 Laser chip

The laser chip is mounted precisely on a heat-sink, which is in turn attached to the laser assembly. When the diode is to be used in this application, one of the facets should be AR-coated to suppress multimirror cavity oscillations (i.e. the cavity modes formed by the external grating and the laser facets). Facets reflectivity has been reduced to less than 1%, comparing to 32% when the facets of the laser chip are uncoated. The lower the reflection of the front facet, the easier it is to get a single longitudinal mode and a narrower spectral band. The laser diode chip is to be mounted with great caution to prevent the chip to be exposed to electrostatic discharges.

3.4.2 Collimating lens

Light coming from the front facet of the diode has to be collimated with a lens, making the light parallel and useful for grating cavity laser applications. The lens, which is mounted inside an adjustable screw (see section 3.3.3), is purchased from Melles Griot and has a focal length of 8 mm and an optical aperture of 8 mm. The distance between the lens and the diode is very critical which makes heavy demands upon the adjusting device mentioned above.

3.4.3 Beam-splitter

In order to provide the system with a feedback signal, a plate glass beam-splitter was used. 10-20% of the optical power in the cavity is fed back passing the acetylene cell and is detected by the photo-diode. The beam-splitter was purchased from Melles Griot, Ø 25 mm.

3.4.4 Half-wave plate

Before the beam of light reaches the grating it is possible to optimise the power further by using a special plate, which rotates the polarisation and thereby fixing the electric field vector in the electromagnetic wave at the same direction as the elliptical cone of light and perpendicular to the grooves of the grating. This plate is however not always necessary. It can be purchased from Melles Griot, Ø30 mm, price 4495 SEK.

3.4.5 Grating

The grating acts as a wavelength-selective mirror which allows the laser to oscillate only on the very narrow spectral band, reflected exactly on the incident direction. Such a structure allows to obtain a much longer cavity including controlling the oscillating wavelength by a spectrally selective element. The size of the grating is 10 x 20 x 6 mm, 1200 l/mm, purchased from Spectrogon AB.

4 Measurements and Results

Figure 4.1 shows the oscillator output analysed in a frequency analyser. A 60 db suppression between 1 kHz and the first harmonic is achieved by using the UAF42 filter.

The lock-in amplifier mentioned in section 3.2.2 consists of two BP-filters which were tested using a spectrum analyser. The frequency was swept from 500 Hz to 2 kHz and from 70 kHz to 100 kHz respectively. The output signals from the filters were measured. Figures 4.2 and 4.3 show that the Q-factors are approximately as requested.

The superposed noise on the dc output from the piezodriver was measured to less than 1 mV peak to peak. This in turn results in negligible laser frequency disturbances (less than 15 MHz).

To be able to confirm the desired function of the integrators and the differentiators, the control unit was tested using a spectrum analyser. Figure 4.4 and 4.5 show that the slopes of the curves are well adapted to their purpose having a steeper gradient when using both integrators. Figure 4.6 shows that higher frequencies are more amplified and the gradient corresponds to the combined effect of both differentiators.

The photodetector response was plotted using a monochromator. Figure 4.7 shows that the photodetector has a maximum response at approximately 1500 nm.

When testing the resonance frequency of the grating holder the frequency was swept. The amplitude is shown in figure 4.8. Using the figure it is easy to adjust the modulation frequency that will result in an acceptably low mechanical resonance frequency (in this case around 1 kHz).

The grating feedback effect was measured and is plotted in figure 4.9. The results shows that the mechanical construction works and can be used for its desired purpose.

The final measurement is of power spectra displaying the laser amplitude noise with and without 1 kHz modulation. Note that the 50 Hz mains hum and its harmonics clearly influence the spectrum and that the 1 kHz oscillating signal propagates through the system as expected. See figures 4.10 and 4.11.

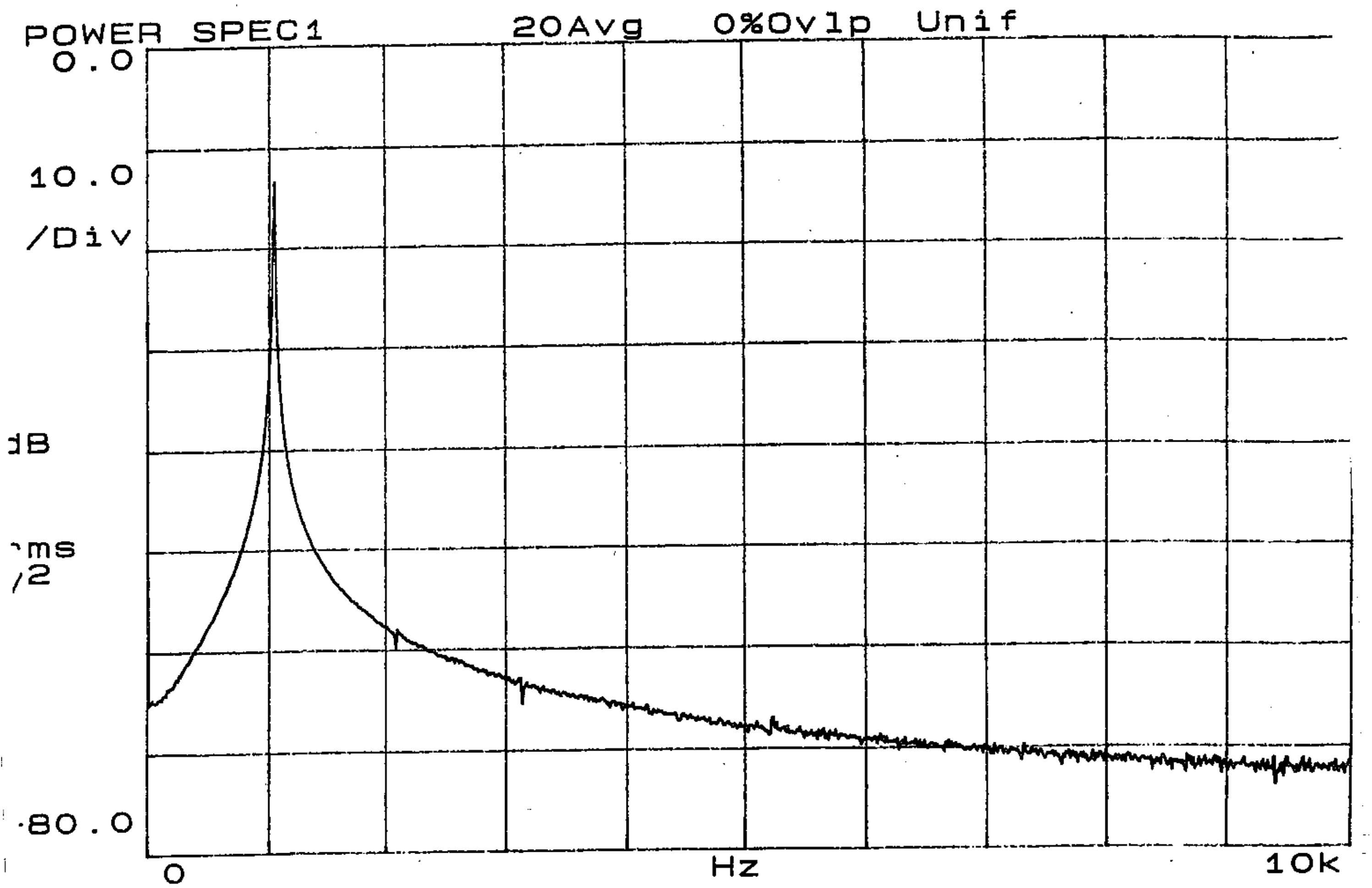


Figure 4.1 Frequency Analysis of Modulation Signal

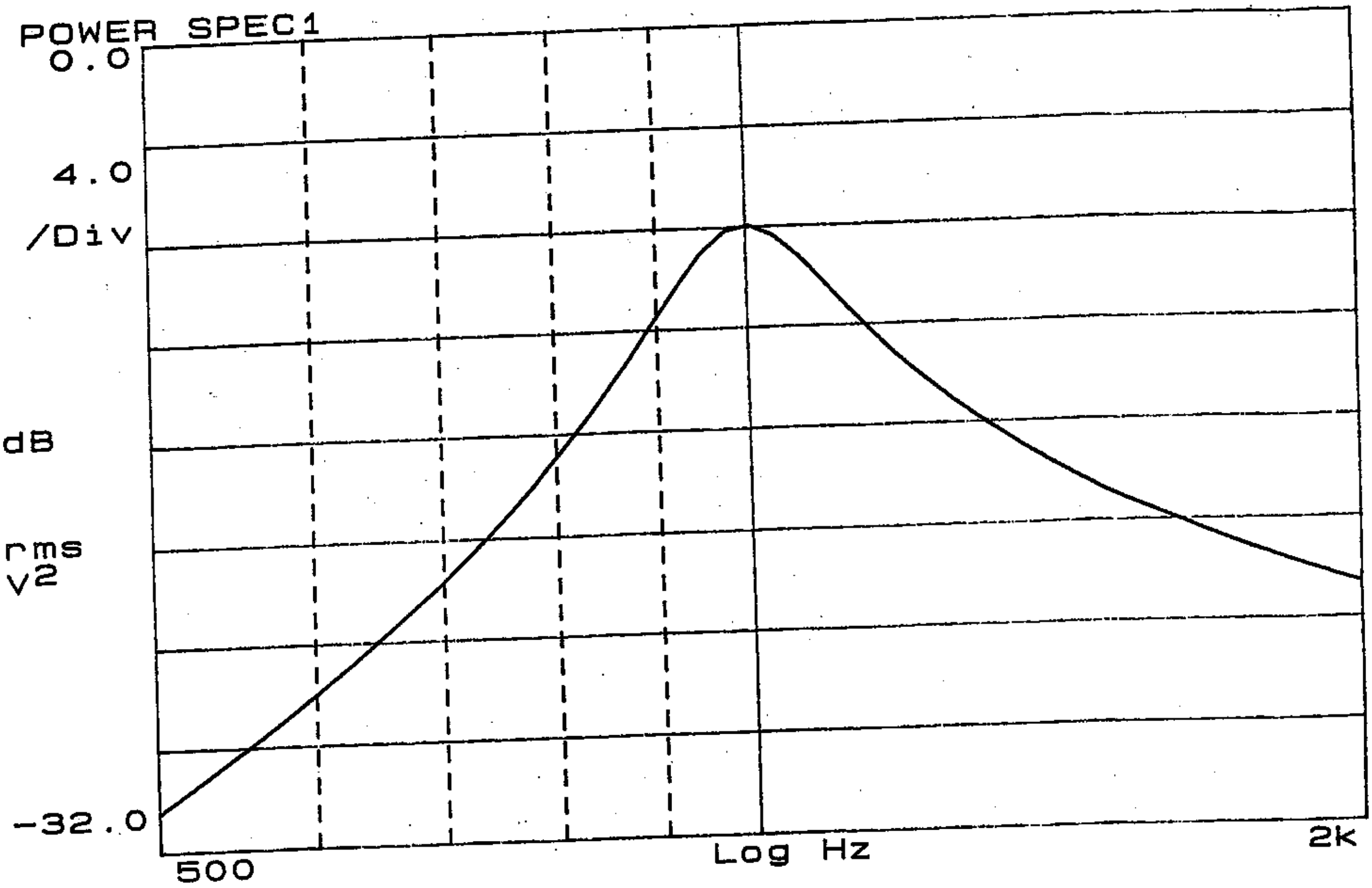


Figure 4.2 BP-filter 1 kHz

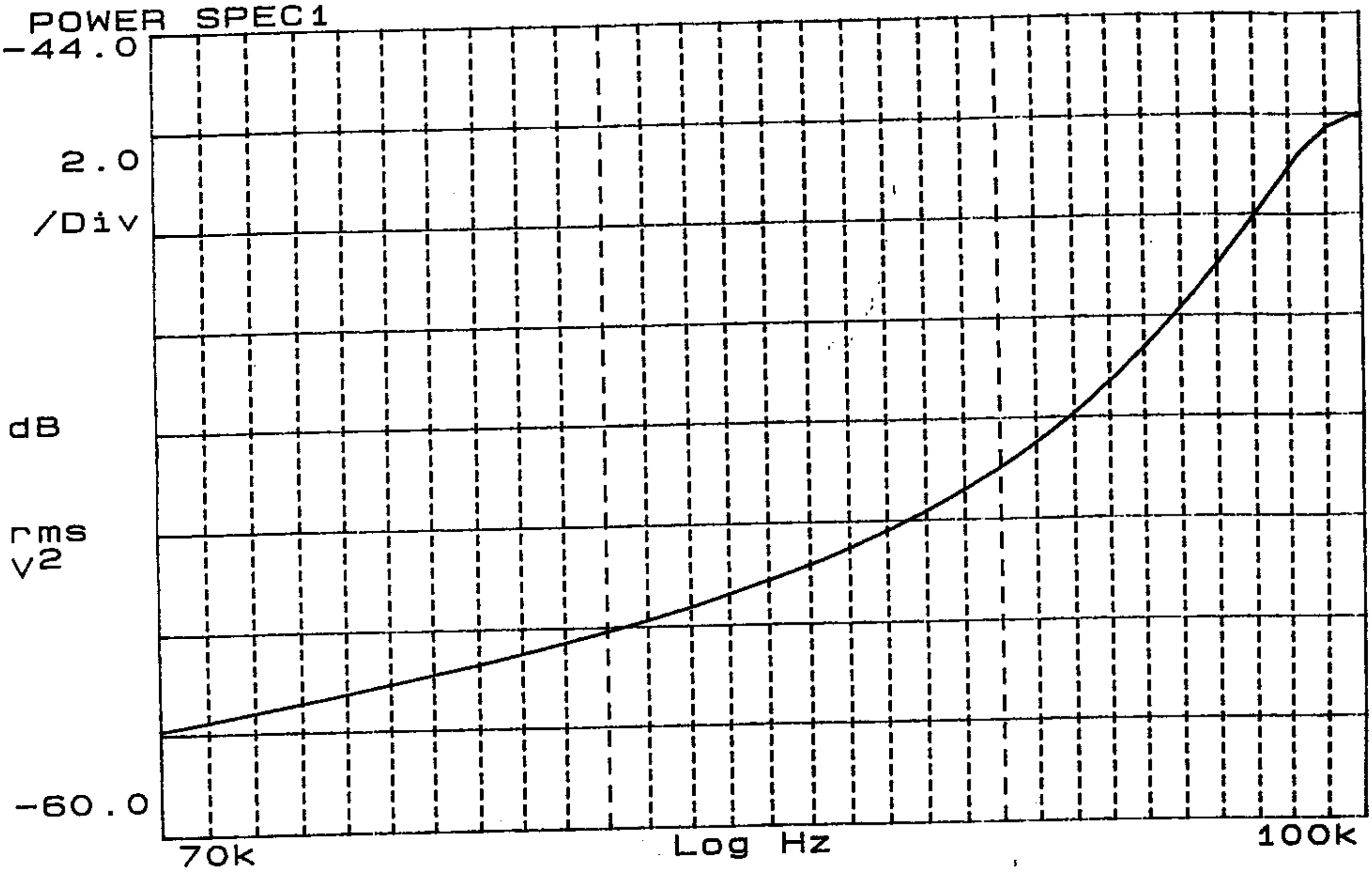


Figure 4.3 BP-filter 100 kHz

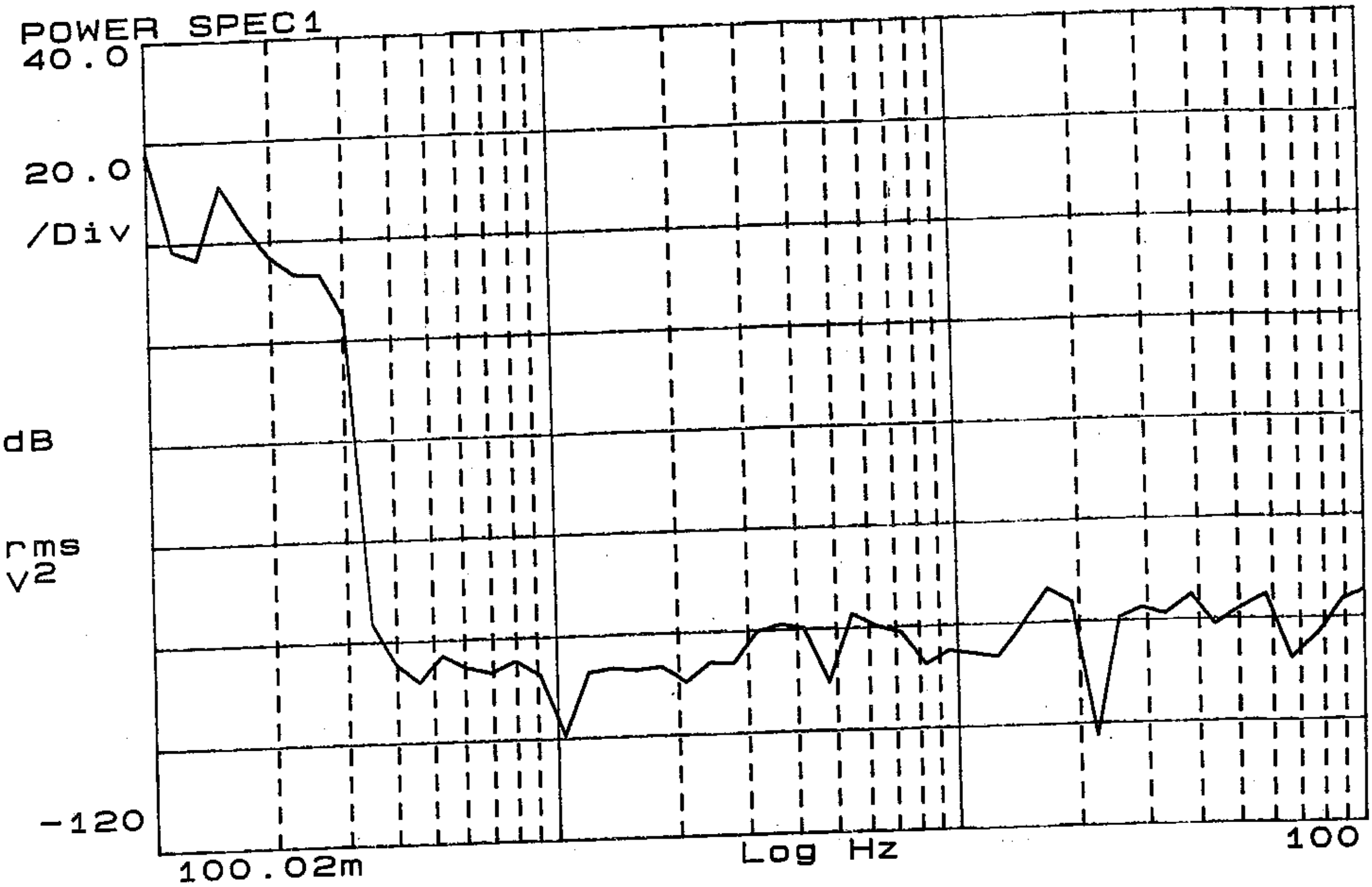


Figure 4.4 The characteristics of two integrators

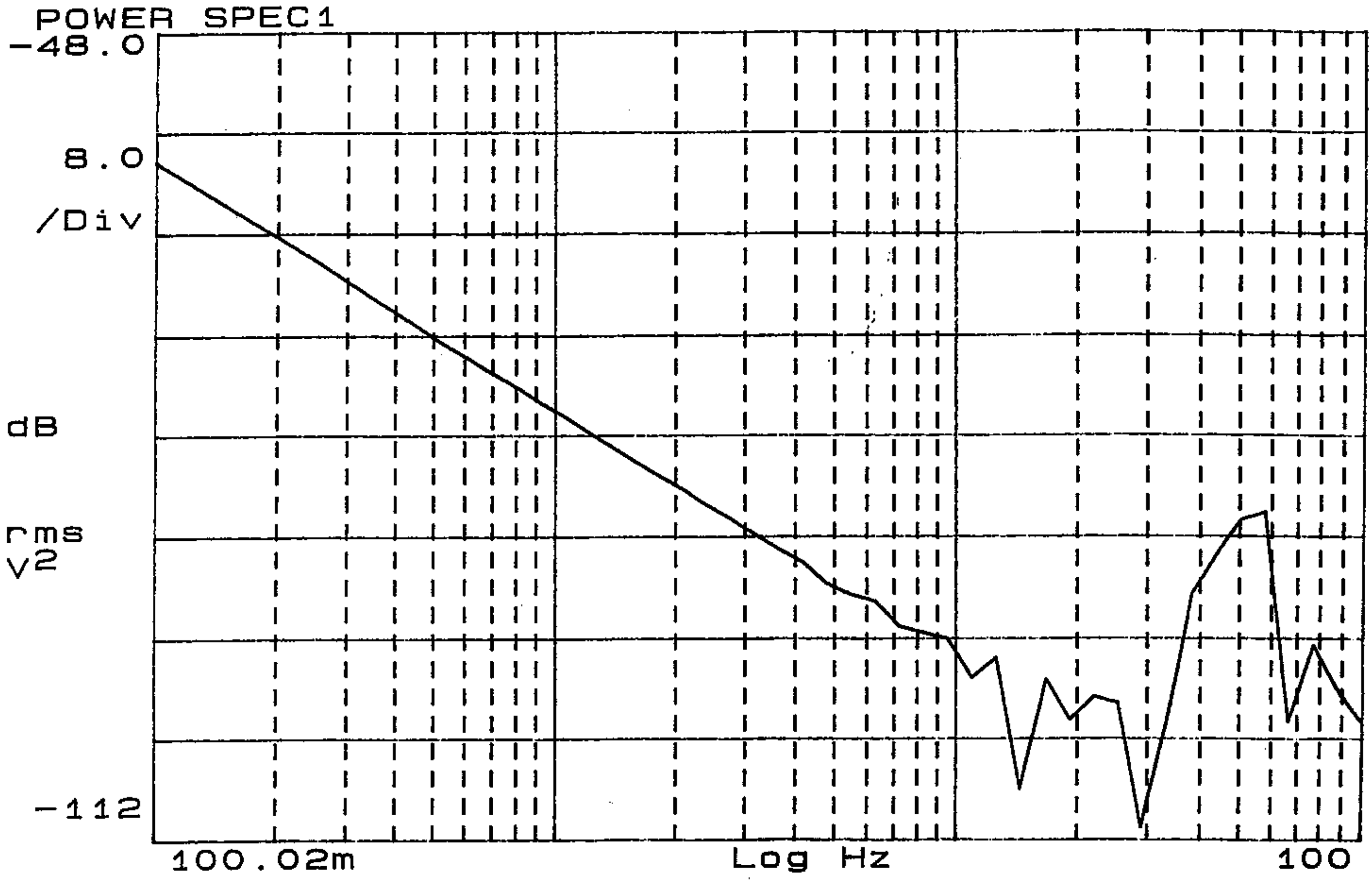


Figure 4.5 The characteristics of one integrator

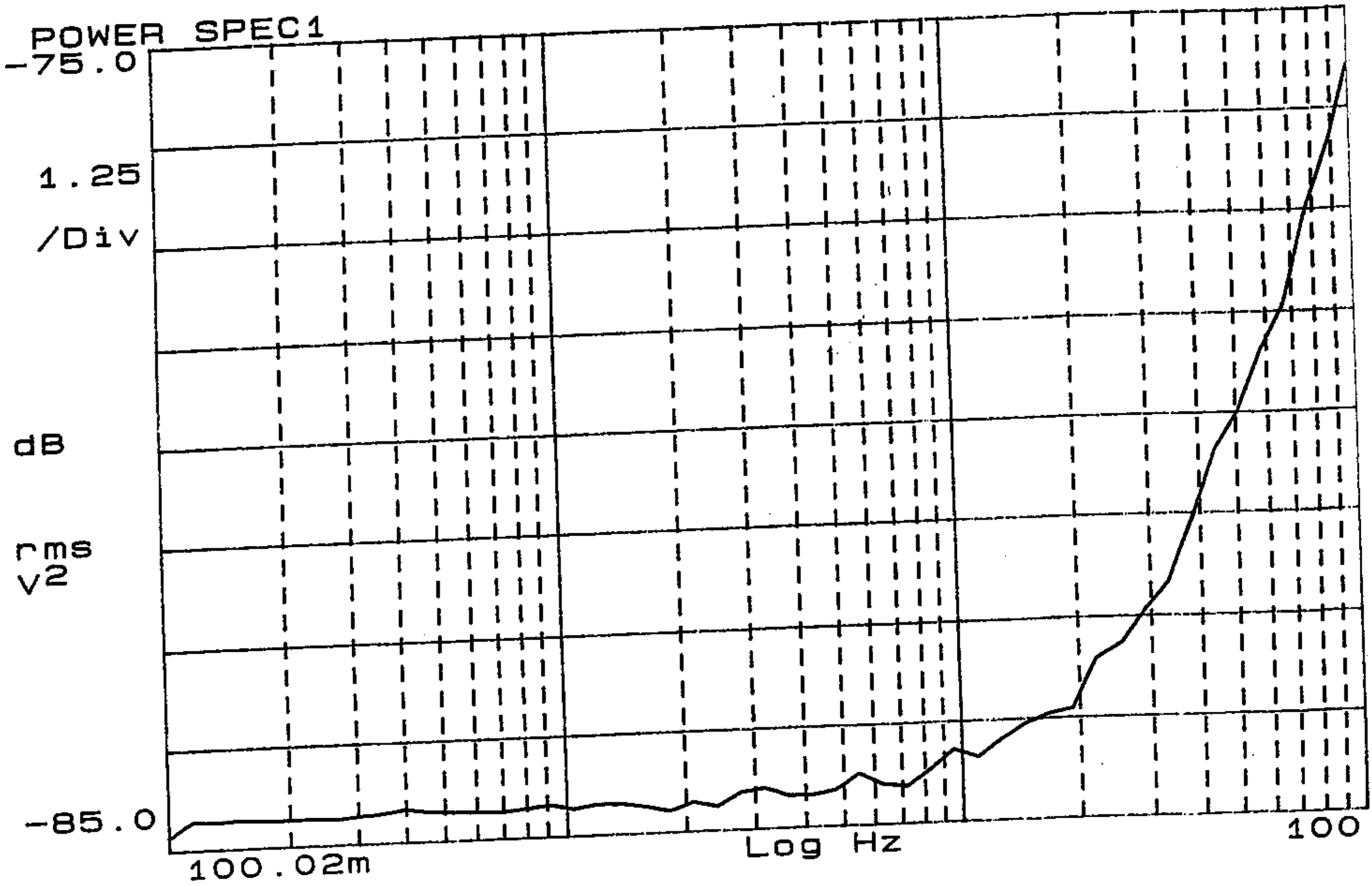


Figure 4.6 The characteristics of the differentiators

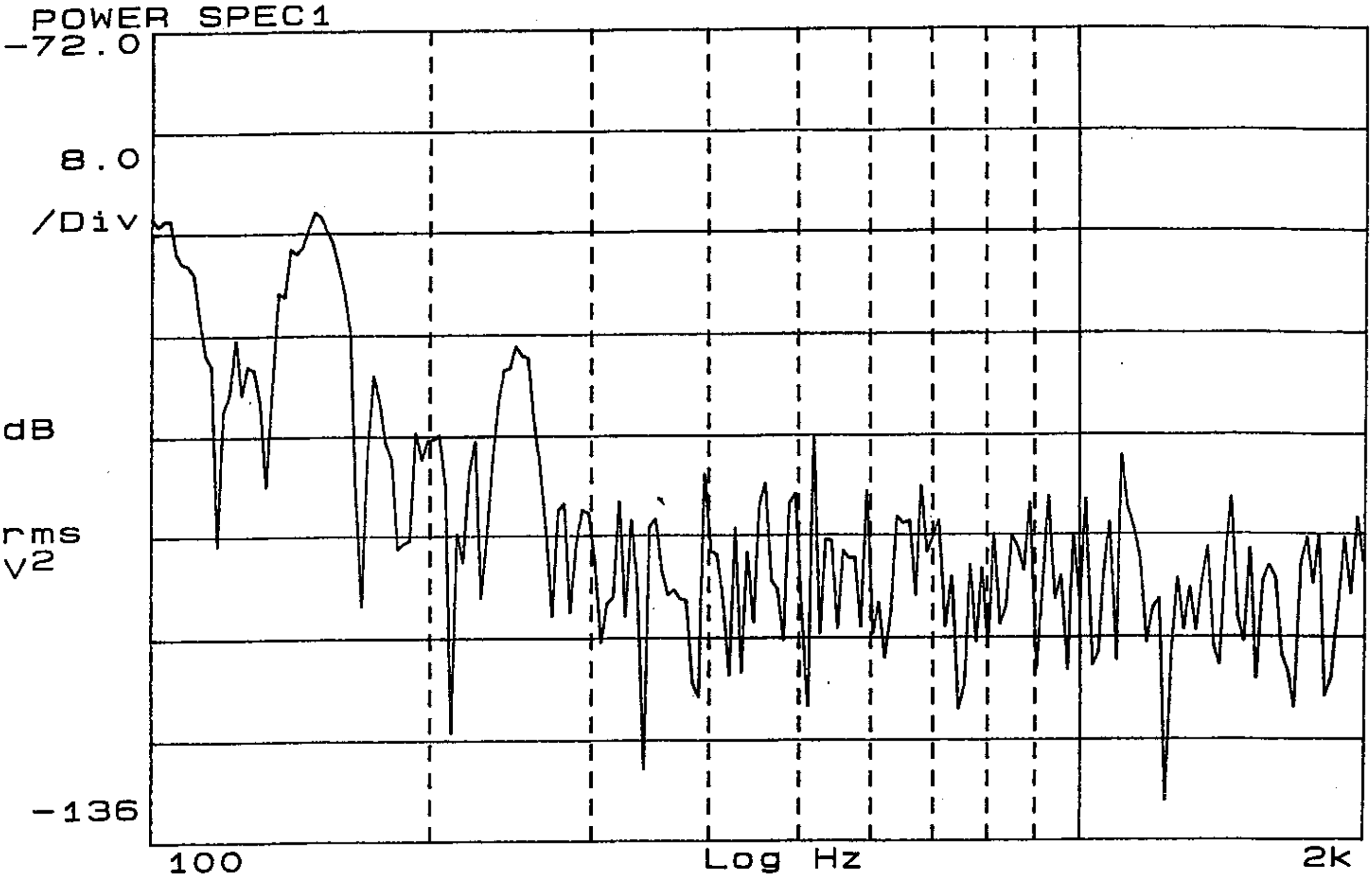


Figure 4.7 Resonance characteristics of the grating

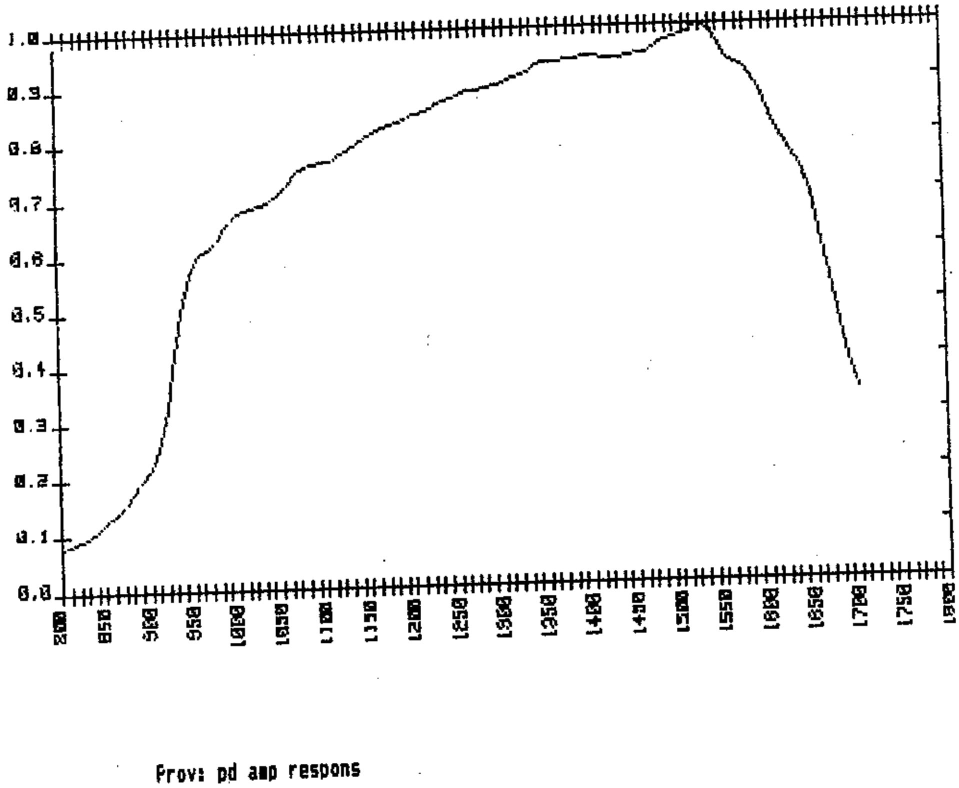


Figure 4.8 Photo diode amplifier response

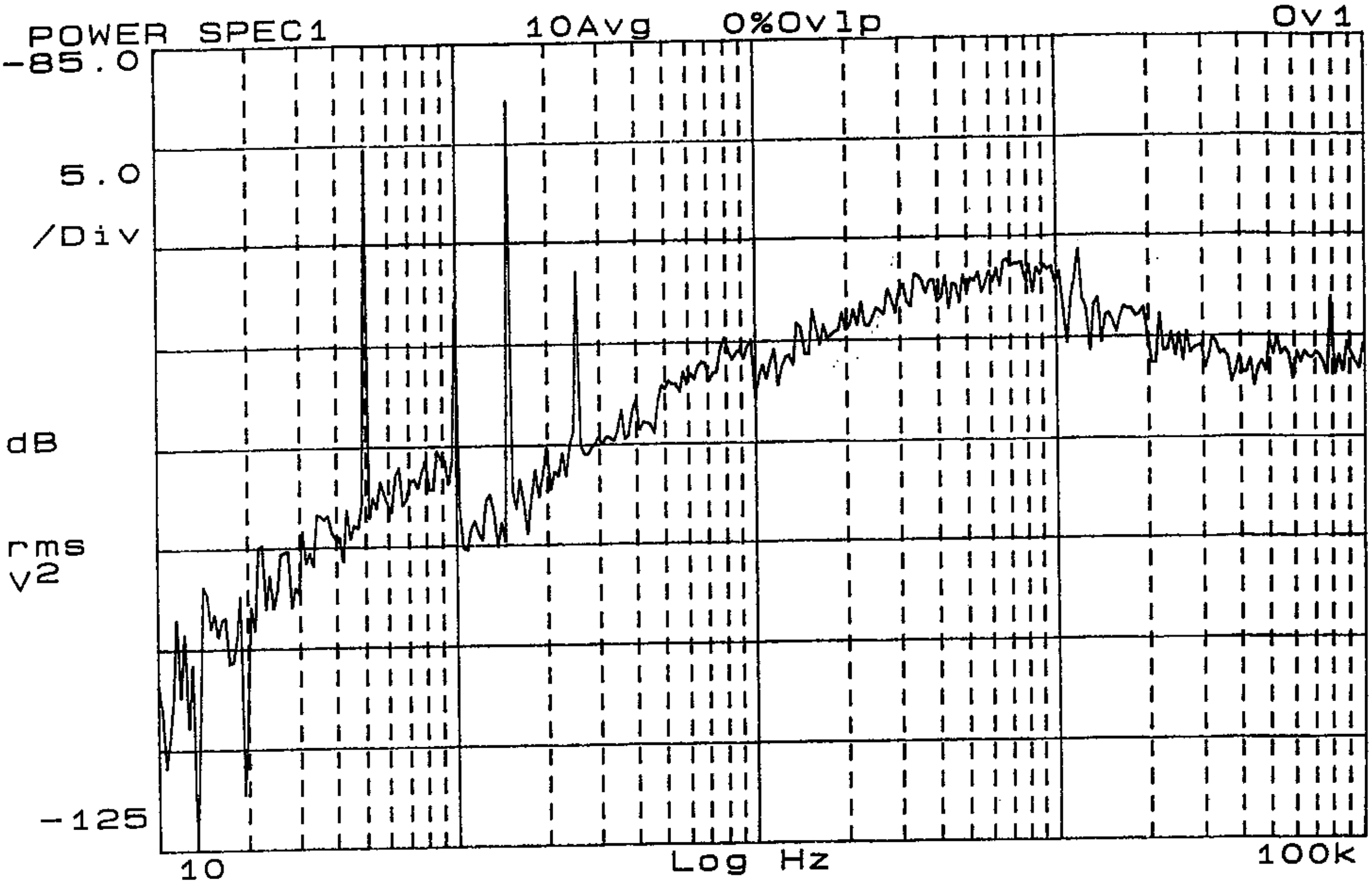


Figure 4.9 Amplitude noise without modulation

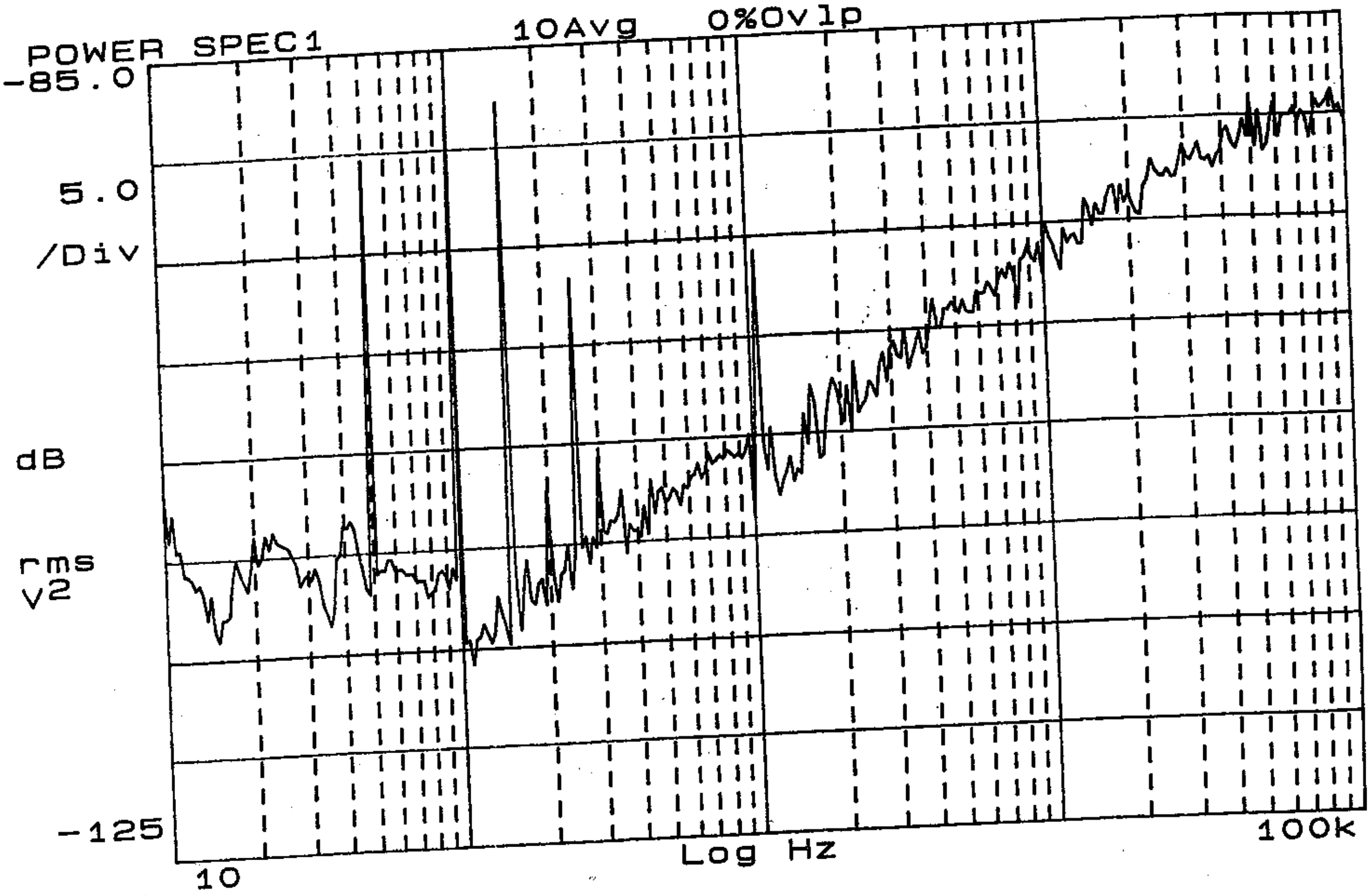


Figure 4.10 Amplitude noise with modulation

5 Conclusion

With the aim of producing an external grating cavity semiconductor laser with a highly coherent and frequency stable output a design and construction has been made. Measurements show that the design and construction has been successful, and the laser should (after further adjustments) satisfy the specified demands.

6 References and bibliography

Hughes, FW 1986. "*Op-amp handbook*", 2nd Edition, Prentice Hall, Englewoods Cliffs, N.J.

Johansson, Mathias 1993. "*En gitterkavitetslaser frekvensstabiliserad till optogalvaniskt spektrum*", **SP REPORT 1993:69**.

Johansson, Mats 1992. "*En frekvensstabiliserad gitterkavitetslaser*", **SP REPORT 1992:45**.

Keiser G 1991 "Optical fibre communications", 2nd edition, McGraw-Hill, Singapore

de Labachelerie M, Latrasse C *et.al.* 1991. "A 1,5-µm Absolutely Stabilised Extended-Cavity Semiconductor Laser", *IEEE Transactions On Instrumentation and Measurement*, **40**, No. 2.

Latrasse C, de Labachelerie M 1994. "Frequency stabilisation of a 1,5-µm distributed feedback laser using a heterodyne spectroscopy method for a space application". *Optical Engineering*, **33**, No. 5.

Mogren, S 1994 "Kalibrering av ljusvåglängd vid 1300 nm och 1550 nm med hjälp av molekylära absorptionslinjer", **SP REPORT 1994:07**

Nakaqawa K, de Labachelerie M *et al.* 1995. "Highly precise 1-THz optical frequency-difference measurement of 1,5-µm molecular absorption lines", *Optics Letters*, **20**, No. 4.

Ohtsu M 1992. "*Highly Coherent Semiconductor Lasers*", Artech House Inc., Norwood, MA.

Pendrill, L R and Åman J 1992. "*Development of a Grating Cavity Laser*" **SP REPORT 1992:18**.

Schremes AT and Tang CL 1990. "External-Cavity Semiconductor Laser with 1000 GHz Continuous Piezoelectric Tuning Range", *IEEE Photonics Technology Letters*, **2**, No. 1.

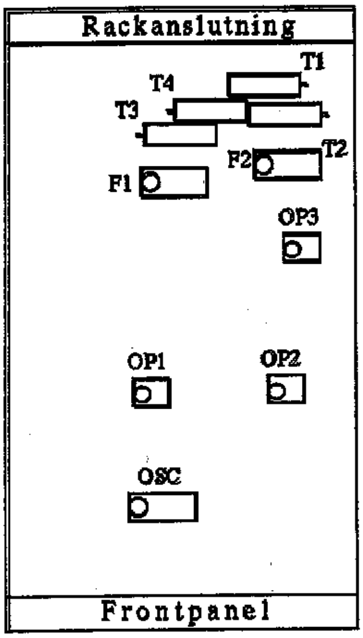
Shoichi Sudo, Yoshihisa Sakai *et al.* 1989. "Frequency Stabilisation of 1,55 µm DFB Laser Diode Using Vibrational-Rotational Absorption of $^{13}C_2H_2$ Molecules", *IEEE Photonics Technology Letters*, **1**, No. 11.

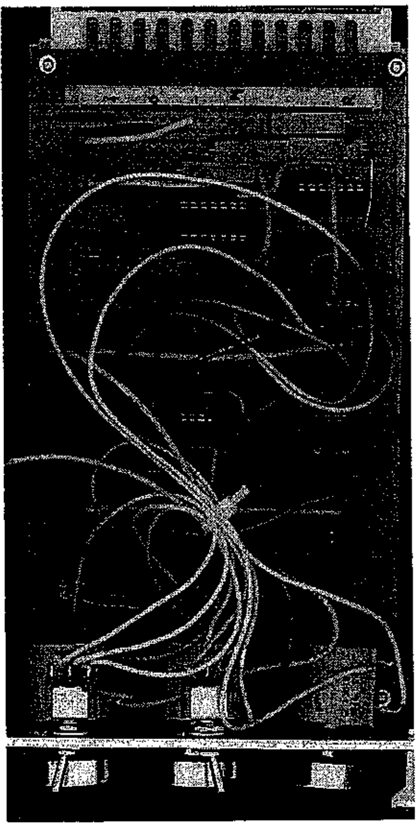
Thuillier G, Brun J-F, Alumni J-M and Roland J-J 1992."Frequency-stabilised He-Ne laser for WINDII interferometer calibration on board the UARS-NASA satellite", *Optical Engineering*, **31**, No. 3.

Appendix

I Layout, list of components, connections

I.1 Oscillator 1 kHz

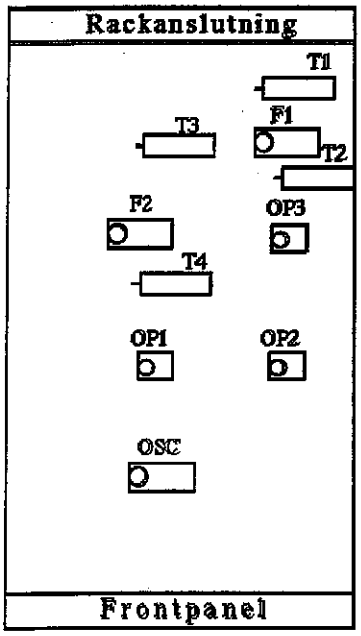


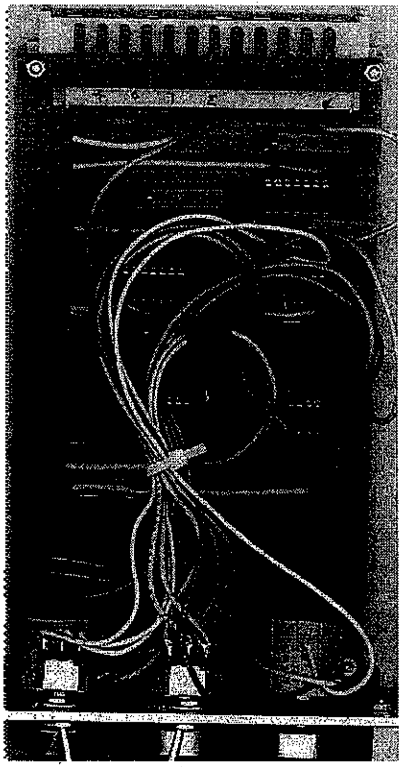


Circuit module	Mark	Component	Datasheet	Notation
Oscillator 1 kHz	R1	100 kW		
	R2	100 kW		
	R3	82 kW		
	R4	100 kW		
	R5	100 kW		
	R6	510 W		
	R7	2 kW		
	R8	5.1 kW		
	R9	6.2 kW		
	R10	10 kW		
	R11	5.1 kW		
	R12	10 kW		
	R13	5.1 kW		
	R14	6.2 kW		
	T1	10 turn 500 kW potentiometer		
	T2	10 turn 500 kW potentiometer		
	T3	10 turn 500 kW potentiometer		
	T4	10 turn 500 kW potentiometer		
	V1	10 turn 10 kW potentiometer		PHASE
	V2	10 turn 100 kW potentiometer		AMPL. GAIN MOD.
	V3	10 turn 10 kW potentiometer		AMPL. GAIN REF.
	C1	330 nF		
	C2	15 nF		
	OP1	OPA177		AMPL. GAIN MOD.
	OP2	LF355		PHASE

Circuit module	**Mark**	**Component**	**Datasheet**	**Notation**
	OP3	OPA177		INVERTER
	ICL8038	ICL8038		OSCILLATOR
	UAF42	UAF42		FILTER
	UAF42	UAF42		FILTER
	S1	SWITCH		ON/OFF
	S2	SWITCH		REF. INV

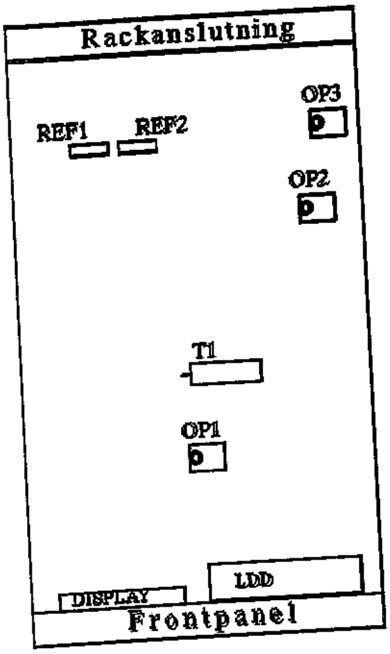
I.2 Oscillator 100 kHz

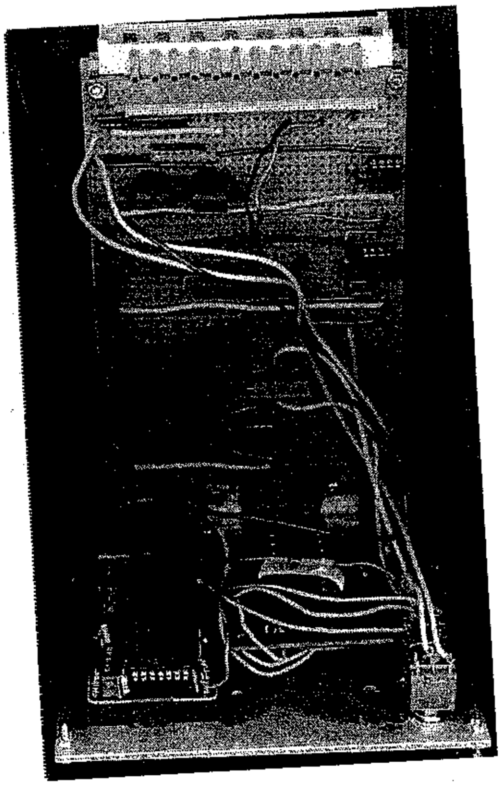




Circuit module	Mark	Component	Datasheet	Notation
Oscillator 100 kHz	R1	10 kW		
	R2	10 kW		
	R3	82 kW		
	R4	100 kW		
	R5	100 kW		
	R6	510 W		
	R7	2 kW		
	R8	5.1 kW		
	R9	6.2 kW		
	R10	1 kW		
	R11	475 W		
	R12	1 kW		
	R13	5.1 kW		
	R14	6.2 kW		
	T1	10 turn 500 kW potentiometer		
	T2	10 turn 500 kW potentiometer		
	T3	10 turn 500 kW potentiometer		
	T4	10 turn 500 kW potentiometer		
	V1	10 turn 10 kW potentiometer		PHASE
	V2	10 turn 100 kW potentiometer		AMPL. GAIN MOD.
	V3	10 turn 10 kW potentiometer		AMPL. GAIN REF.
	C1	33 nF		
	C2	15 nF		
	OP1	OPA177		AMPL. GAIN MOD.
	OP2	LF355		PHASE
	OP3	OPA177		INVERTER
	ICL8038	ICL8038		OSCILLATOR
	UAF42	UAF42		FILTER
	UAF42	UAF42		FILTER
	S1	SWITCH		ON/OFF
	S2	SWITCH		REF. INV

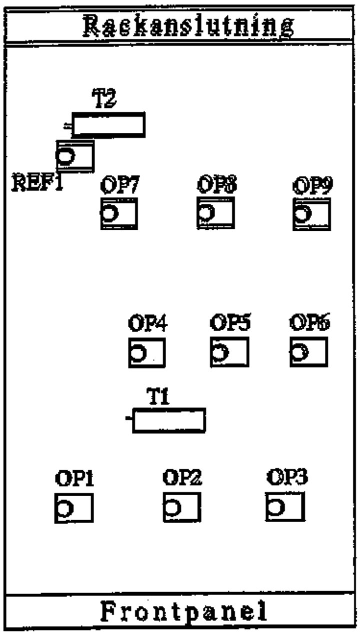
I.3 Laser Diode Driver

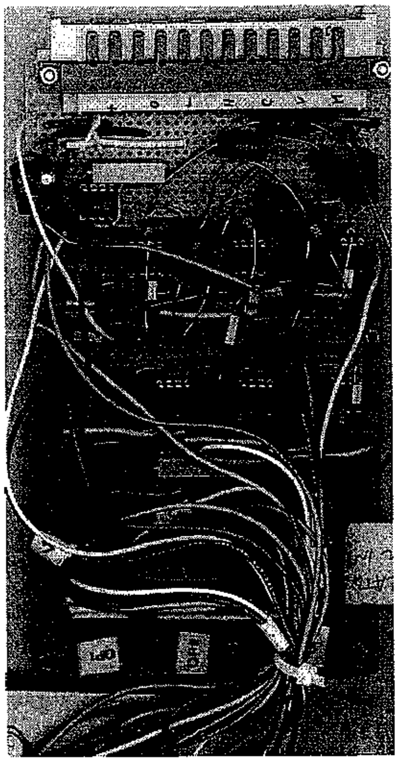




Circuit module	Mark	Component	Datasheet	Notation
LDD	R1	2 kΩ		
	R2	10 kΩ		
	R3	10 kΩ		
	R4	10 kΩ		
	R5	5.1 kΩ		
	R6	10 kΩ		
	R7	10 kΩ		
	R8	5.1 kΩ		
	T1	100 kΩ		
	OP1	OPA177		VOLTAGE FOLLOWER
	OP2	OPA177		ADDER
	OP3	OPA177		INVERTER
	LDD	LDD100	Y	
	DISPLAY	UP-5135		

I.4 Low voltage Piezo Driver

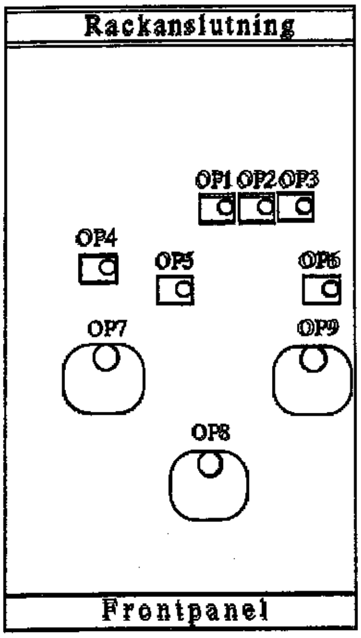


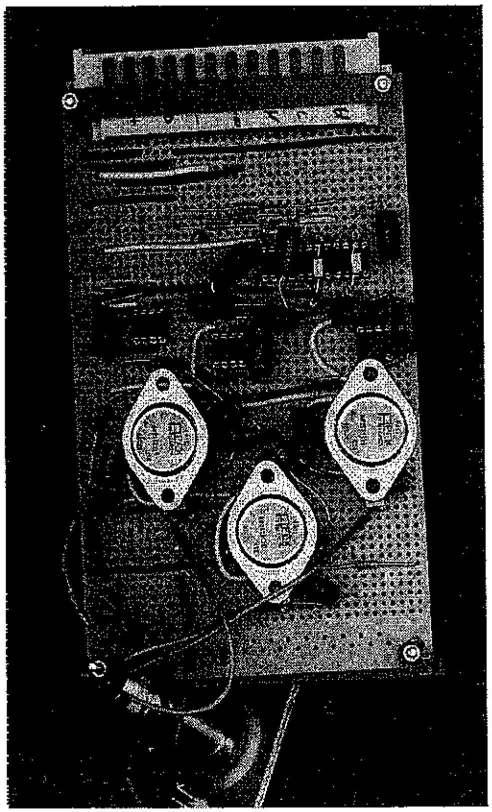


Circuit module	Mark	Component	Datasheet	Notation
PZTLV	R1	10 kΩ		PREC. RES.
	R2	6 kΩ		PREC. RES.
	R3	10 kΩ		
	R4	1 kΩ		PREC. RES.
	R5	10 kΩ		
	R6	10 kΩ		
	R7	10 kΩ		
	R8	10 kΩ		
	R9	1 kΩ		
	R10	10 kΩ		PREC. RES.
	R11	1 kΩ		PREC. RES
	R12	1 kΩ		PREC. RES.
	R13	520 Ω		
	R14	1 kΩ		PREC. RES.
	R15			OMITTED
	R16	1 kΩ		PREC. RES.
	R17	520 Ω		
	R18	1 kΩ		PREC. RES.
	R19	100 kΩ		PREC. RES.
	R20	100 kΩ		PREC. RES.
	R21	50 kΩ		
	R22	2 kΩ		PREC. RES.
	R23	100 kΩ		PREC. RES.
	R24	100 kΩ		PREC. RES.
	R25	50 kΩ		
	R26	2 kΩ		PREC. RES.
	R27	100 kΩ		PREC. RES.
	R28	100 kΩ		PREC. RES.
	R29	50 kΩ		
	R30	2 kΩ		PREC. RES.
	R31	100 kΩ		PREC. RES.
	R32	100 kΩ		PREC. RES.
	R33	50 kΩ		

R34	2 kΩ	PREC. RES.
R35	2 kΩ	PREC. RES.
R36	2 kΩ	PREC. RES.
T1	10 turn 100 kΩ potentiometer	SWEEP RATIO
T2	10 turn 100 kΩ potentiometer	VOLTAGE REF.
C1	0.1μF	NOISE BYPASS
C2	0.1μF	NOISE BYPASS
C3	10nF	
C4	10nF	
C5	0.1μF	NOISE BYPASS
C6	10nF	
C7	0.1μF	NOISE BYPASS
C8	10nF	
C9	0.1μF	NOISE BYPASS
C10	10nF	
C11	0.1μF	NOISE BYPASS
C12	10nF	
V1	10 turn 10 kΩ potentiometer	FINE TUNING
V2	10 turn 10 kΩ potentiometer	COARSE TUNING
V3	10 turn 10 kΩ potentiometer	HORIZONTAL TUNING
V4	10 turn 10 kΩ potentiometer	VERTICAL TUNING
V5	10 turn 10 kΩ potentiometer	CENTER TUNING
V6	10 turn 10 kΩ potentiometer	TRANSL.
S1	SWITCH	MOD. ON/OFF
OP1	OPA177	
OP2	OPA177	
OP3	OPA177	
OP4	OPA177	
OP5	OPA177	
OP6	OPA177	
OP7	OPA177	
OP8	OPA177	
OP9	OPA177	
REF1	REF01CP	VOLTAGE REF.

I.5 High voltage Piezo Driver

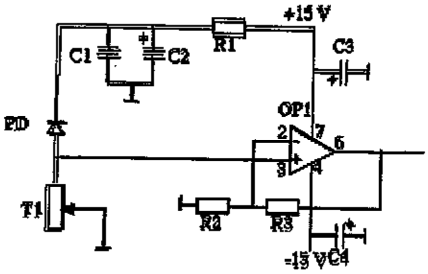


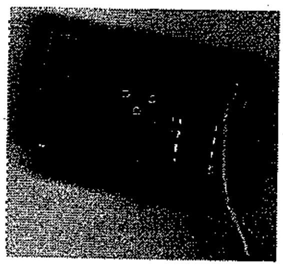


Circuit module	Mark	Component	Datasheet	Notation
PZTHV	R1	2 kΩ		PREC. RES.
	R2	1 kΩ		
	R3	2 kΩ		PREC. RES.
	R4	2 kΩ		PREC. RES.
	R5	1 kΩ		
	R6	1 kΩ		PREC. RES.
	R7	10 kΩ		PREC. RES.
	R8	2.2 kΩ		
	R9	1 kΩ		
	R10	100 Ω		
	R11	510 Ω		
	R12	2 kΩ		PREC. RES.
	R13	1 kΩ		
	R14	2 kΩ		PREC. RES.
	R15	2 kΩ		PREC. RES.
	R16	1 kΩ		
	R17	1 kΩ		PREC. RES.
	R18	10 kΩ		PREC. RES.
	R19	2.2 kΩ		
	R20	1 kΩ		
	R21	100 Ω		
	R22	510 Ω		
	R23	2 kΩ		PREC. RES.
	R24	1 kΩ		
	R25	2 kΩ		PREC. RES.
	R26	2 kΩ		PREC. RES.
	R27	1 kΩ		
	R28	1 kΩ		PREC. RES.
	R29	10 kΩ		PREC. RES.
	R30	2.2 kΩ		
	R31	1 kΩ		

R32	100 Ω		
R33	510 Ω		
C1	10 nF		
C2	10 nF		
C3	10 pF		
C4	330 pF		
C5	10 nF		
C6	10 nF		
C7	10 pF		
C8	330 pF		
C9	10 nF		
C10	10 nF		
C11	10 pF		
C12	330 pF		
OP1	OPA177		
OP2	OPA177		
OP3	OPA177		
OP4	OPA177		INVERTER
OP5	OPA177		INVERTER
OP6	OPA177		INVERTER
OP7	PA41	Y	HIGH VOLTAGE
OP8	PA41	Y	HIGH VOLTAGE
OP9	PA41	Y	HIGH VOLTAGE

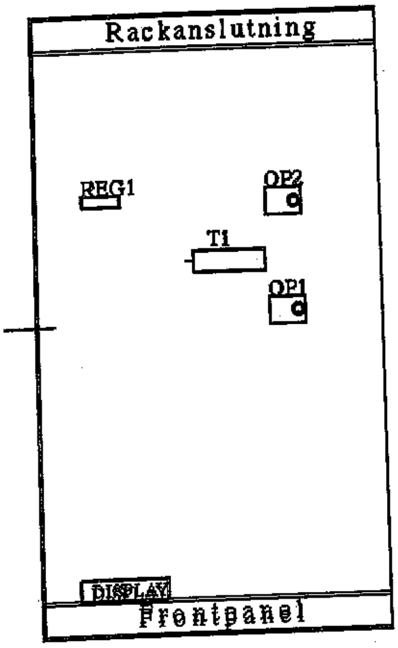
I.6 Photo-diode Electronics

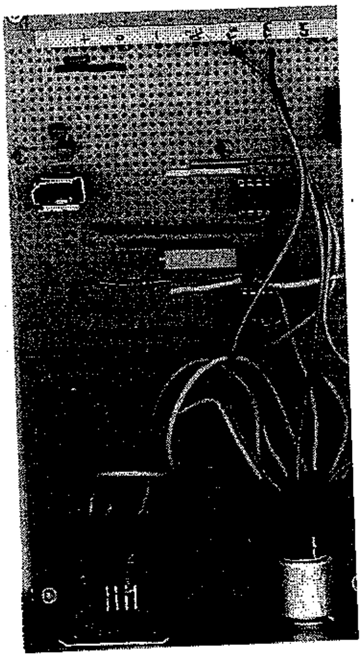




Circuit module	Mark	Component	Datasheet	Notation
PD	R1	10 kΩ		
	R2	100 Ω		
	R3	1 kΩ		
	T1	10 turn 1kΩ potentiometer		
	C1	0.1 μF		
	C2	10 μF		
	C3	1 μF		
	C4	1 μF		
	OP1	OPA603		FAST
	PD	G5832-02		

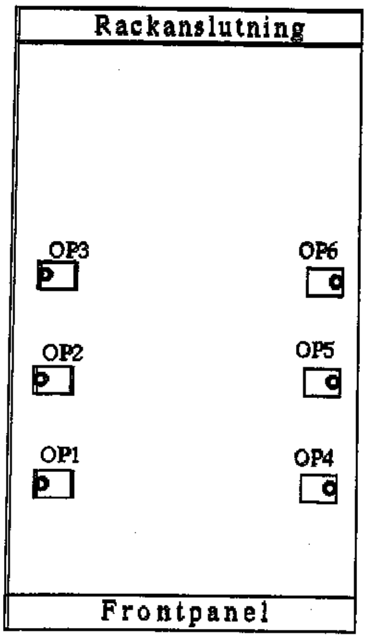
I.7 Temperature Controller





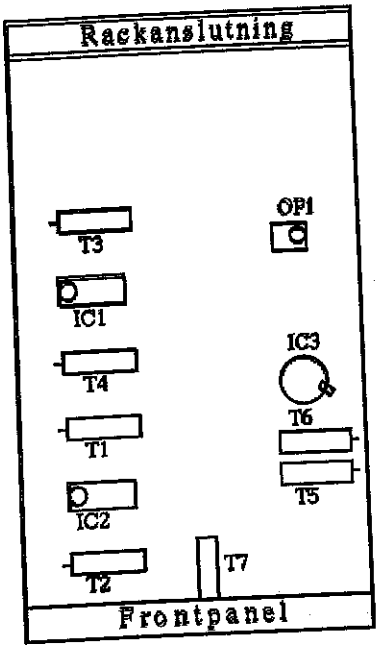
Circuit module	Mark	Component	Datasheet	Notation
TEMP	R1	10 kΩ		
	R2	1 kΩ		
	R3	10 kΩ		
	R4	10 kΩ		
	R5	10 kΩ		
	R6	1 MΩ		
	T1	10 turn 10 kΩ trimpot		
	OM1	3 WAY SWITCH		
	OP1	OPA177		
	OP2	OPA177		
	DISPLAY	DMS-2 UPC		TEMP.

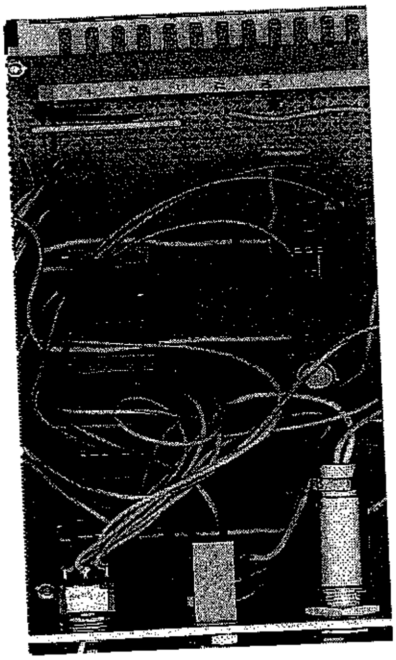
I.8 Output signal electronics



Circuit module	Mark	Component	Datasheet	Notation
OUTPUT	R1	10 kΩ		
	R2	100 kΩ		
	R3	10 kΩ		
	R4	10 kΩ		
	R5	10 kΩ		
	R6	10 kΩ		
	R7	100 kΩ		
	R8	10 kΩ		
	R9	10 kΩ		
	R10	10 kΩ		
	R11	100 kΩ		
	R12	10 kΩ		
	R13	10 kΩ		
	R14	10 kΩ		
	R15	10 kΩ		
	R16	100 kΩ		
	R17	10 kΩ		
	R18	10 kΩ		
	Coff	0.1 µF		offset comp.
	OM1G	3 WAY SWITCH		
	OM1S	3 WAY SWITCH		
	OP1	MAX420CPA		+20 dB
	OP2	MAX420CPA		0 dB
	OP3	MAX420CPA		- 20 dB
	OP4	MAX420CPA		+20 dB
	OP5	MAX420CPA		0 dB
	OP6	MAX420CPA		- 20 dB

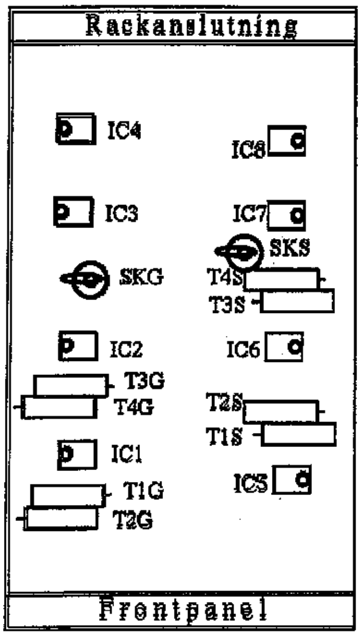
I.9 Lock-in amplifier





Circuit module	Mark	Component	Datasheet	Notation
LOCKIN	R1	6.2 kΩ		
	R2	6.2 kΩ		
	R3	50 kΩ		
	R4	50 kΩ		
	R5	500 kΩ		LP FILTER
	R6	500 kΩ		LP FILTER
	T1	10 turn 500 kΩ potentiometer		
	T2	10 turn 500 kΩ potentiometer		
	T3	10 turn 2 kΩ potentiometer		
	T4	10 turn 2 kΩ potentiometer		
	T5	10 turn 100 kΩ potentiometer		
	T6	10 turn 100 kΩ potentiometer		
	T7	10 turn 100 kΩ potentiometer		
	C1	10 nF		LP FILTER
	C2	10 nF		LP FILTER
	OP1	OPA177		
	IC1	UAF42		BP FILTER
	IC2	UAF42		BP FILTER
	IC3	ICL8013		MULTIPLIER

I.10 Control Unit



Circuit module	Mark	Component	Datasheet	Notation
CTRLUNIT	R1G	10 kΩ		
	R2G	100 Ω		
	R3G	10 kΩ		
	R4G	10 kΩ		
	R5G	100 Ω		
	R6G	10 kΩ		
	R7G	10 kΩ		
	R8G	10 kΩ		
	R9G	5 kΩ		
	R10G	50 kΩ		
	R11G	50 kΩ		
	R12G	10 kΩ		
	T1G	10 turn 1 MΩ potentiometer		
	T2G	10 turn 100 kΩ potentiometer		
	T3G	10 turn 1 MΩ potentiometer		
	T4G	10 turn 100 kΩ potentiometer		
	V1G	10 turn 100 kΩ potentiometer		
	S1G	SWITCH		PI CTRL ON/OFF
	S2G	SWITCH		INT ON/OFF
	SKG	SWITCH		INV.
	C1G	1 μF		RC time const.
	C2G	1 μF		RC time const.
	Coff	0.1 μF		
	OP1	MAX420CPA		INT.
	OP2	MAX420CPA		INT.
	OP3	MAX420CPA		INV.
	OP4	MAX420CPA		GAIN
	R1S	10 kΩ		
	R2S	10 kΩ		
	R3S	10 kΩ		
	R4S	10 kΩ		
	R5S	5 kΩ		
	R6S	10 kΩ		
	R7S	10 kΩ		
	R8S	10 kΩ		
	T1S	10 turn 10 kΩ potentiometer		
	T2S	10 turn 10 kΩ potentiometer		

Circuit module	Mark	Component	Datasheet	Notation
	T3S	10 turn 10 kΩ potentiometer		
	T4S	10 turn 10 kΩ potentiometer		
	V1S	10 turn 100 kΩ potentiometer		
	S1S	SWITCH		PD CTRL ON/OFF
	S2S	SWITCH		DIFF ON/OFF
	SKS	SWITCH		INV.
	C1S	1 μF		
	C2S	1 μF		
	OP5	MAX420CPA	Y	DIFF.
	OP6	MAX420CPA	Y	DIFF.
	OP7	MAX420CPA	Y	INV.
	OP8	MAX420CPA	Y	GAIN.

I.11 Eurorac connections

Module unit	I/O Pin	Comment
Oscillator 1 kHz	4	
	6	+ 15V
	8	
	10	N input
	12	N output to BNC
	14	- 15V
	16	
	18	Mod. output to BNC
	20	
	22	
	24	N output to BNC
	26	
	28	
	30	Ref. output to BNC
	32	
Oscillator 100 kHz	4	
	6	+ 15V
	8	
	10	N input
	12	N output to BNC
	14	- 15V
	16	
	18	Mod. output to BNC
	20	
	22	
	24	N output to BNC
	26	
	28	
	30	Ref. output to BNC
	32	
Lock-in Amplifier	4	
	6	+ 15V
	8	
	10	N input
	12	N output to osc.1 kHz
	14	- 15V
	16	N output to BNC
	18	Ref. input from BNC
	20	N output to osc.100 kHz
	22	Ctrl output signal to BNC
	24	N output to BNC
	26	
	28	
	30	
	32	
Ctrl Unit	4	
	6	+ 15V
	8	
	10	N input
	12	
	14	- 15V
	16	
	18	
	20	N output to BNC
	22	Ctrl input signal from lock-in from BNC

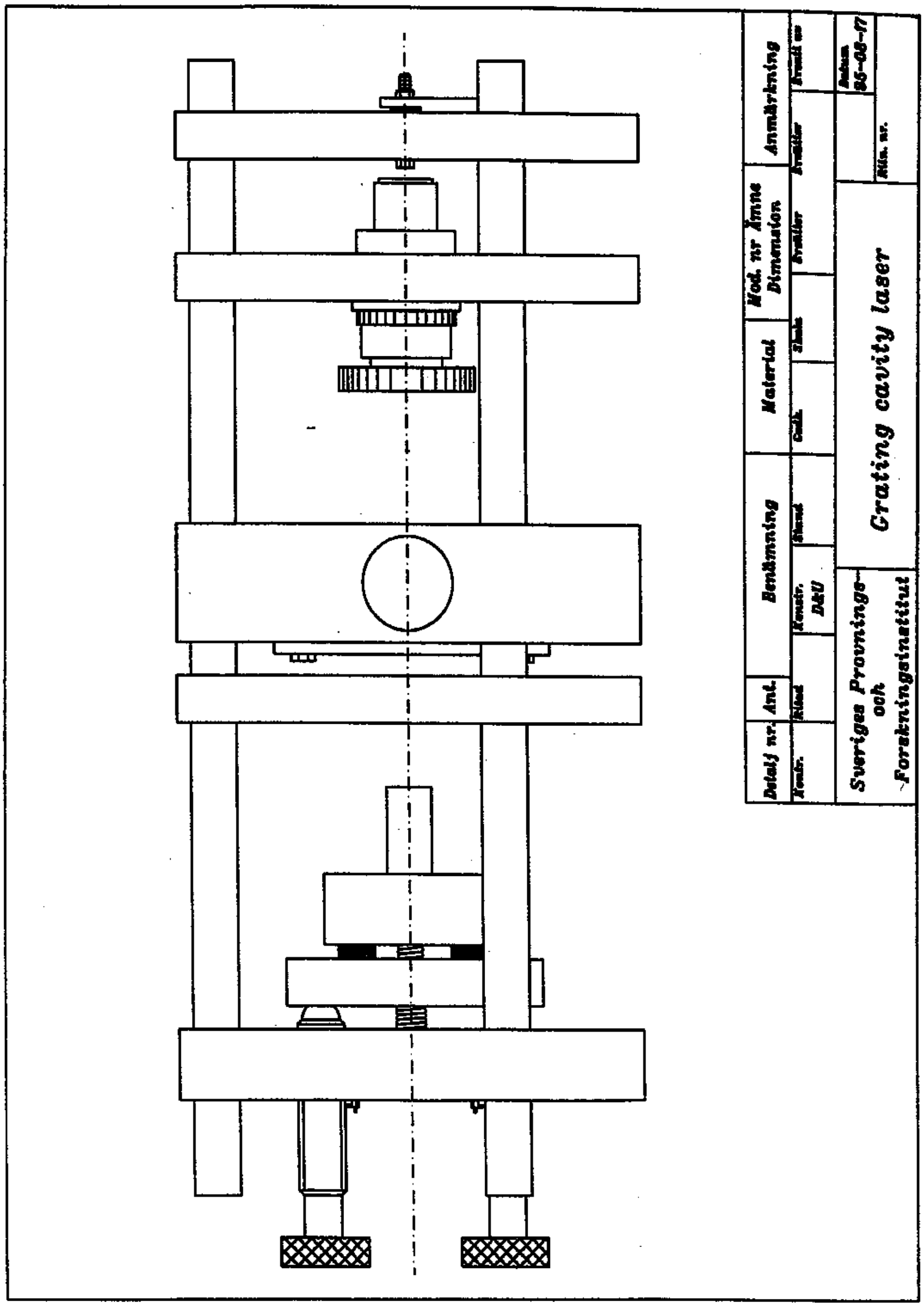
Module unit	I/O Pin	Comment
	24	N output to BNC
	26	Jumper to pin 18 on output unit
	28	N output to BNC
	30	Jumper to pin 22 on output unit
	32	
Output unit	4	
	6	+ 15V
	8	
	10	
	12	
	14	- 15V
	16	
	18	Jumper from pin 26 on Ctrl Unit
	20	
	22	Jumper from pin 30 on Ctrl Unit
	24	
	26	Grating Ctrl Signal output to BNC
	28	
	30	Current Ctrl Signal output to BNC
	32	
LV piezodriver	4	N output to BNC
	6	+ 15V
	8	
	10	N input
	12	N output to BNC
	14	- 15V
	16	
	18	Jumper to pin 30 on HV piezodriver
	20	
	22	Jumper to pin 26 on HV piezodriver
	24	
	26	Jumper to pin 22 on HV piezodriver
	28	
	30	Mod. input signal from BNC
	32	Ctrl input signal from BNC
HV piezodriver	4	
	6	+ 15V
	8	
	10	N input
	12	
	14	- 15V
	16	
	18	+ 150V
	20	
	22	Jumper from pin 26 on LV piezodriver
	24	
	26	Jumper from pin 22 on LV piezodriver
	28	
	30	Jumper from pin 18 on LV piezodriver
	32	

LDD	4	
Module unit	**I/O Pin**	**Comment**
	6	+ 15V
	8	
	10	N input
	12	
	14	- 15V
	16	
	18	Ctrl input signal from BNC
	20	
	22	Anode voltage output to LD
	24	N for shielding on cable
	26	Cathode voltage output to LD
	28	N output to BNC
	30	Mod. input from BNC
	32	N output to BNC
150 V= supply	4	
	6	Phase input from pin 14 on 230 V AC
	8	
	10	Neutral input from pin 10 on 230 V AC
	12	
	14	
	16	
	18	
	20	
	22	
	24	
	26	150 V output
	28	
	30	N input from pin 14 on ±15 V=
	32	
±15 V= supply	4	
	6	+ 15V
	8	Jumper to pin 14
	10	
	12	
	14	N output
	16	- 15V
	18	
	20	
	22	
	24	
	26	
	28	Phase input from pin 18 on 230 V AC
	30	Neutral input from pin 4 on 230 V AC
	32	Earth from pin 30 on 230 V AC
230 V AC	4	
	6	N output
	8	
	10	N output
	12	
	14	Phase output
	16	
	18	Phase output
	20	
	22	

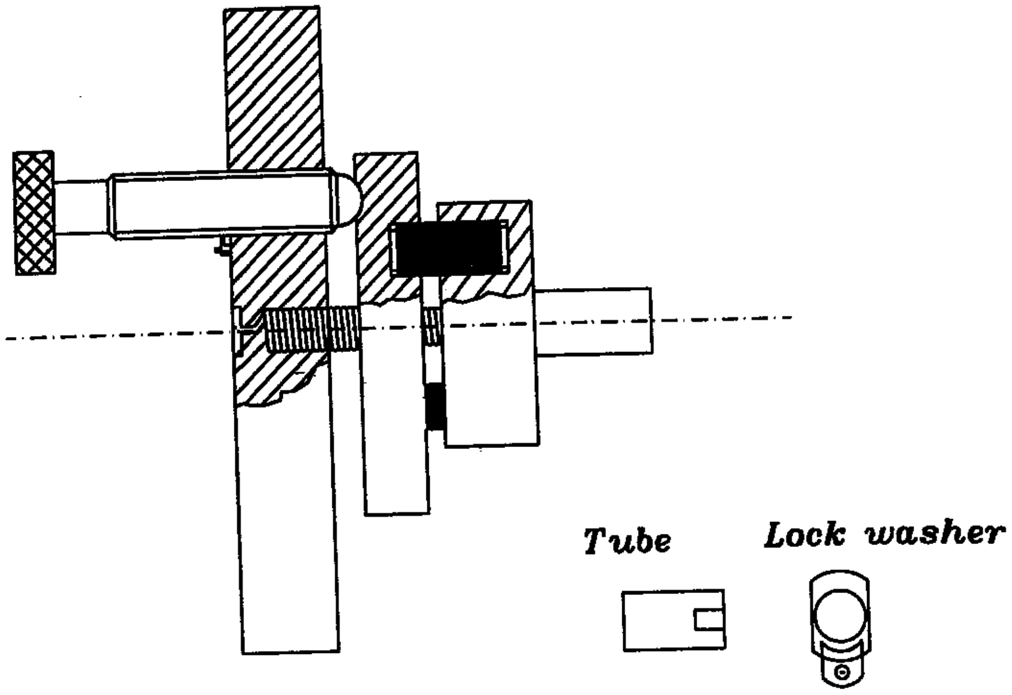
Module unit	**I/O Pin**	**Comment**
	24	
	26	
	28	
	30	Earth output
	32	
Temp. Ctrl.	4	+ 15V output to controller
	6	+ 15V
	8	N output to controller
	10	N input
	12	- 15V output to controller
	14	- 15V
	16	
	18	N output to monitor
	20	Positive AD 590 input from DIN
	22	Temperature set input to monitor
	24	Negative AD 590 input from DIN
	26	Measured temperature input to monitor
	28	White cable from output kit
	30	Current input to monitor
	32	Green cable from output kit

II Mechanical Drawings

II.1 Grating cavity laser mainframe



II.2 Grating holder - side view



Lock washer
PZT–actator 5x5x18 3pcs
Tube 3pcs
Casing 3pcs
Spring 2pcs $L_0$20 D_t0.8 30.2 N
2pcs $L_0$26.2 D_t1.2 85.3 N
Spring stick 2x11 4pcs
2x12 2pcs
2x14 2pcs

Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning

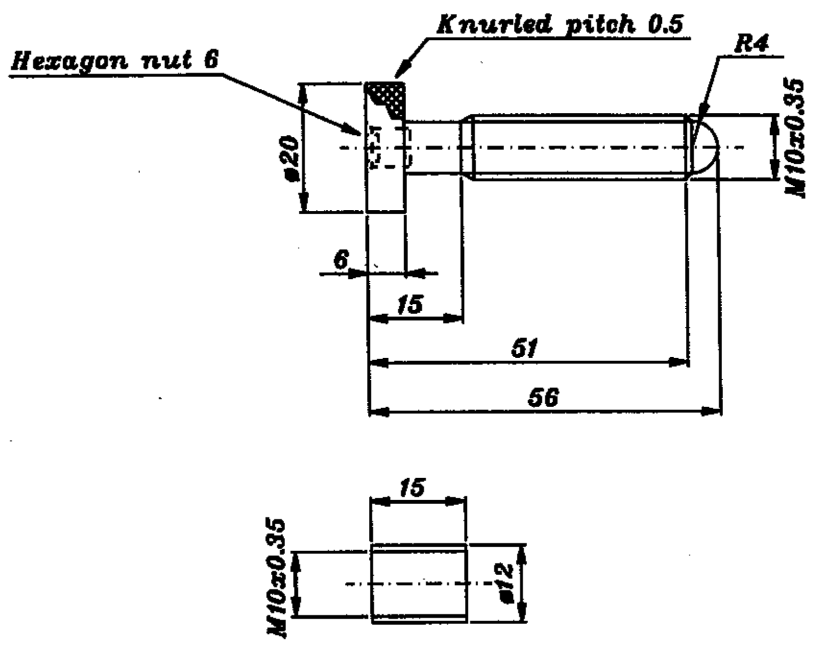
Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 1:1	Ersätter	Ersätter	Ersatt av
								Datum 95–08–17

Sveriges Provnings–
och
Forskningsinstitut

Grating holder

Ritn. nr.

II.3 Screw with sleeve

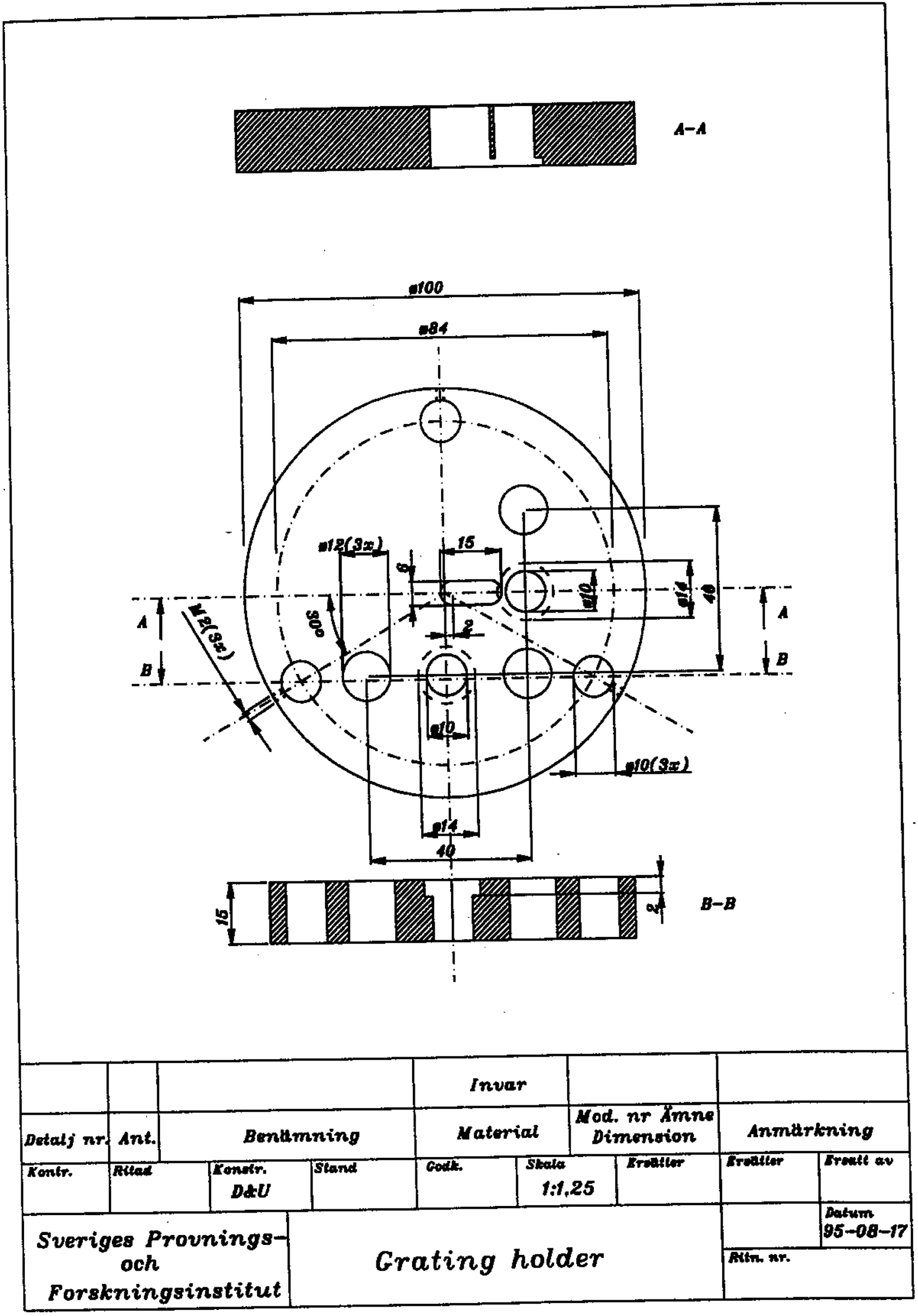


			Invar		
Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning

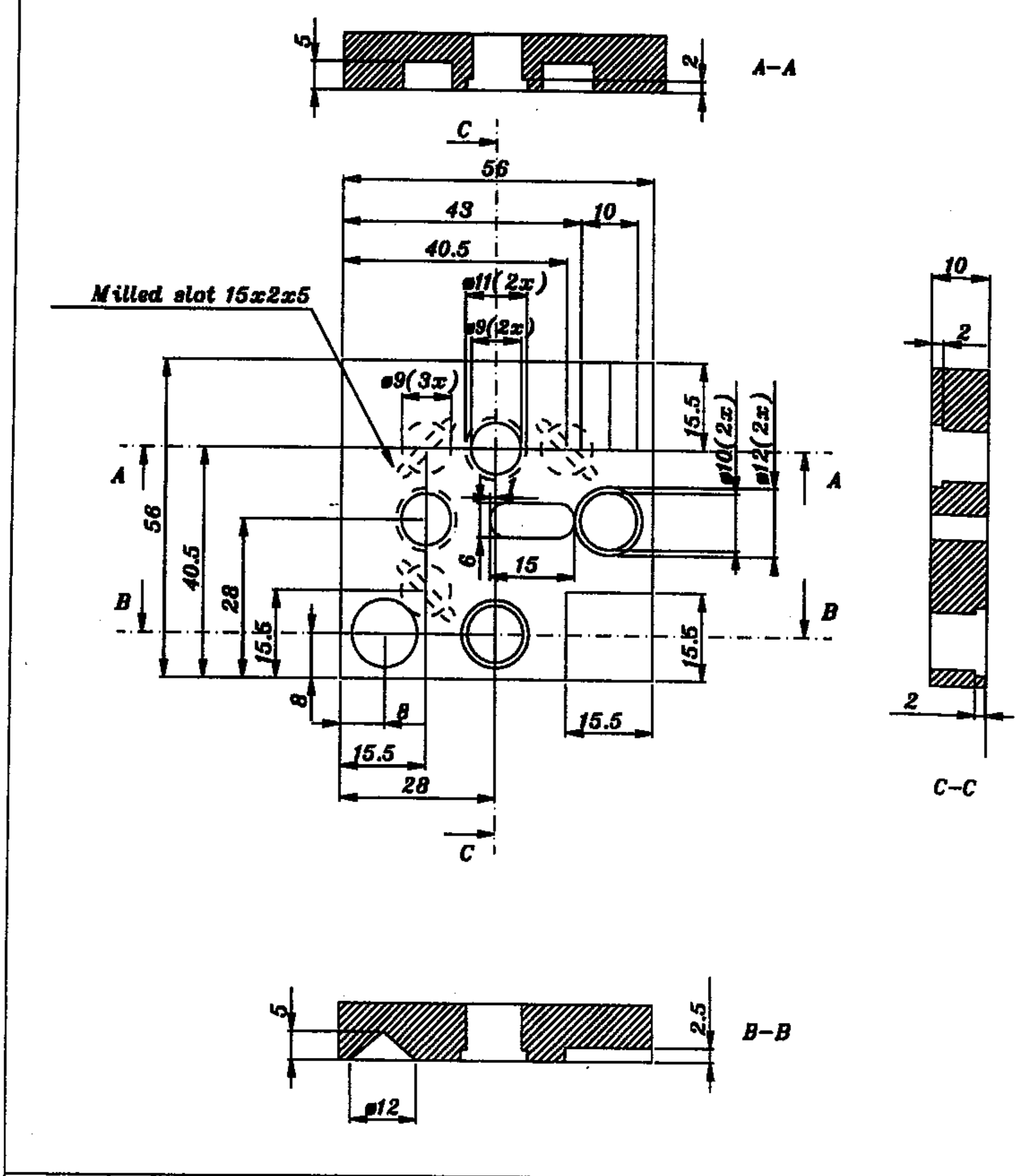
Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 1:1	Ersätter	Ersätter	Ersatt av

Sveriges Provnings- och Forskningsinstitut	Screw with sleeve	Datum 95-08-17
		Ritn. nr.

II.4 Grating holder - plate 1



II.5 Grating holder - plate 2



Invar

Detalj nr. | Ant. | Benämning | Material | Mod. nr Ämne Dimension | Anmärkning

Kontr. | Ritad | Konstr. D&U | Stand | Godk. | Skala 1:1 | Ersätter | Ersätter | Ersatt av

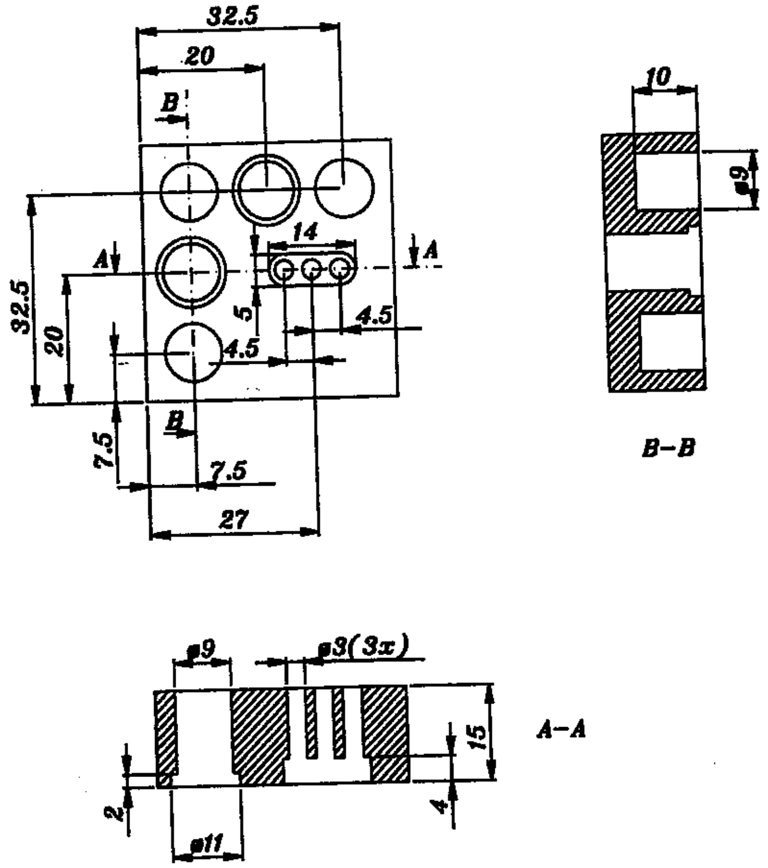
Sveriges Provnings-
och
Forskningsinstitut

Grating holder II

Datum
95-08-17

Ritn. nr.

II.6 Grating mount

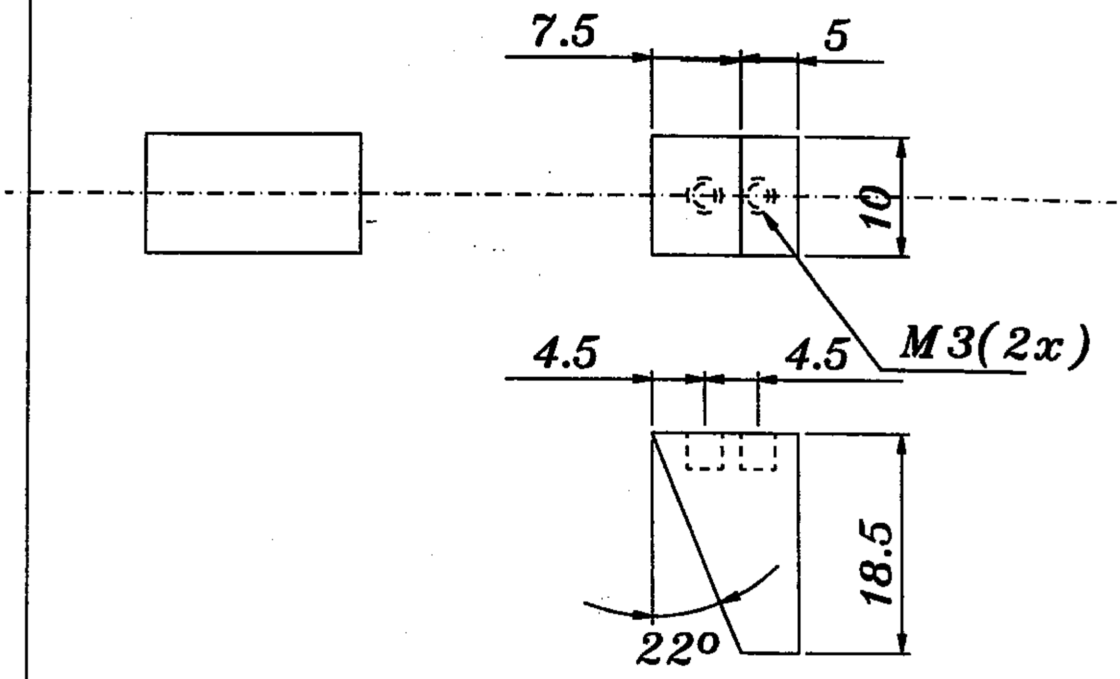


			Invar		
Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning

Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 1:1	Ersätter	Ersätter	Ersatt av

Sveriges Provnings- och Forskningsinstitut	Grating mount	Ritn. nr.	Datum 95-08-17

II.7 Grating wedge

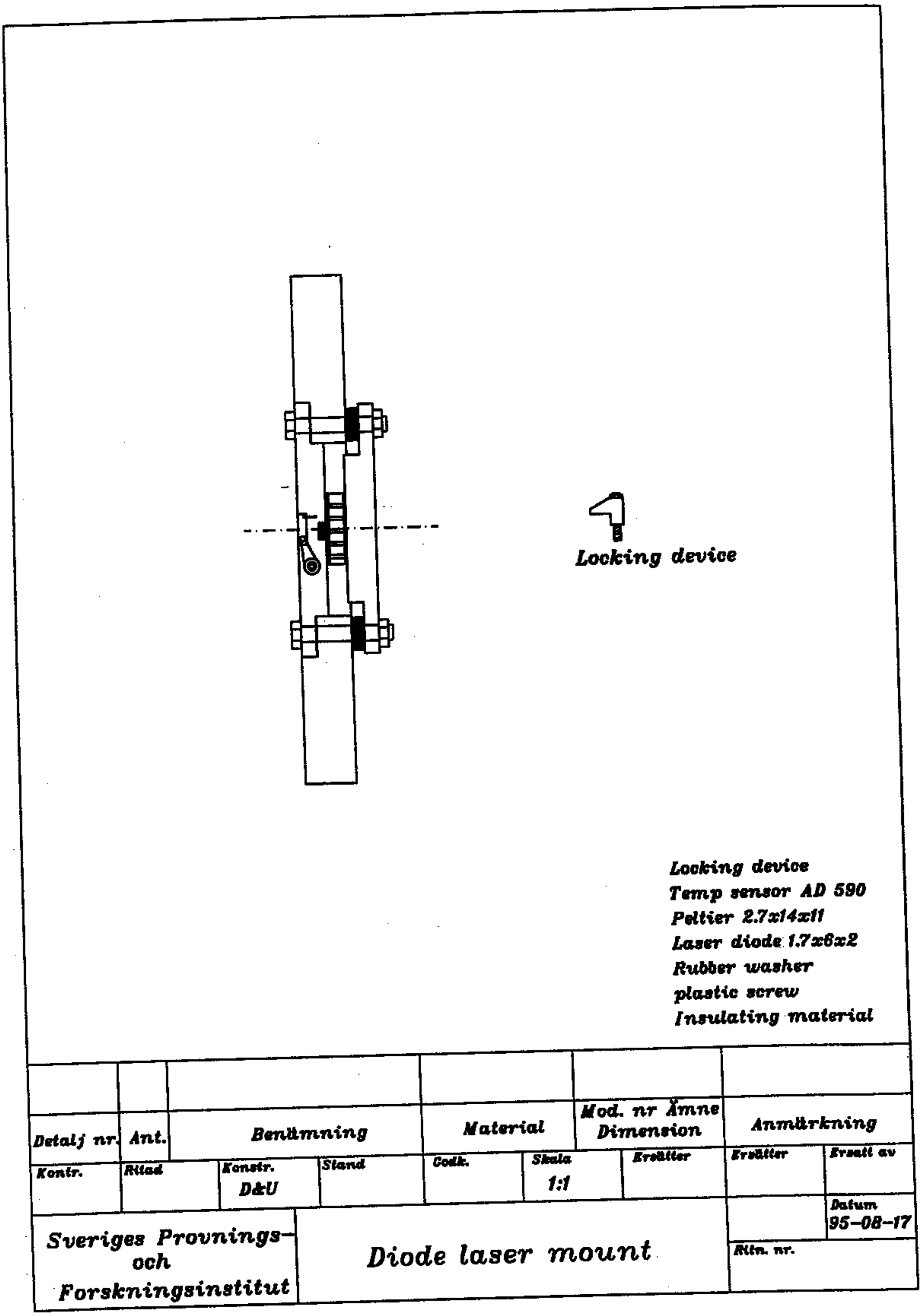


			Invar		
Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning

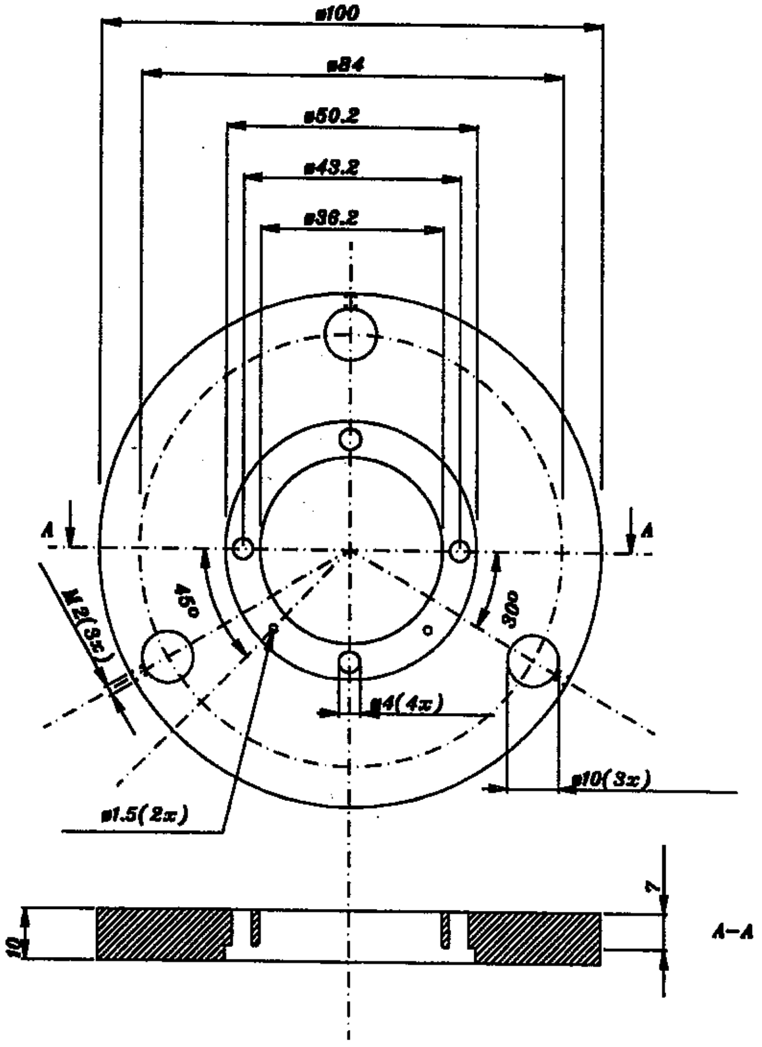
Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 2:1	Ersätter	Ersätter	Ersatt av

Sveriges Provnings- och Forskningsinstitut	Grating wedge		Datum 95-08-17
		Ritn. nr.	

II.8 Diode laser mount

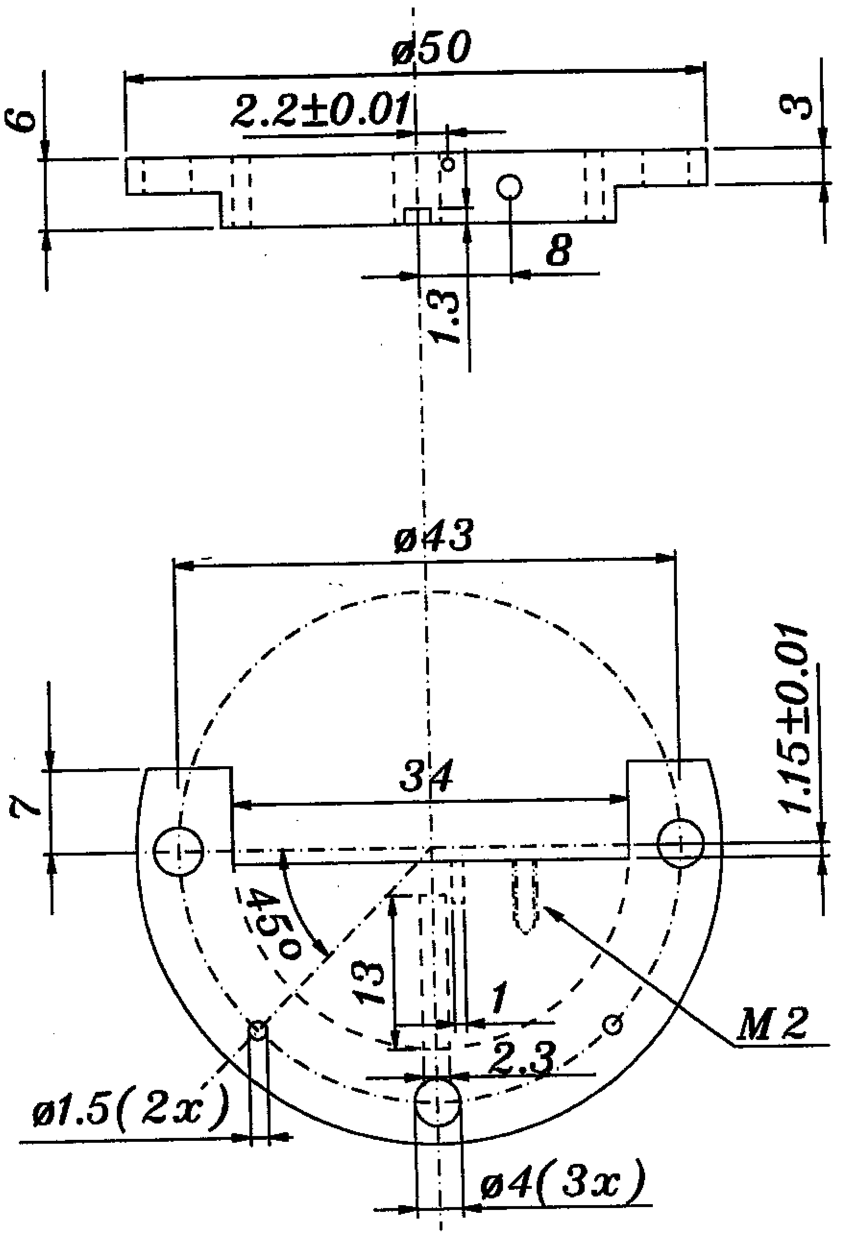


II.9 Diode laser plate



				Invar				
Detalj nr.	Ant.	Benämning		Material		Mod. nr Ämne Dimension	Anmärkning	
Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 1:1.25	Ersätter	Ersätter	Ersatt av
Sveriges Provnings- och Forskningsinstitut		Diode laser plate					Ritn. nr.	Datum 95-08-17

II.10 Diode laser mount Cu

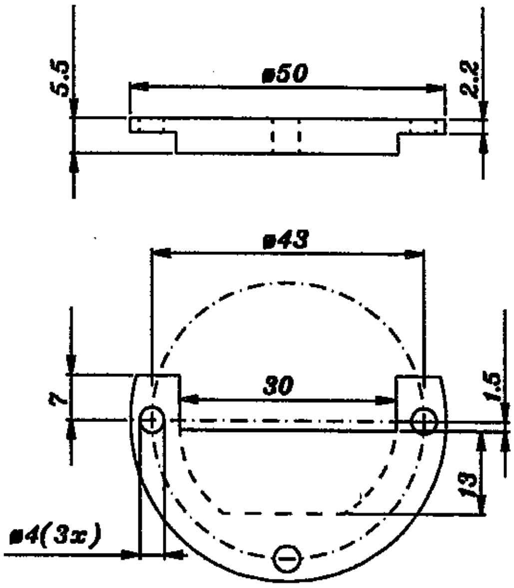


			Cu		
Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning

Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 2:1	Ersätter	Ersätter	Ersatt av

Sveriges Provnings- och Forskningsinstitut	Diode laser mount	Datum 95-08-17 Ritn. nr.

II.11 Heat-sink

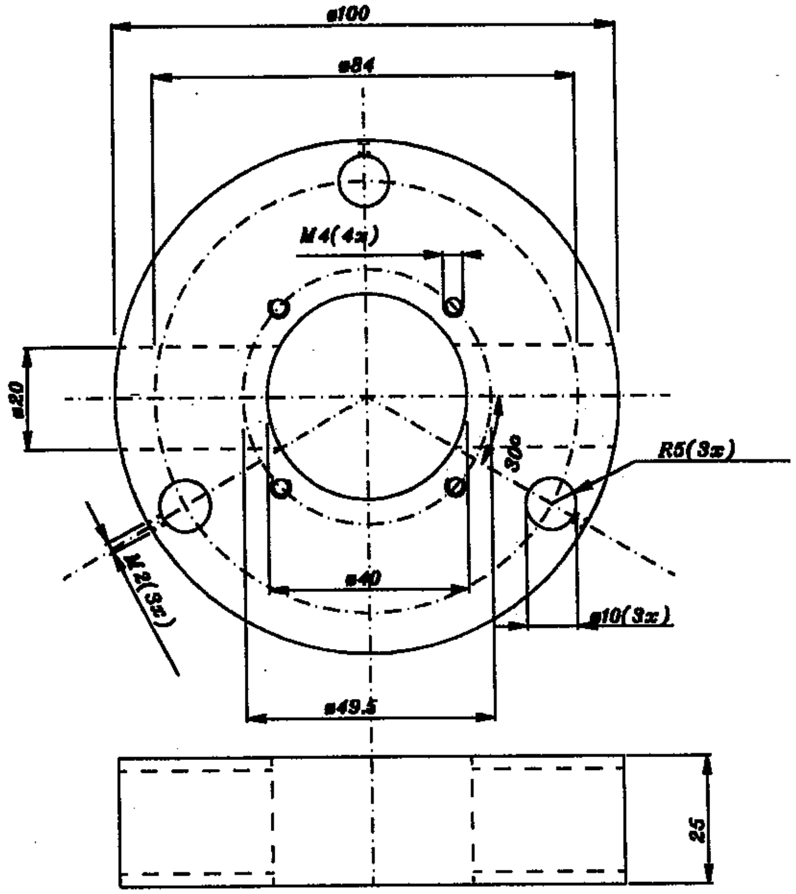


			Al		
Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning

Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 1:1	Ersätter	Ersätter	Ersatt av

Sveriges Provnings- och Forskningsinstitut	Heatsink		Datum 95-08-17
		Ritn. nr.	

II.12 Beam-splitter plate



			Al		
Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning

Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 1:1.25	Ersätter	Ersätter	Ersatt av

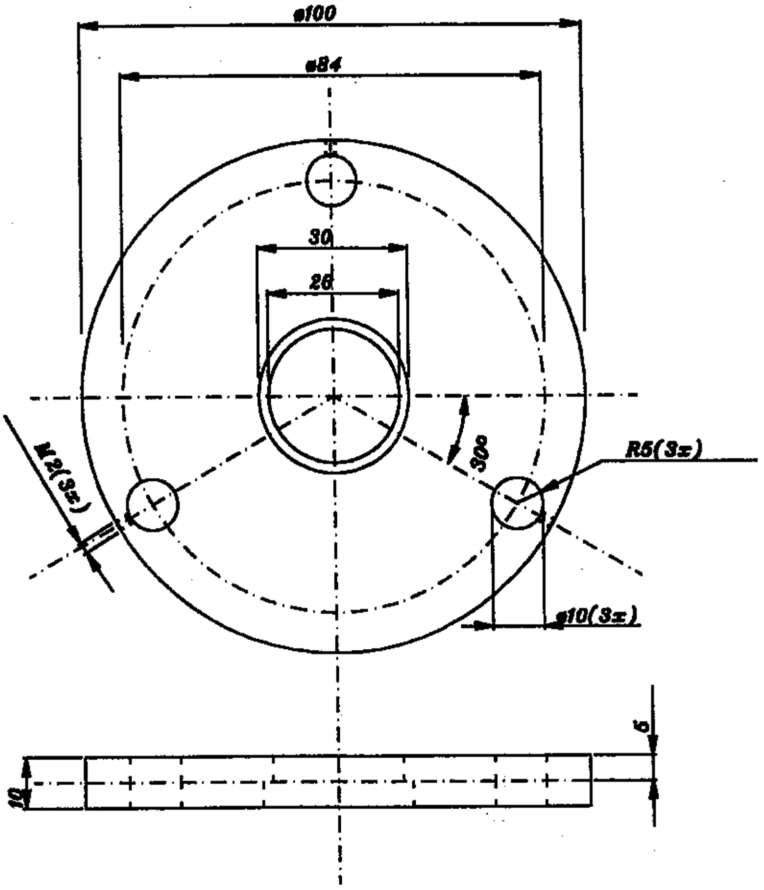
Sverige Provnings-
och
Forskningsinstitut

Beamsplitter plate

Datum
95-08-17

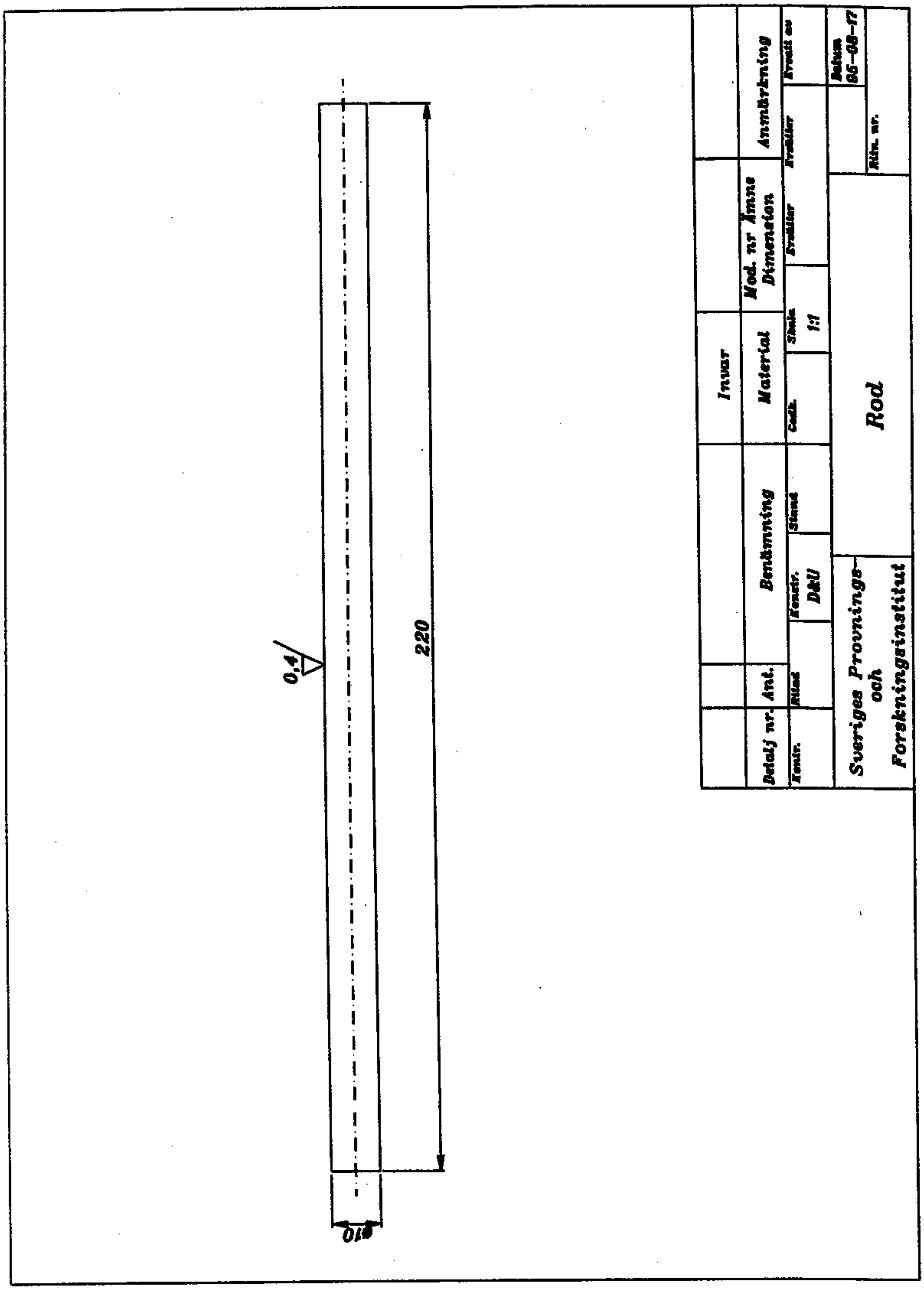
Ritn. nr.

II.15 Half-wave plate mount



			Al					
Detalj nr.	Ant.	Benämning	Material	Mod. nr Ämne Dimension	Anmärkning			
Kontr.	Ritad	Konstr. D&U	Stand	Godk.	Skala 1:1.25	Ersätter	Ersätter	Ersatt av
Sveriges Provnings- och Forskningsinstitut	Half-wave lens mount						Ritn. nr.	Datum 95-08-17

II.16 Rod


220
⌀10
0,4
Detalj nr.
Ant.
Benämning
Invar
Material
Mod. nr Ämne Dimension
Anmärkning
Konstr.
Ritad
Konstr.
D&U
Stand.
Godk.
Skala
1:1
Ersätter
Ersätter
Ersatt av
Datum
85-08-17
Ritn. nr.
Rod
Sveriges Provnings- och Forskningsinstitut

III Data sheets

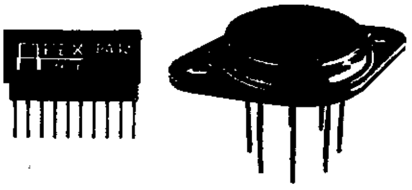
III.1 High voltage power operational amplifier PA41/42 apex

PA41/42 • PA41A/PA42A

APEX MICROTECHNOLOGY CORPORATION • APPLICATIONS HOTLINE 800 546 APEX (800 546 2739)

FEATURES

- MONOLITHIC MOS TECHNOLOGY
- LOW COST
- HIGH VOLTAGE OPERATION—350V
- LOW QUIESCENT CURRENT—2mA
- NO SECOND BREAKDOWN
- HIGH OUTPUT CURRENT—120 mA PEAK
- AVAILABLE IN DIE FORM—PA41DIE



PA41/PA42 • PA41A/PA42A

ABSOLUTE MAXIMUM RATINGS
SPECIFICATIONS

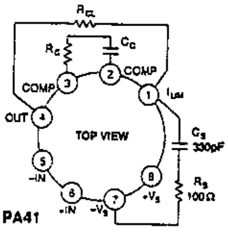
ABSOLUTE MAXIMUM RATINGS

	PA41/PA41A	PA42/PA42A
SUPPLY VOLTAGE, $+V_S$ to $-V_S$	350V	350V
OUTPUT CURRENT, continuous within SOA	60 mA	60 mA
OUTPUT CURRENT, peak	120 mA	120 mA
POWER DISSIPATION, continuous @ T_C = 25°C	12W	9W
INPUT VOLTAGE, differential	±16 V	±16 V
INPUT VOLTAGE, common mode	$\pm V_S$	$\pm V_S$
TEMPERATURE, pin solder – 10 sec	300°C	220°C
TEMPERATURE, junction[2]	150°C	150°C
TEMPERATURE, storage	–65 to +150°C	–65 to +150°C
TEMPERATURE RANGE, powered (case)	–55 to +125°C	–55 to +125°C

SPECIFICATIONS

PARAMETER	TEST CONDITIONS[1]	PA41/PA42 MIN	TYP	MAX	PA41A/PA42A MIN	TYP	MAX	UNITS
INPUT								
OFFSET VOLTAGE, initial			35	60		15	30	mV
OFFSET VOLTAGE, vs. temperature[4,7]	Full temperature range		70	130		40/•	65/•	µV/°C
OFFSET VOLTAGE, vs supply			20	32		•	•	µV/V
OFFSET VOLTAGE, vs time			75			•		µV √kh
BIAS CURRENT, initial[7]			5/100	50/2000		•	•	pA
BIAS CURRENT, vs supply			.2/.5	.5/50		•	•	pA/V
OFFSET CURRENT, initial[7]			2.5/100	50/400		•	•	pA
INPUT IMPEDANCE, DC			10^{11}			•		Ω
INPUT CAPACITANCE			5			•		pF
COMMON MODE, voltage range		$\pm V_S$–12			•			V
COMMON MODE REJECTION, DC	V_{CM} = ±90V DC	84	94		•	•		dB
NOISE, broad band	10kHz BW, R_S = 1KΩ		50			•		µV RMS
NOISE, low frequency	1-10 Hz		110			•		µV p-p
GAIN								
OPEN LOOP at 15Hz	R_L = 5KΩ	94	106		•	•		dB
BANDWIDTH, open loop			1.6			•		MHz
POWER BANDWIDTH	C_C = 10pf, 280V p-p		26			•		kHz
PHASE MARGIN	Full temperature range		60			•		°
OUTPUT								
VOLTAGE SWING	I_O = 40mA	$\pm V_S$–12	$\pm V_S$–10		$\pm V_S$–10	$\pm V_S$–8.5		V
CURRENT, peak[5]		120			•			mA
CURRENT, continuous		60			•			mA
SETTLING TIME to .1%	C_C = 10pF, 10V step, A_V = –10		12			•		µs
SLEW RATE	C_C = OPEN		40			•		V/µs
CAPACITIVE LOAD	A_V = +1	10			•			nF
RESISTANCE[5], no load	R_{CL} = 0		150			•		Ω
RESISTANCE[6], 20mA load	R_{CL} = 0		25			•		Ω
POWER SUPPLY								
VOLTAGE[3]	See Note 3	±50	±150	±175	•	•	•	V
CURRENT, quiescent			1.6	2.0	.9	1.4	1.8	mA
THERMAL								
PA41 RESISTANCE, AC junction to case	F > 60Hz		5.4	6.5		•	•	°C/W
PA42 RESISTANCE, AC junction to case	F > 60Hz		7	10		•	•	°C/W
PA41 RESISTANCE, DC junction to case	F < 60Hz		9	10.4		•	•	°C/W
PA42 RESISTANCE, DC junction to case	F < 60Hz		12	14		•	•	°C/W
PA41 RESISTANCE, junction to air	Full temperature range		30			•		°C/W
PA42 RESISTANCE, junction to air	Full temperature range		55			•		°C/W
TEMPERATURE RANGE, case	Meets full range specifications	–25		+85	•		•	°C

EXTERNAL CONNECTIONS

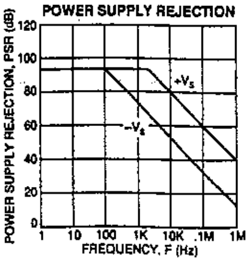


PHASE COMPENSATION

Gain	C_C	R_C
1	18pF	2.2KΩ
≥10	10pF	2.2KΩ
≥30	3.3pF	2.2KΩ

C_S, C_C ARE NPO RATED FOR FULL SUPPLY VOLTAGE.

$R_{CL} = \frac{3}{I_{LIM}}$



III.2 Laser diode drivers- 100, 200, 400 mA

LASER DIODE DRIVERS- 100, 200, 400mA

PERFORMANCE SPECIFICATIONS

Absolute Maximum Ratings

Supply Voltage	+12.5V
Current at Power Supply Pin 8 (LDD100)	150mA
(LDD200)	250mA
(LDD400)	450mA
Lead Temperature (Soldering, 10 sec.)	260°C
Storage Temperature Range	-50°C to 85°C
Operating Temperature Range	0°C to 50°C
Power Dissipation	2.5 Watts

General Mechanical Specifications

Size	1.5" x 2.05" x 0.43"
Weight	< 1 oz.

DC Electrical Characteristics

Unless otherwise specified, all limits for T = 25°C and V+ = +5V

LDD - APC General Specifications	*Typ.*	*Min.*	*Max.*	*Units*
Supply Voltage Range	5 to 12			Volts
Power Supply Quiescent Current	22		24	mA
Photodiode Input Bias Current (V+ = 12V)	1000			nA
Power Up Trip Point (Note 1)	4.9	4.8	4.93	Volts
Power Down Trip Point (Note 1)	4.2	4.1	4.3	Volts
Long Term Stability (24 Hours) (Note 2)	.02		.05	%
RMS Current Noise (Note 3)	5		10	µA rms
Modulation 3dB Frequency (constant power)	100			kHz
Modulation 3dB Frequency (constant current)	200			kHz
Depth of Modulation at 10kHz		90		%

Model Number	*Max drive current*	*Current transfer conversion*	*Photodiode current range*	*Photodiode current conversion*
	mA	mA/Volt	µA	µA/Volt
LDD100-APC-1P	100	40	15 to 2500	1000
LDD100-APC-3P	100	40	5 to 125	50
LDD200-APC-1P	200	80	15 to 2500	1000
LDD200-APC-3P	200	80	5 to 125	50
LDD400-APC-1P	400	160	15 to 2500	1000
LDD400-APC-3P	400	160	5 to 125	50

Note 1- The LDD series has internal control circuitry which turns the output on and off depending on voltage at pin 8 (V+). When the voltage reaches the power up voltage, the module soft starts the laser diode. When the voltage reaches the power down trip point, the module shunts current around the laser diode powering it down in a controlled fashion.

Note 2- Stability is a measure of variation of photodiode current around the setpoint photodiode current. Test was performed in an ambient air environment.

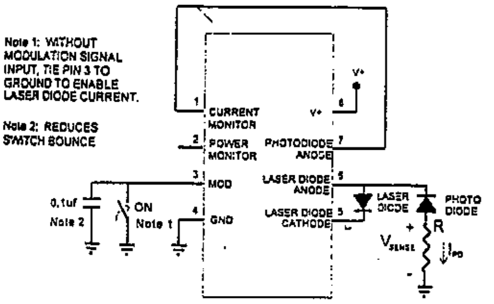
Note 3- Laser diode forward current noise. Test was performed by measuring the ac voltage across a 50 ohm metal film resistor in series with laser diode.

WARNING: Do not slow start the power supply by bringing the supply voltage up slowly. This can result in damage to the laser diode.

OPERATING PROCEDURES- CONSTANT CURRENT MODE

LDD100, LDD200, LDD400

OPTION 1P OR 3P



OPERATING PROCEDURES- CONSTANT CURRENT MODE

Step 1: Turn the current limit adjust trimpot fully counter clockwise. Turn the photodiode current adjust trimpot fully clockwise.

Step 2: Set the current limit. Short pin 5 to pin 6. Connect the power supply to pins 4 and 8 and short pin 1 to pin 7 as shown in the connection diagram. Ground pin 3. Power on the unit and monitor the voltage from pin 2 to ground. Use Equation 4 in Conversions to calculate the voltage for the proper laser diode limit current. Adjust the current limit potentiometer clockwise until the voltage at pin 2 is appropriate.

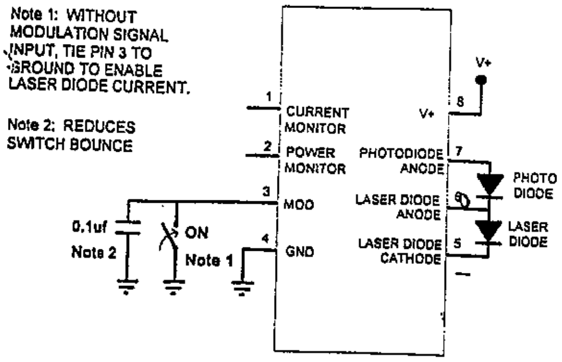
Step 3: Power the unit down and turn the photodiode current adjust trimpot fully counterclockwise. Remove the short between pins 5 and 6. Connect a laser diode to the driver as shown in the connection diagram above.

Step 4: Monitor the voltage from pin 2 to ground. Use Equation 4 to calculate the proper laser diode current setpoint.

Step 5: Turn the power supply on. Turn the Photodiode Current setpoint trimpot clockwise until the desired laser diode current output is achieved.

LDD100, LDD200, LDD400

OPTION 1P OR 3P



LASER DIODE ANODE/
PHOTO DIODE CATHODE
COMMON

Step 6: Allow the unit to warm up for ten minutes and readjust the laser diode current if necessary.

Step 7: Input the modulation signal as determined by Equation 5 and monitor the laser diode current from pin 2 with an oscilloscope. Adjust the modulation signal until you achieve the desired frequency and depth.

CONVERSIONS- CONSTANT CURRENT MODE

CURRENT MONITOR OUTPUT PIN 2:

Using Equation 4, the laser diode's forward current can be calculated. Note the Power Monitor output becomes the Current Monitor output.

LDD100 Equation 4: $I_F = V_2 \times (40mA / Volt)$
LDD200 Equation 4: $I_F = V_2 \times (80mA / Volt)$
LDD400 Equation 4: $I_F = V_2 \times (160mA / Volt)$

where I_F is the laser diode current (in mA) and V_2 is the POWER MONITOR output voltage (in Volts).

MODULATION INPUT PIN 3:

Using Equation 5, you can determine what input modulation signal to use to achieve the desired current modulation at the laser diode.

LDD100 Equation 5: $I_{LD} = I_{SETPOINT} - 20mA/Volt \times V_3$
LDD200 Equation 5: $I_{LD} = I_{SETPOINT} - 40mA/Volt \times V_3$
LDD400 Equation 5: $I_{LD} = I_{SETPOINT} - 80mA/Volt \times V_3$

where I_{LD} is the current through the laser diode, $I_{SETPOINT}$ is the current through the laser diode as set by the photodiode current adjust trimpot, and V_3 is the voltage input at pin 3.

MONITOR PHOTODIODE CURRENT (OPTIONAL):

If you want to monitor the photodiode current while in constant current mode, hook up the photodiode as shown in the previous connection diagram. For photodiode currents greater than 100µA, choose R equal to 1kΩ. Then:

$V_{SENSE} = I_{PD}$ (mA)

To get better sensitivity, for photodiode currents less than 100µA, choose R equal to 10kΩ. Then:

$V_{SENSE} * 100 = I_{PD}$ (µA)

III.3 DC Power supply, Kayser Elektronik 23000 series

KAYSER
Elektronik
Herdweg 163 · D-7030 Böblingen

23000 SERIES

DC POWER SUPPLIES

FEATURES

- VDE safety transformer
- 100/120/220/240 VAC Input
- Remote sense — most outputs
- Full Power Rating to 50° C
- Industry standard sizes
- VDE 0806 according
- UL 1012 according

SPECIFICATIONS

AC Input:	100/120/220/240 VAC + 10 %, −12 %, 47—63 Hz. See AC connection table under APPLICATION NOTES for jumper information. Fuse information is next to outline and mounting drawings.
DC Output:	See Voltage/Current Rating Chart. Adjustment range ± 5% minimum.
Line Regulation:	± 0.05% for a 10% line change
Load Regulation:	± 0.05% for a 50% load change
Output Ripple:	2V to 15V unit: 5.0mV PK-PK maximum 20V to 28V unit: 0.02% PK-PK maximum
Transient Response:	50 µ seconds for 50% load change
Short Circuit and Overload Protection:	Automatic current limit/foldback
Overvoltage Protection:	Built-in on all 5V outputs. Set at 6.2V ± 0.4 V. Other models use optional overvoltage protection.
Remote Sensing:	Provided on most models, open sense load protection built in
Stability:	± 0,3% for 24 hour period after 1 hour warm-up
Temperature Rating:	0°C to 50°C full-rated, derated linearly to 40% at 70°C
Temperature Coefficient:	± 0.03%/°C maximum
Efficiency: (typical)	5 V unit: 45%; 12 V and 15 V units: 55% 20V and 24V units: 60%
Vibration:	Per MIL-STD-810C, Method 514, Procedure X
Shock:	Per MIL-STD-810C, Method 516, Procedure V
Isolation:	Input to ground: 3750 VAC min. Input to output(s): 3750 VAC min. Output to ground: 500 VAC min. Leakage current (live to ground): 25 µA max.
Safety:	according to VDE 0806 and UL 1012.