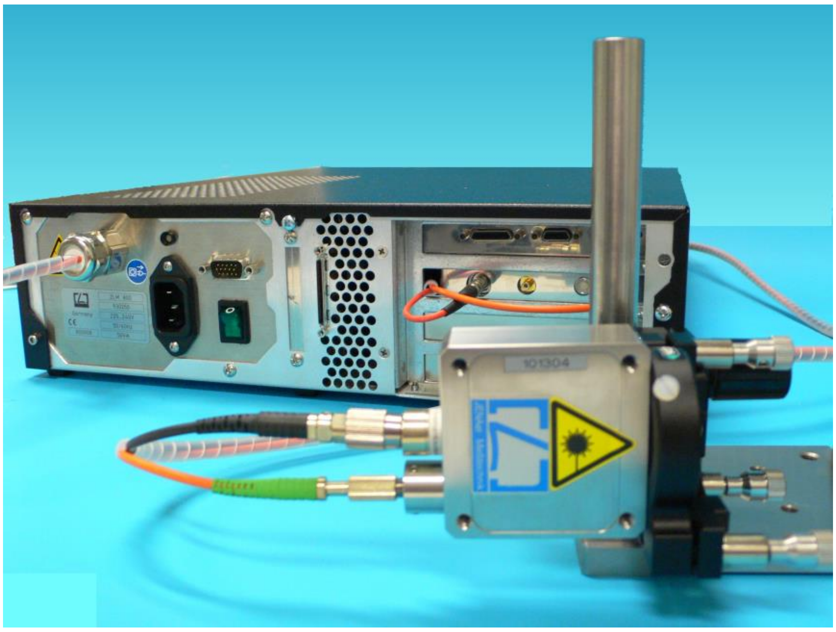
Dual-Frequency Laser Interferometer

ZLM 900 LSI

Manual



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The equipment described in this manual is subject to technical upgrading and other changes without prior notice.

Familiarity with the contents of this manual is imperative for safe operation of your equipment. Therefore study the manual thoroughly before starting up the equipment.

Keep this manual and any other user documentation supplied within reach of the operator.

Modifications and repairs of the equipment may not be carried out by persons other than our own service staff or competent engineers expressly authorized by us.

The ZLM 900 Laser Interferometer is guaranteed by the seller for a period of 24 months from the date of delivery.

The seller expressly disclaims any responsibility for damage to equipment and/or persons which should result from improper use, failure to observe the operating instructions, faulty or negligent handling or natural wear.

Furthermore, the purchase of the equipment is subject to the General Conditions of Sale of JENAer Messtechnik GmbH.

ZLM 900 LSI – content list

1. Safety notes

1.1. Generally notes

Please study the manual thoroughly before starting up the equipment! Additionally information you can get by our service!

☝ Please pay attention to the warnings and hints in this manual!

1.2. Notes on handling HeNe-Gas Lasers

The He-Ne gas laser used in the ZLM is powered by DC from the equipment's power supply unit. Mind the safety precautions common for electrical equipment:

1. Connect the laser to a properly grounded mains socket outlet only.
2. Do not operate the He-Ne laser when the enclosures of laser head and/or power supply unit are open.

The laser used in the ZLM 700 / 800 is a class 2 laser acc. to DIN EN 60825-1:2015-07. No safety goggles are needed, since the low-power radiation (max. 1 mW) is harmless to human eyes. (The eyelid closure reflex protects your eyes against the direct laser beam). There is no fire hazard.
The Laser Interferometer may only be switched on, operated and adjusted by persons who have been authorised to do so and can be proved to have received through instructions on handling and operation.

☝ **Warning !**

Do not leave the Laser Interferometer in unattended operation. Mind the following recommendations:

- Arrange your setup so as not to have the laser beam at eye level.
- Avoid looking into the direct or reflected beam.
- Do not look at the laser beam with optical aids not belonging to the equipment, except your own eyeglasses.
- Do not direct the laser beam at persons.
- Avoid accidental reflections.

☝ **DANGER ! LASER RADIATION !**

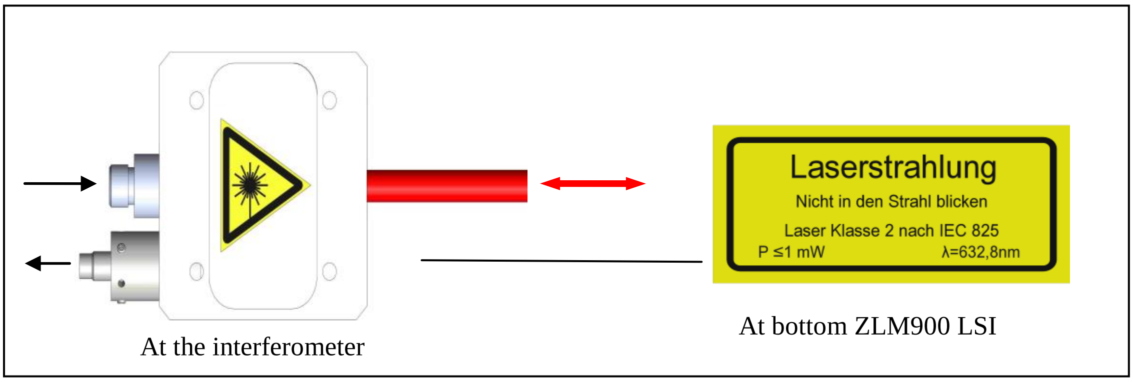
NEVER LOOK INTO THE LASER BEAM,
NOT EVEN WITH ANY OPTICAL AID OR INSTRUMENT !

Laser class 2

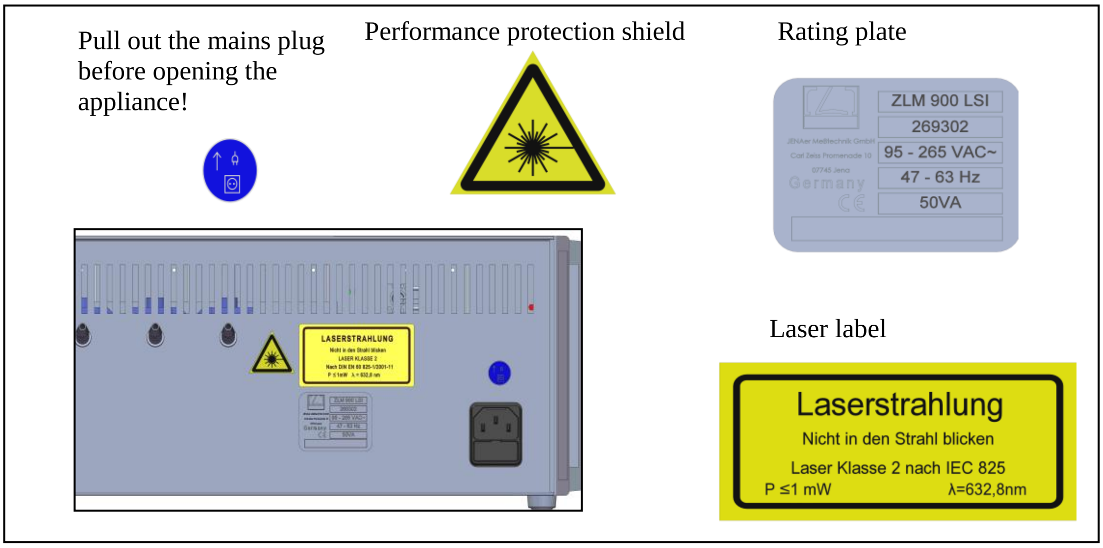
1.3. Instruction and Warning Labels

1.3.1. - European standard and American Standard 95- 265 Volt (47- 63 Hz)

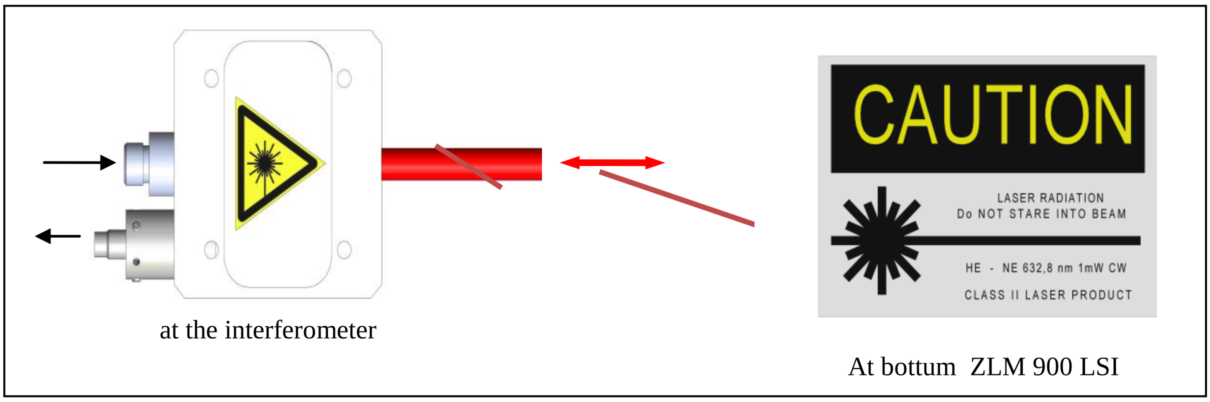
Label on top of electronic unit **ZLM 900 LSI and Interferometer**



Label electronic unit AE 900 LSI – back plane



Amerikanische Norm / 110 Volt



1.4. Notes for electromagnetic compatibility EMI

The measuring unit system corresponds to the regulations of the law over technical terms (Equipment safety law).
The measuring system satisfies the safety regulations for electrical measuring – steering – regulation and laboratory - equipment IEC 1010 – 1.
Electromagnetic compatibility EMI examination was proving:

- The radio interference suppression fulfills the requests EN 55011 class A

- The interference immunity fulfills the requests EN 50082 - 2

To get this condition, this has to be use for the measuring unit system only as agreed. Please following notes and warnings.

The gauge is EG – concurring and is having CE – symbol

Low voltage	2014/35/EU
EMV	2014/30/EU

1.5. Indications for transportation and storage

The measuring system ZLM 900 LSI is delivered in corresponding storage and transportation cases. It is advisable, these to use permanently for storage and further. This way the equipment components are protected. At the transportation intense pushes have to be avoided.
The range of temperature for transport and storage should not be oversteped: > -25°C <75°C.
before installation the equipment must adapt to the room temperature. The measuring system works in range of temperature >10°C <30°C.

2. Components of the ZLM 900 LSI

2.1. Electronic unit AE 900 LSI

Order-No.: 26 93 02 – 5095.026

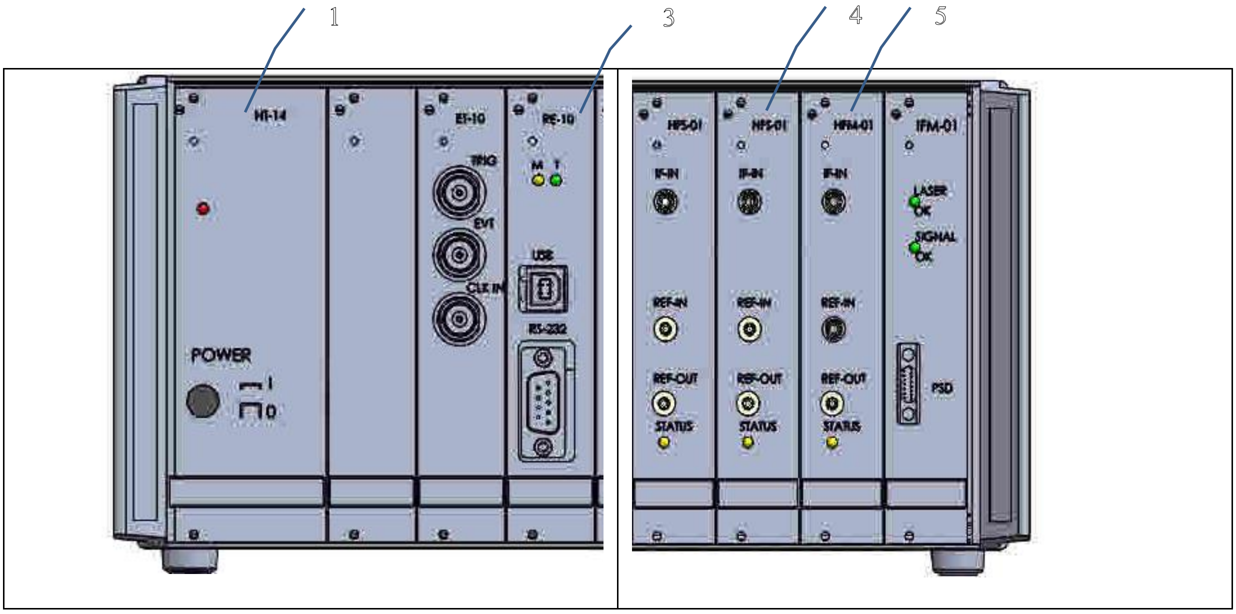


Fig.: 1

<u>Legend:</u>

1) NT-14 power supply with on/off switch
2) ET 10 trigger card
3) RE-10 evaluation card designed for a maximum of 4 counter units
4) HRS -01 High frequency measuring card (slave)
5) HRM -01 High frequency measuring card (master)
6) IFM 01 Interferometer measuring card (laser signals)

2.2. 2.1.1. Rechnermodul RE-10

The RE-10 computer module is the evaluation and PC interface module of the interferometer. It is used for vibration and length measurement of up to four interferometer channels. The board is assigned to a fixed module slot within the supply and evaluation unit, which supplies it with the necessary supply voltages and signal lines. A schematic diagram of the computer module is shown in the following figure 1.

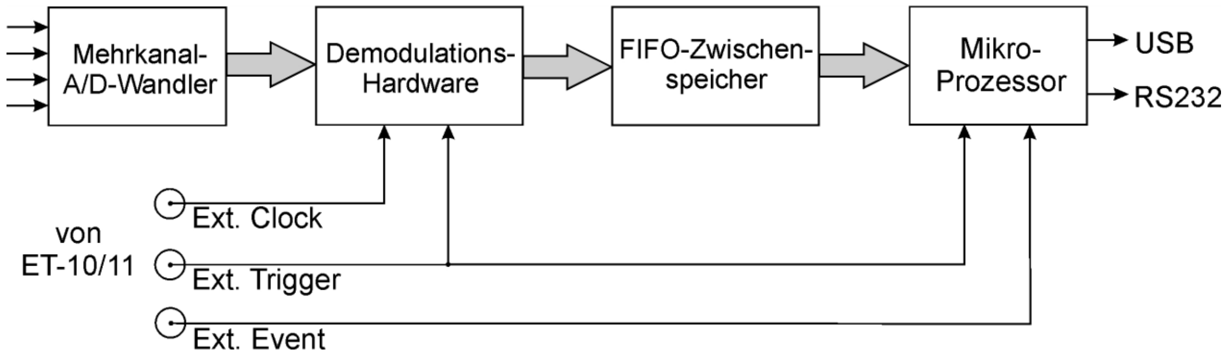


Fig 1: Principle of the RE-10

The RE-10 card can be operated in two working modes, continuous mode or block mode.
In continuous mode, the measured values are output immediately.

In block mode, on the other hand, the measured value acquisition and output are decoupled by the FIFO buffer. This allows much higher sampling rates, but only permits data record lengths that do not exceed the size of the buffer memory.
The sampling as well as the start and stop of a measurement can be triggered by external signals. This is described in more detail below in the section on the ET-10/ET-11 trigger card.

The counting range of the card is sufficient for measuring object movement in the range of ±160 m. The microprocessor of the RE-10 card is responsible for the necessary signal pre-processing, ensuring the following functions:• Auslesen der Messwerte aus der Demodulationshardware bzw. dem Zwischenspeicher

- Pre-processing (filtering) of the measured values
- Query of the current environmental measured values from an existing environmental measurement card
- Output of data via USB or RS232 interface
- Communication with other cards in the system

The front view and the pin assignment of the RE-10 are shown in figure 2.

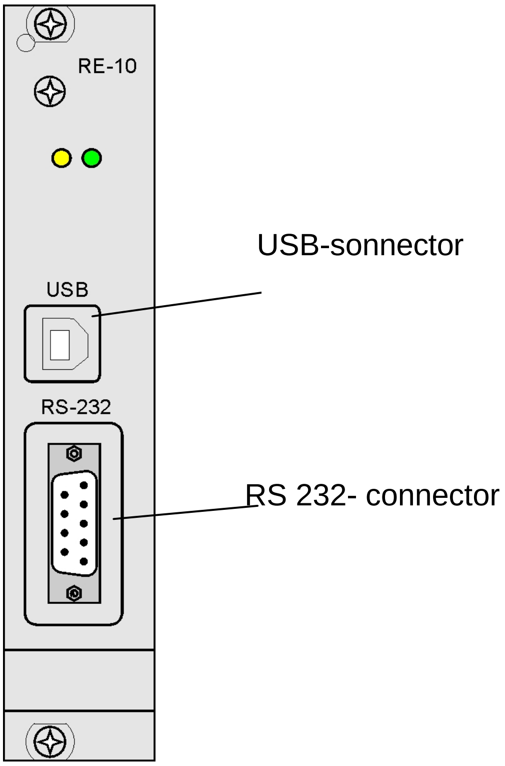


Figure 2: Front view of the RE-10 card and pin assignment

2.1.2. External trigger card ET-10

The ET-10 and ET-11 are also plug-in cards for the evaluation unit of interferometers. They provide galvanically decoupled trigger and clock inputs for the RE-10 computer card. In addition, the ET-11 can be used to synchronise the AD converter clocks of several RE-10s.

The trigger card is available on request in a special high-speed configuration, whereby the maximum trigger frequency and the delays have been optimised at the expense of the input voltage tolerance (5V TTL level only).

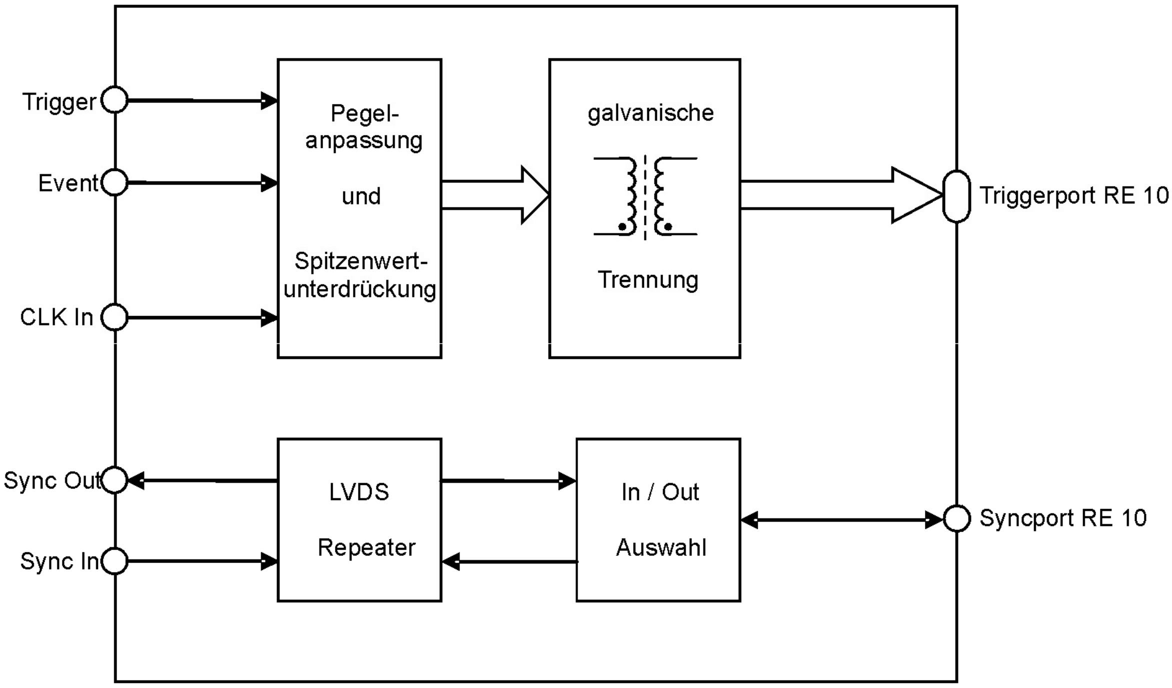


Fig 3: Prinzipal of ET-10 / ET-11

Description of the inputs and outputs

The location of the sockets on the front panel is shown in figure 4.

1. trigger input (TRIG)

With the trigger input, a measurement or the recording of a data block can be started and, if necessary, also stopped again.

2 Event input (EVT)

The event input is used to trigger the measurement of preprocessed samples. A trigger signal at this input causes the microprocessor to generate a processed sample with the set filter chain.

3. clock input (CLK In)

The clock input triggers the measurement of an unprocessed sample and thus sets the sampling rate.

The trigger and clock inputs act directly on the demodulation hardware and thus offer very low latency times.

The polarity of the trigger pulses and the exact operating mode can be set via the measuring software or via API commands.

All three inputs are led out on the front via BNC sockets. 4.

4 Sync sockets of the ET-11

The inputs and outputs Sync In and Sync Out of the ET-11 are used to synchronise the data of two RE-10s. One RE-10 is configured as master and one RE-10 as slave. The Sync Out of the ET-11M of the master unit must be connected to the Sync In of the ET-11S of the slave unit. A corresponding cable is included with the purchase of the ET-11. The direction selection on the ET-11 is done at the factory. The master card is labelled ET-11M, the slave card ET-11S.

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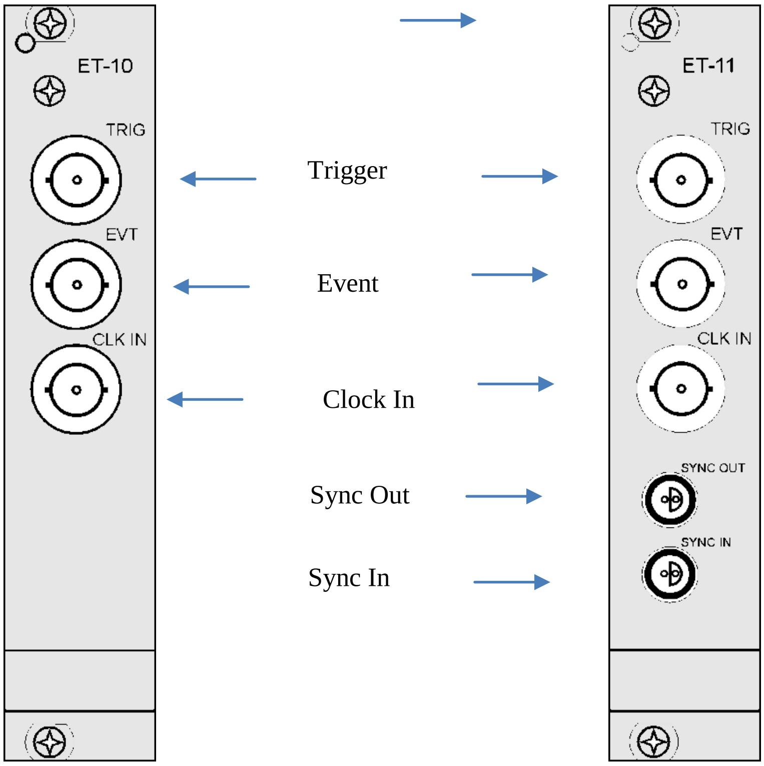
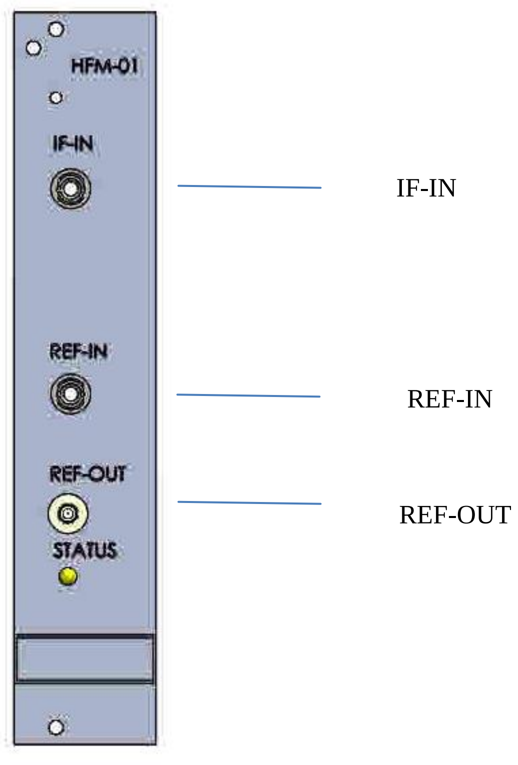


Figure 4: Front sides of the trigger cards ET-10 / ET-11

2.1.3. High frequency measuring card (master) - HFM-01



IF - in	Connections of the gradient fibre optic cables of the individual interferometer axes (1x per rack/axis)
Ref - in	Connection of the gradient optical waveguide of the reference beam of the laser measuring head
Ref - in/out	Connections of the cables for the reference signal of the laser measuring head of the individual measuring cassettes

The card prepares the laser signals for the counter card of the ZLM laser systems. The optical signals are converted and electronically processed so that the RE - 10 evaluation card can process them in the counter. The signals of the interferometer input (IF-IN) and the values of the reference signal from the laser (REF-IN) are measured, resulting in a SIN/COS signal.

The resulting SIN/COS signal has a peak-to-peak value of +/-1.5V after conversion. The difference frequency of the two laser modes is approx. 640 MHz.

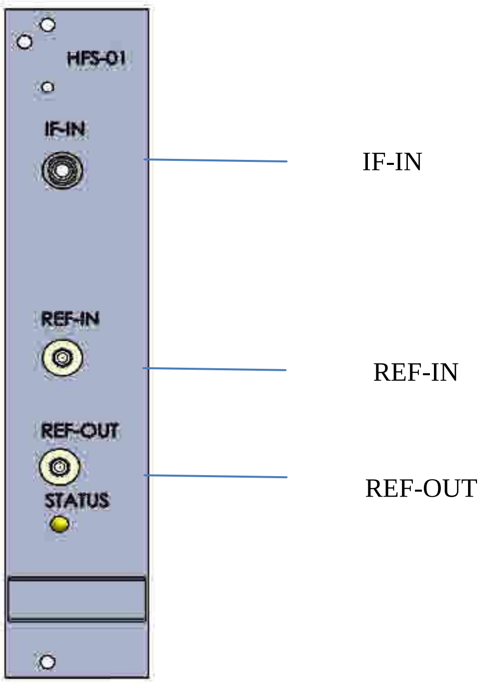
Furthermore, the measuring card is supplied with a supply voltage of +/-5V and +/- 12V.

The reference channel (Ref-Out) has a signal strength of approx. -25 to -20 dBm.

The status lamp indicates whether laser light is present at the input (REF- In & IF-IN) in the laser-specific average wavelength of c. 632.8nm.

Dimensions of the board: width of 5HP and a height of 3U and depth of 160 mm

2.1.4. High frequency measuring card (Slave) - HFS-01



IF - in	Connections of the gradient fibre optic cables of the individual interferometer axes (1x per rack/axis)
Ref - in	Connection of the gradient optical waveguide of the reference beam of the laser measuring head
Ref - in/out	Connections of the cables for the reference signal of the laser measuring head of the individual measuring cassettes

The card prepares the laser signals for the counter card of the ZLM laser systems. The optical signals are converted and electronically processed so that the RE - 10 evaluation card can process them in the counter. The signals of the interferometer input (IF-IN) and the values of the reference signal from the laser (REF-IN) are measured, resulting in a SIN/COS signal..

The resulting SIN/COS signal has a peak-to-peak value of +/-1.5V after conversion. The difference frequency of the two laser modes is approx. 640 MHz..

Furthermore, the measuring card is supplied with a supply voltage of +/-5V and +/- 12V..

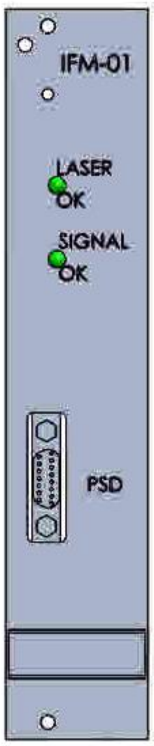
Der Referenzkanal (Ref-Out) weist eine Signalstärke von ca. -25 bis -20 dBm auf.

The coupling between master and slave is achieved by serially connecting the REF-OUT (master) with the subsequent REF-IN socket of the slave card. If you have more than one slave, the REF-OUT socket of the slave is connected to the REF-IN socket of the following slave axis.

The status lamp indicates whether laser light is present at the input (REF- In & IF-IN) in the laser-specific average wavelength of c. 632.8nm.

Dimensions of the board: width of 5TE and a height of 3U and depth of 160 mm

3. 2.1.5. Interferometer card Mess – IFM-01



PSD

Laser measuring head	Measuring head cable to the laser measuring head (for screen display of the quality of the adjustment of the reference and measuring beam)

The provided laser signals (such as the status signal of the internal laser control and the calibration voltages of the quadrants) are processed in the card. The quadrant signals included with dual-frequency laser systems are used for the basic alignment of the laser to the measurement object (mirror or retroreflector).

The laser alignment is shown in the menu laser alignment in the measuring software:

LSI – Interferometer 401
Order-No.: 26 93 02 – 5005.424

Fig.: 2

Triple reflector 9mm
Order-No.: 26 93 02 – 5003.524
Dazu Justierblende

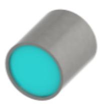


Fig.: 3

Angular reflector 9mm
Order-No.: 26 93 02 – 5003.624

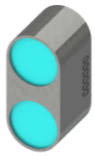


Fig.: 4

3.1. Mounting accessories

Magnetic base 506
Order-No.: 26 02 98 – 3000.128

Rod 140
Order-No.: 26 02 97 – 9900.128

Fig.: 5

Tiltable holder 531
Order-No.: 269302 – 4040.725

Fig.: 6

Automatic environmental compensator AUK
Order-No.: 26 93 02 – 5017.024

Fig.: 7

Surface temperature sensor 2
Order-No.:26 93 00 – 3904.824

Fig.: 9

Magnethalter
Order-No.:26 93 92 – 3900.424

Fig.: 10

4. Applications / Functions

4.1. Applications of the ZLM 900 LSI

The ZLM 900 LSI dual-frequency laser displacement measuring system is an optical length measuring device that enables the measurement of lengths up to 20m with a displacement resolution of 2.5nm (optionally 1.25nm or 0.63nm) and a maximum measuring speed of up to 4m/s (optionally up to 12m/s).

In addition, geometric and kinematic measurement variables derived from the length, such as speed and acceleration, angle and flatness, can also be determined.

ZLM 900 LSI differs from ZLM 700 / 800 in that the laser tube and evaluation unit are combined into one unit. The laser light is brought to the interferometer via fibre optic cable. This eliminates the need for beam adjustment between the laser measuring head and the interferometer (see Fig.: 11).

The ZLM 900 LSI is mainly used as a calibration system in the machine tool industry, coordinate measuring technology and as a laboratory device for various measuring tasks.

The modular design allows the user to configure the system according to his measuring task by combining system components. A wide selection of different interferometers, reflectors and associated mounting and adjustment units are available to the user.

As a multi-axis system, the ZLM 900 LSI is used in fast precision positioning systems. As a dynamic system of the highest resolution, it is used to determine the positional deviation of the measurement objects.

The measuring accuracy of the ZLM 900 LSI depends on the detection of the ambient conditions (air temperature, air pressure, air humidity as well as material temperature). These parameters are required to determine the air refractive index or the material expansion.

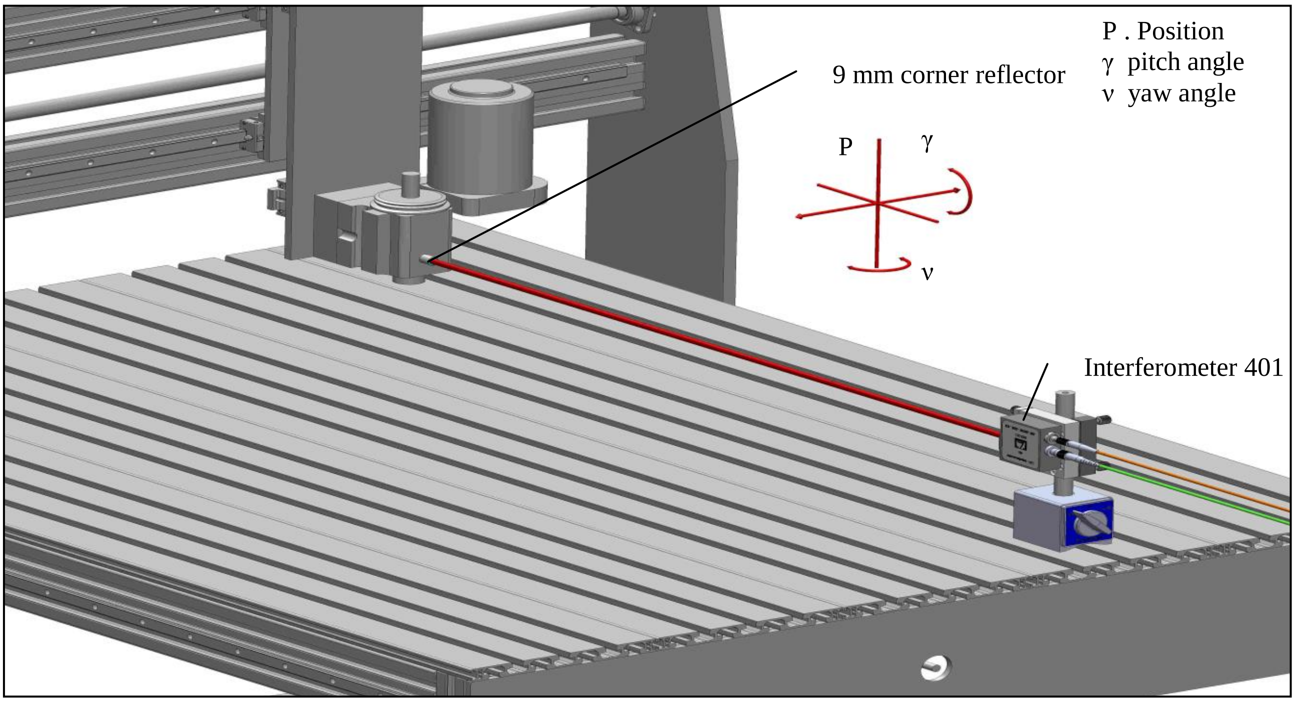


Fig.: 11

4.2. Functional principle of the entire system

The dual-frequency laser displacement measuring system ZLM 900 LSI consists of the 3 main assemblies Electronic unit with laser tube and evaluation unit, optics modules and notebook (Fig. 12 and 13).

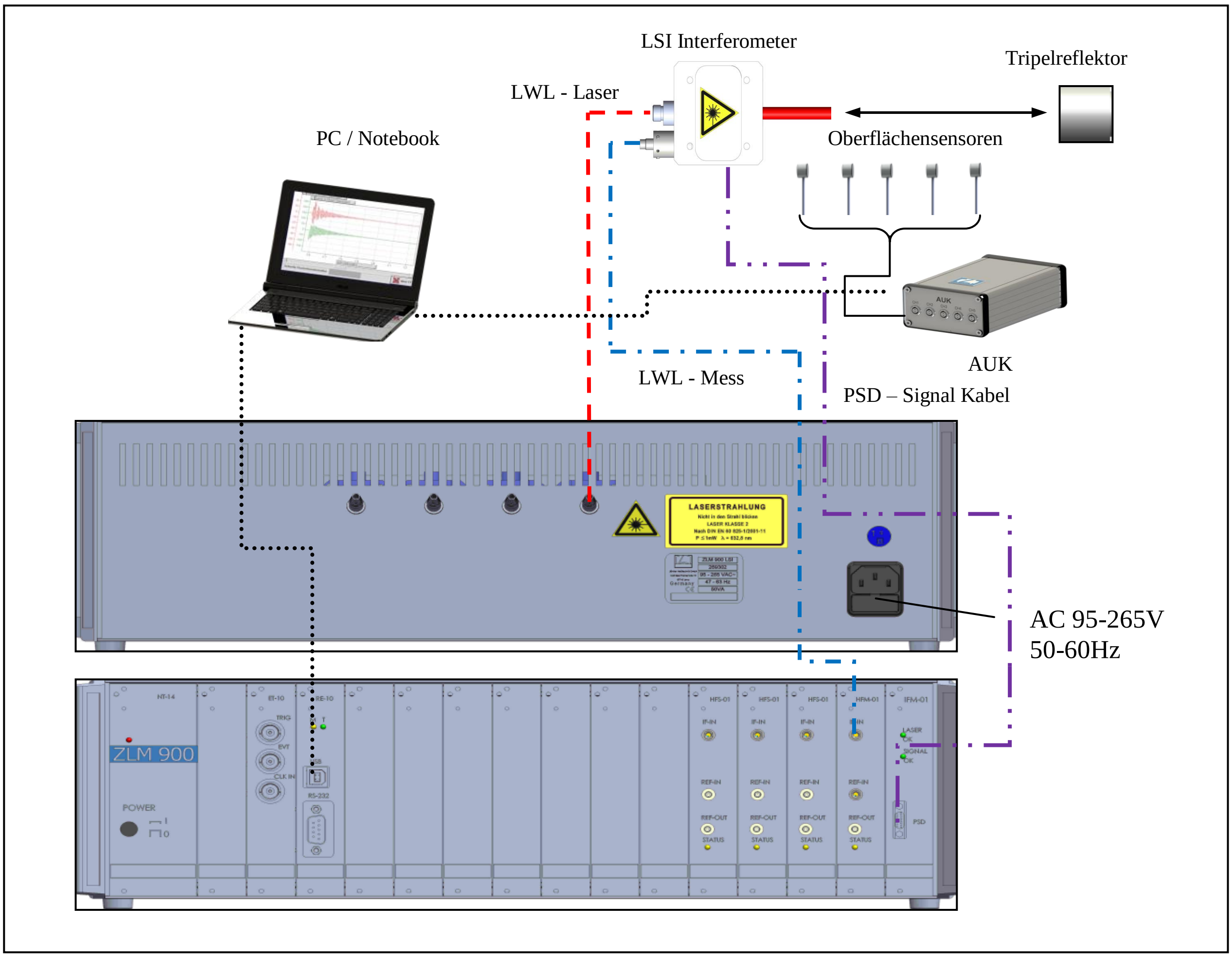


Fig. 12 : Basic structure of the dual-frequency laser displacement measuring system ZLM 900 LSI

The laser measurement system exploits the property of the interference capability of coherent laser light. In the laser tube, the frequency-stabilised He-Ne laser generates a laser beam consisting of two orthogonally polarised oscillation modes with the frequencies f1 and f2 with a beat frequency of f1 - f2 = 640 MHz (Fig. 14). The orthogonally polarised laser light is guided to the corresponding interferometer by polarisation-preserving single-mode fibre optic cable.

The different types of interferometers in the modular system are explained on pages 9 and 10.

The collimator in the interferometer shapes the laser beam to a diameter of 4 mm. This ensures a measuring length of up to 20 m (longer measuring lengths are achieved by using beam expansion systems).
In the interferometer, the two frequencies are separated at the polarisation-splitting layer of the interferometer due to the different oscillation planes. The measuring beam divided in this way reaches a measuring reflector and a reference reflector. Only light of frequency f1 reaches the measuring reflector and only light of frequency f2 reaches the reference reflector. The reflected light components are recombined in the interferometer and reach the "LWL-Mess" input of the evaluation unit via optical fibres.

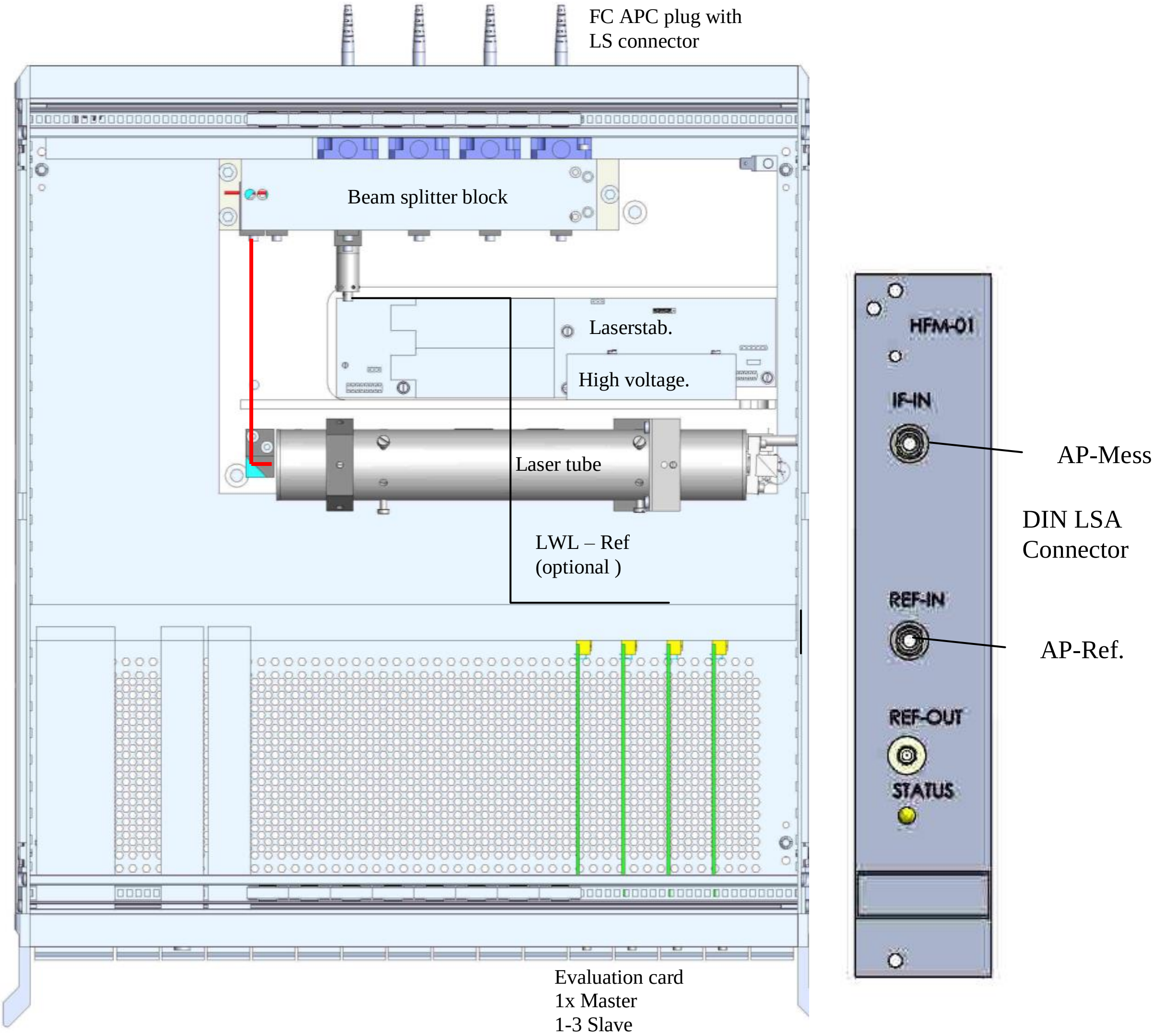
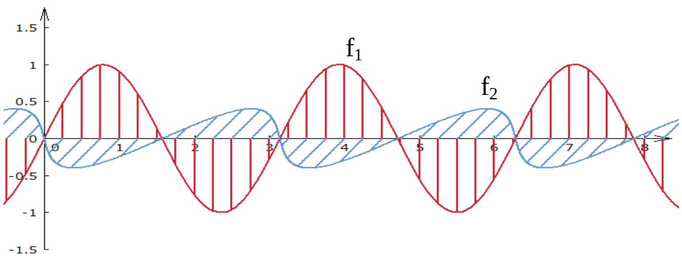


Fig.: 13

Internally in the electronics unit, a part of the laser light with the beat frequency 640 MHz is guided via optical fibers to the input "LWL-Ref".
At both inputs, the beat signal of 640 MHz reaches each one avalanche photodiode AP_{Mess} and AP_{Ref}

Fig. 14:
The plane of vibration of f_1 is vertical and the plane of oscillation of f_2 is horizontal in the laser beam



If the measuring reflector is not moved, APMess detects f1 - f2 = 640 MHz. If the measuring reflector is moved, the reflected partial beam of frequency f1 experiences a Doppler shift ± df1. Accordingly, APMess now detects a difference frequency f1 - f2 ± df1, shifted by the Doppler frequency, as the measuring frequency (+ df1 or -df1 depending on the direction of movement of the measuring reflector).

Both, reference frequency f1 - f2 and measuring frequency f1 -f2 ± df1, are compared with each other in the high frequency section of the evaluation unit. The result is the frequency shift ± df1 generated by the Doppler effect, which is a measure of the desired shift of the reflector. The evaluation electronics form a logical sequence of square-wave signals from the Doppler shift. The measured values are calculated from this with the aid of the notebook and the associated software.

Operating principle interferometer

3.1 Interferometer with triple mirror reflector

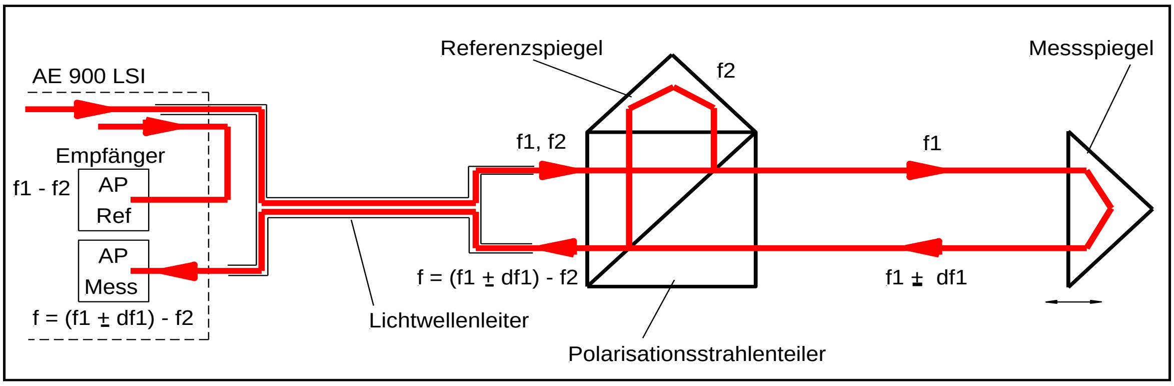


Fig.: 15

Only the horizontally polarized mode is reflected at the reflection layer of the polarization splitter, the vertically polarized part is transmitted. The triple reflectors reflect the light in parallel. The reflected partial beams are mixed again after passing through the reflection layer of the pole splitter and interference occurs. The pole-splitting reflective layer thus forms the "0 - point" of the measuring system. When the measuring mirror is moved, Doppler shift occurs between the fixed reference channel and the moving measuring channel.

3.2 Interferometer with plane mirror reflector

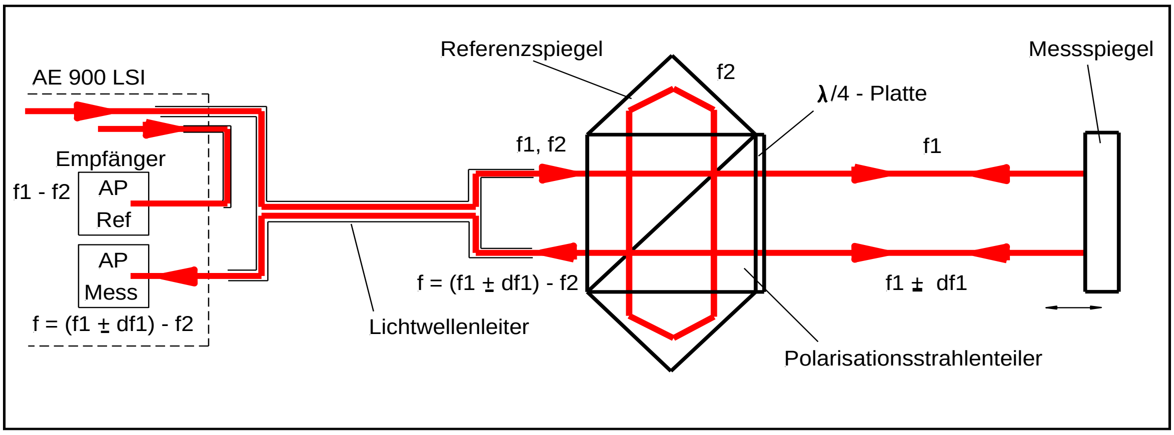


Fig.: 16

A plane mirror serves as the measuring reflector. This reflects the laser beam back into itself. The polarization of the laser beam must be rotated by 90° so that it does not pass through the pole-dividing layer of the polarization-dividing cube again but is reflected. This is done by the λ/4 - plate. The second triple reflector shifts the beam parallel exactly as with the reference beam. After renewed reflection at the measuring mirror, the polarization direction is again rotated by 90° by the λ/4 - plate, so that the returning beam is transmitted and can interfere with the reference beam. With the plane mirror interferometer, the light path in the measuring channel is doubled. Consequently, the resolution increases by a factor of 2.

e.g.: triple mirror interferometer → resolution 2.5nm

plane mirror interferometer → resolution 1.25nm

3.3 Angular interferometer with triple reflectors

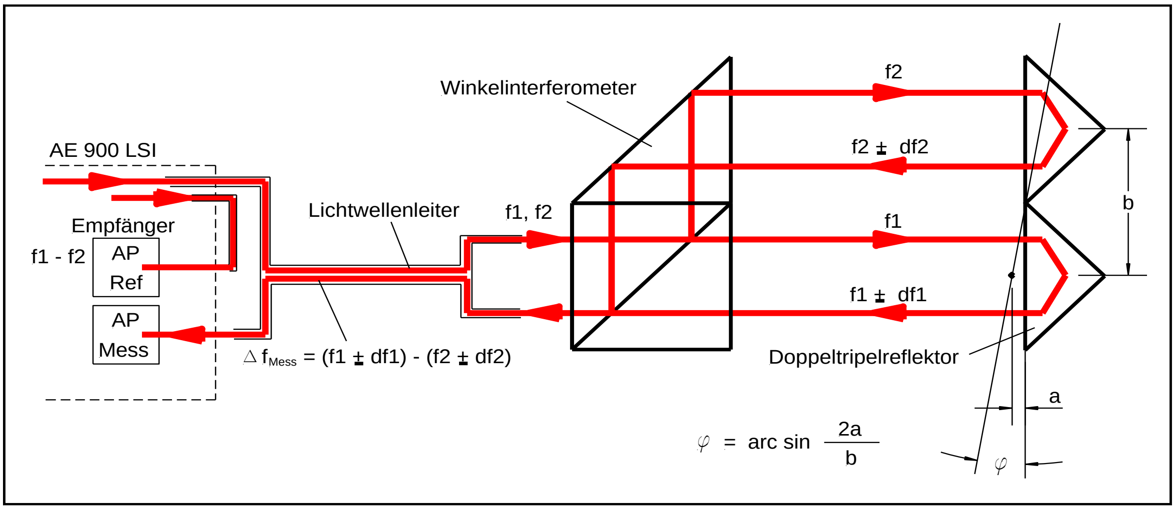


Fig.: 17

The two triple prisms are rigidly connected to each other. Instead of the reference channel, this creates a second measuring channel. When the triple prisms are tilted, a path difference occurs between the two channels. If the double triple reflector is moved without tilting, there is no path difference. The measured value remains at "zero".

For small tilt angles, the approximation is:
(see Fig.: 17)

$$\boxed{\varphi = \arcsin \frac{2a}{b}}$$

3.4 Single beam - interferometer

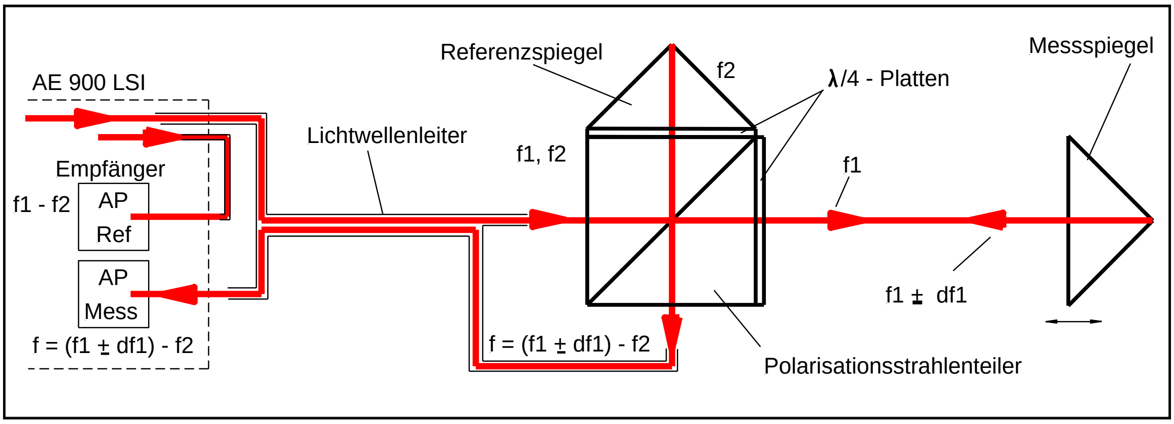


Fig.: 18

In the single-beam interferometer, the laser beam hits the center of the triple prisms. As a result, both beams are not displaced parallel, but run exactly back into each other. The polarization directions of the reference beam and the measurement beam are rotated by 90° by the two λ/4 plates, so that the two channels are reflected by 90° and converge again and interferometer measurement method.

3.5 Combined position and angle interferometer (Type 401)

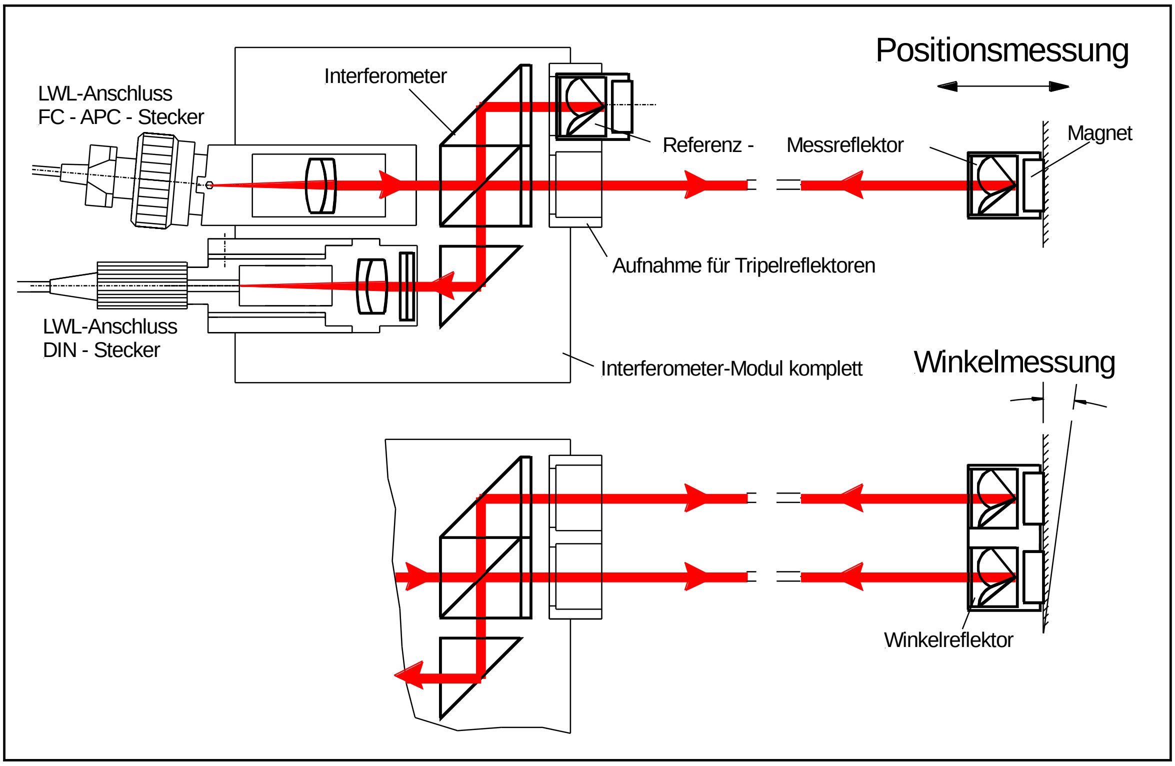


Fig.: 19

3.6 Position measurement

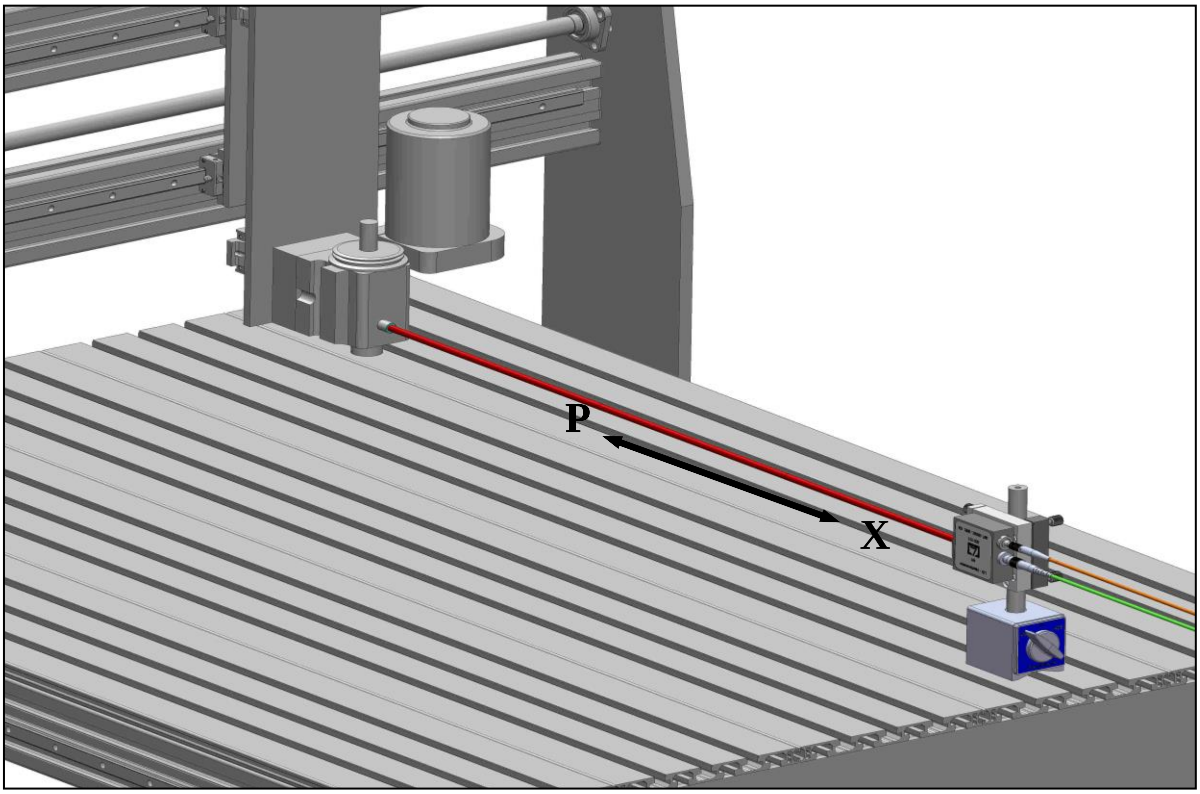


Fig.: 20 shows the position measurement on a milling machine

3.7 Procedure for measurement setup and adjustment

- Determine the distance to be measured.
- Move the quill of the machine to the starting point of the measurement.
- Mount the interferometer (with tilt holder for adjustment).
- Couple light tube from AE 900 LSI with interferometer using FC APC connector (Fig.: 1).
- Switch on AE 900 LSI, laser beam must emerge from interferometer.
- Align the interferometer so that the laser beam impinges on the quill parallel to the direction of movement of the X axis.
- Attach the triple reflector to the quill at the height of the emerging laser beam using a holding magnet. It is advantageous to use the auxiliary diaphragm belonging to the triple reflector. This allows the triple reflector to be aligned exactly in the center of the beam.

  - **Position alignment at the starting point by parallel displacement of the triple reflector.** (Note: if the triple reflector is firmly connected to the quill, e.g. by screwing, the interferometer must be moved in parallel.)

- Move the quill to the target point of the measurement. Deviation of the laser beam from the center of the triple reflector means that the laser beam is not yet adjusted exactly parallel to the direction of movement. In this position, the deviation can only be corrected by tilting the interferometer with the tilt holder. The triple reflector should be as perpendicular as possible to the incident laser beam. This can be seen from the reflection from the entrance surface of the triple reflector. This should be close to the light exit window of the interferometer, but not absolutely exact because of **Feedback*.**

  - **Establish position alignment at the target point by angular tilting of the interferometer.**

- The position correction between start and target point must be repeated 2 to 3 times, then the beam path is usually sufficiently adjusted.

*Feedback:

If even a small part of the light power of the laser beam is exactly reflected back into itself, the control will fail due to feedback. This case can occur especially with the use of plane mirror interferometers, if absolutely exact adjustment is made. Normally, due to the tolerances of the components and residual errors in the adjustment, the reflecting surfaces are slightly tilted. The occurrence of feedback can be seen by the fact that the display "Laser OK" flickers red or remains completely red.
If feedback should occur, then it is to be stopped by a slight tilting of the causing component.

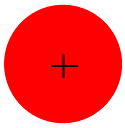
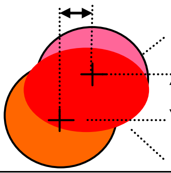
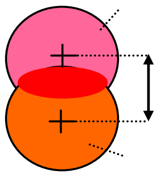
The "Laser OK" display must no longer be red!

3.8 Checking the adjustment state of the measuring system

Measuring beam and reference beam must be brought to interference, therefore they must overlap. (see Fig. 21) The degree of overlapping is important for the signal formation in the electronic evaluation unit. At the optical fiber output, the overlap can be observed by projecting the laser beam onto a piece of white paper. The coincidence of the measuring and reference beams can be detected by alternately covering the measuring beam path and comparing it with the reference beam path.

Fig.: 21 Quality of the overlap

- **Overlapping must be present in the entire measuring range!**

 complete coverage of measuring- and reference beam	Ideal case! Software display at the bottom right of the screen shows "light signal OK Evaluation unit (PCI card) LED is green
 Measurement beam Beam displacement Reference beam partly overlapping of measuring and reference beam	At slight misalignment (up to 20%) the function is still guaranteed. Software display on the bottom right of the screen shows "Light signal OK Evaluation unit: (PCI card) LED is green
 Measurement beam Beam displacement Reference beam insufficient overlapping of measuring and reference beam	No function! Software display at the bottom right of the screen shows "no light signal" on a red background Evaluation unit: (PCI card) LED is red

The total light power at the interferometer output must be at least
20 µW, 50% from the reference channel and **50% from the measuring channel**.
If the coverage is present, the optical fiber can be plugged between the interferometer and AE 900 LSI (DIN connector) and the measurement readiness is established.

The application of the notebook and the software for the ZLM 900 LSI can be found in the Software - Description.

3.9 Cosinus error

For the measuring axis, the associated laser beam must be adjusted **parallel to the direction of movement** in which the measurement is to be made.
Deviations of the direction of the laser beam to the direction of movement of the measurement axis result in the "cosine error". Since the displacement of the reflector (whether plane mirror or triple reflector), or more precisely its centrally symmetrical point, takes place with the machine along its axis direction, the laser measurement distance x_L appears smaller than the displacement path x_M. It is the context:

$$x_L = x_M \cdot \Delta\rho \quad (< x_M)$$

The resulting "cosine error" is derived from it as an approximation and the error second order:

$$\Delta x_{cos} = x_L - x_M = x_M \cdot \Delta\rho^2/2$$

The following table 2 shows for different alignment $\Delta\rho$ (in arcsec or mrad) an overview of the misalignment (in mm/m) and the two resulting effects.
These are the measurement error $\Delta x/x$ and the beam offset V for the returning beam relative to its ideal direction. For example, a deviation of the parallelism of the axes from 0.5mm/m generated a relative measurement error of $\Delta X/X = 0.12 \cdot 10^{-6} = 0.12 \mu m/m$. The resulting beam offset V of 1mm/m of measurement path can create problems with the signal formation if there is a larger displacement of measurement mirror. One measurement may no more be possible. (Fig. 28)

angular deviations $\Delta\rho$		corresponding alignment error	resulting effects	
"	mrad	mm/m	measurement error $\Delta x/x$	beam offset V mm/m
412	2	2	$-2 \cdot 10^{-6}$	4
206	1	1	$-0,5 \cdot 10^{-6}$	2
103	0,5	0,5	$-0,12 \cdot 10^{-6}$	1
21	0,1	0,1	$-0,005 \cdot 10^{-6}$	0,2
10	0,05	0,05	$-0,001 \cdot 10^{-6}$	0,1

Table 2: Effects of misalignment on measurement error ("cosine error")

3.10 Establishing readiness for measurement:

- **Lasee stability must be present:**

  Control - LED red/green "Laser" (Fig.: 1) must be switched from **red** to **green**.
  Red means "heating". Heating time approx. 15 to 20min
  (On the monitor on the bottom right "Laser OK" must not be **red**).

- **Overlap must be guaranteed**

  Control - LED red/green "Measuring signal" (Fig.: 1) must not be **red**, but **green**.
  (On the monitor on the right under "Light signal OK" must not be **red**).

If these requirements are met, the measurement can be started.
The measurement procedures are described in the software description.

4.3. AUK Environmental Sensor

Environmental influences can be compensated in two ways:

1. "Manual" input of the current data for air temperature, humidity and pressure and the material temperature of the testpiece via the PC keyboard.
   This requires regular reading of separate instruments and regular updating of the data entered. In a measuring room, this should be done at least once every day, and in production environments several times a day, in order to obtain a measuring accuracy of **2 µm/m.**

2. Use of the AUK 500 Automatic Environment Detector (*269302-5017.024)* with sensors for air temperature, air pressure and humidity, and facilities for connecting up to five material temperature sensors. The data are automatically updated at an inquiry rate of < 1 Hz. Unless coarse mistakes are made when setting up the Laser Interferometer configuration, (if, e.g., Fige's comparator principle is maintained), a measuring accuracy of **0.9 µm/m** can be achieved.

4.3.1. Determining the refractive index of the air

In order to reliably and constantly ensure the high measuring accuracy of the ZLM 700/800 Dual-Frequency Laser Interferometer in non-vacuum operation, it is necessary to continuously record the refractive index of the ambient air and to correct the laser wavelength accordingly. Basically, this can be achieved by three methods:

1. Reading the air temperature, air pressure and humidity off classical analogue instruments, and entering these data via the PC keyboard. The intervals at which readings must be taken depend on the rate at which the air parameters change. This method is the simplest one and will be sufficient in many applications.

   Uncertainty of measurement: 2 µm/m

2. Use of high-resolution sensors (*Parameter method*). In connection with a PC, the sensors automatically sense the temperature, pressure and humidity of the ambient air with a high precision, so that these parameters are constantly updated. As a rule, it is also possible to connect special material temperature sensors for automatically monitoring the temperature of the testpiece or of the entire measurement setup.

   Uncertainty of measurement: 0.6 µm/m

3. Installation of a refractometer (r*eference method*). This is the most expensive method. There is a wide variety of versions to suit the specific application, ranging from "simple" wavelength tracking refractometers to complex multi-chamber vacuum refractometers. They all have in common that refractive index is always measured against an external reference distance and that an extra interferometer channel is needed.

   Uncertainty of measurement: 0.3 µm/m

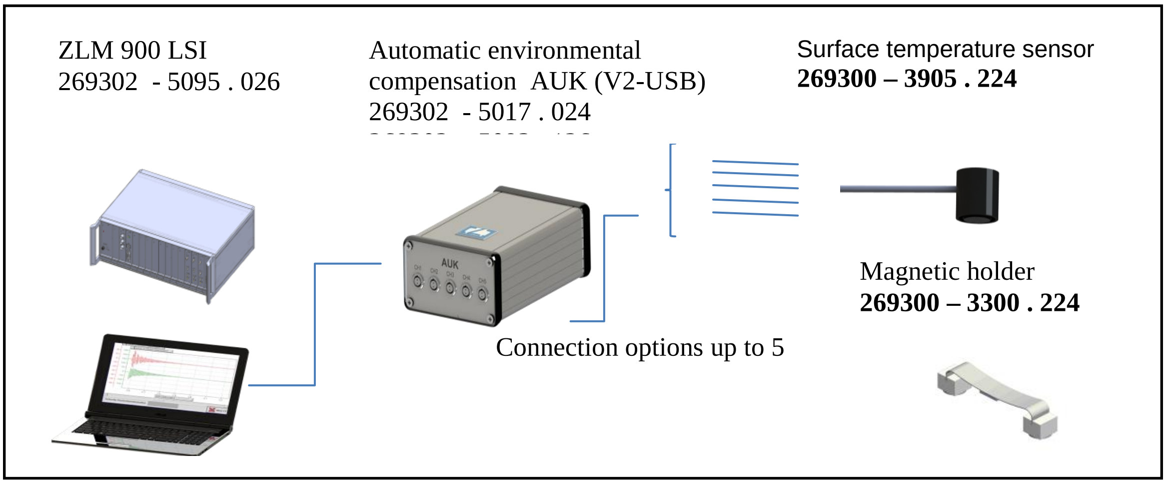
Once the refractive index of air has been identified by one of the three methods, the laser wavelength in air is computed via the equation

$$\lambda = \lambda_o / n$$

where λ : wavelength of laser light in air
λ_o : wavelength of laser light in a vacuum
n : refractive index of air

4.3.2. Design and Mode of Operation

The AUK Environment Sensor operates by the parameter method. The sensors integrated in the unit continuously measure air temperature, air pressure and humidity with high precision and transmit the measured data to the PC. Via the ***Edlen formula*** /1/ the PC determines the refractive index of the ambient air, and from this the current wavelength of the laser radiation.



Edlen's formula applies to humid "standard air" (containing, in addition to nitrogen and oxygen, a content of 300 ppm of carbon dioxide):

$$n = 1 + (2{,}8793 \cdot 10^{-7} \cdot P) : (1 + 0{,}003671 \cdot T) - (3{,}6 \cdot 10^{-8} \cdot P_w)$$

B: *Refractive index of „standard air“*
P: *Atmospheric pressure in hPa*
T: *Air temperature in °C*
P_w: *Water vapour partial pressure in hPa*
100% rel. air humidity at 20°C: 23hPa

Given the following conditions, which are **typical for a measuring room**,

T = 20°C ± 1K P = 1013 hPa ± 10hPa F = 50% ± 20%

the Edlen formula yields a mean refractive index for the measurement room air of

$$n = 1.0002712 \pm 4 \cdot 10^{-6}$$

The necessity to constantly correct the refractive index is obvious from the amount of variation in refractive index.

The table below shows, for specified measurement lengths and any variations of the air parameters, the amount of apparent length change measured with the laser interferometer as a function of the changing air parameters.

Parameter	**Deviation from measured value**	
Air temperature	- 0.92µm/m/K	$(dn/dT \approx -0.92 \cdot 10^{-6} K^{-1})$
Atmospheric pressure	0.27µm/m/hPa	$(dn/dP \approx +0.27 \cdot 10^{-6} hPa^{-1}$
Air humidity	0.01µm/m/% rel. humidity	$(dn/dP_w \approx -3.6 \cdot 10^{-8} hPa^{-1})$

4.3.3. The Influence of Air Pollutants

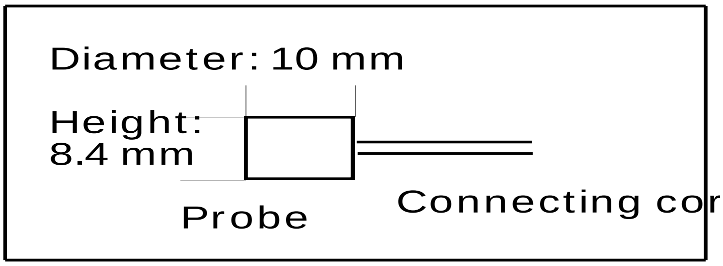
The parameter method assumes a standard composition of air. In industrial use, however, the ambient air may contain considerable admixtures of other gases, which are not allowed for by the AUK Environmental Sensor. In order to compute the change in refractive index in such cases, the following table specifies, for the most important gases, the concentration in air that will change its refractive index by $1 \cdot 10^{-7}$:·

	Specific refractive index n - 1 $(\cdot 10^{-4})$	Concentration in air required for $dn = 1 \cdot 10^{-7}$ in ppm
Air	2.72	-
Carbon monoxide	3.2	2100
Carbon dioxide	4.2	680
Sulphur dioxide	6.3	280
Hydrogen cyanide	4.0	780
Ammonia	3.5	1300
Propane	10.3	130
Butane	12.9	98
Octane	23.0	50
Benzene	15.8	77
Ethanol	8.1	190
Acetone	10.2	130
Ethyl acetate	13.0	97
Tetrachlorethylene	18.7	63
Freons F22	7.3	220
F12	10.3	130
F1281	12.0	110

The values specified apply to an air temperature of 20 °C and an atmospheric pressure of 1013 hPa.

4.3.4. Surface Temperature Sensors

In practice, the limit of the uncertainty of measurement is not only determined by the uncertainty of refractive index measurement.
In order to avoid faulty measurements, it is also necessary to exactly know the temperature of the testpiece, or the temperature distribution throughout the measurement setup (thermal expansion coefficient of the materials!). Therefore, the AUK Environmental Sensor also has connection facilities for up to five material temperature sensors (surface temperature sensors). They precisely measure the temperatures on smooth, plane contact surfaces of technical components with a specific thermal conductivity of better than 10 $Wm^{-1}K^{-1}$.



The sensors are delivered in series with cable lengths of 5 m. Other lengths will be supplied on request. The sensors are hermetically sealed and will therefore withstand rough conditions in production environments.
The sensors are offers with screw-on, magnetic or adhesive holders for fixation to the testpiece.

4.3.5. Dynamic behaviour

The dynamic behaviour depends on the specific conditions of the measurement. The time percentages specified are guideline figures only and refer to a testpiece of steel with a thermal conductivity of 50 $Wm^{1}K^{-1}$.

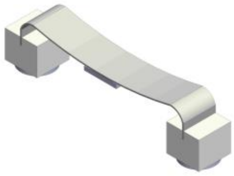
time percentages	T/50	T/90	T/95	T/98
(in sec)	3,2	7,8	12,4	30

On request, the sensors can be supplied with a manufacturer's certificate or with a certificate of the German Calibration Service (DKD) or PTB. The measurement error specified does not include any user-specific error influences (thermal conductivity of the testpiece, heat transmission conditions at the point of contact between sensor and testpiece).

4.4. Scope of Equipment Supplied, Order Numbers

AUK Environmental Sensor 269302-5053.226	

Supplement to AUK: Material temperature sensor
(Material compensation)

Surface sensor 2 269300-3904.824	
Magnetic holder 2 269300-3900.524	

4.4.1. Technical specification

AUK Environmental Sensor

Measuring range

Air temperature	10 °C...40 °C
Atmospheric pressure	800 hPa...1200 hPa
Air humidity	10 %....90 % rel.humidity
Sensor reading cycle	1 s
Measurement uncertainty of individual components	
Air temperature	100 mK
Atmospheric pressure	0.4 % of the measuring range
Air humidity	5.0 % rel.humidity
Measuring inaccuracy referred to the measuring distance	1.5 µm/m

Surface temperature sensor

Measuring range

Type OF 040050	-20 °C...+ 40 °C
Type OF 060050	0 °C...+ 60 °C
Sensor reading cycle	1 s
Measuring inaccuracy	100 mK

Literature

/1/ Edlen,B.: The Refractive Index of Air.
Metrologia 2 (1966), 71 - 80

3.11 Electronics unit ZLM 900 LSI / laser tube / interferometer

errors	causes	action
Laser doesn't ignite	- fuse defect - power supply defect - high voltage defect - aging laser tube - wrong line voltage	- inform customer service - inform customer service - inform customer service - inform customer service - right line voltage
LED remains permanently "red"	- Regulation altered or faulty - Location laser measuring head too warm - Feedback *	- inform customer service - keep temperature ≦30°C - new adjusting of measuring set-up
LED switches to "red" or flashes during the operation	- Laser control altered or faulty - Location laser measuring head too warm - Feedback *	- inform customer service - keep temperature ≦30°C - new adjusting of measuring set-up
No light at electrical socked „Reference“ (reference = upper electrical socked)	- inner defect in the laser measuring head	- inform customer service
No light at electrical socked „Mess“ (measuring = beneath electrical socked)	- beam path not correctly adjusted - inner defect in the laser measuring head	- new adjusting of measuring set-up - inform customer service
At the measuring head cable no light at the reference egress	- Measuring head cable defect, if light is available at electrical socked (reference egress = upper electrical socked)	- Exchanging measuring head cable
At measuring head cable is no light at measuring egress	- Measuring head cable defect, if light is available at electrical socked (measuring egress = below electrical socked)	- Exchanging measuring head cables

*** Feedback**

If even a small part of the light power of the laser beam is exactly reflected back into itself, the control will fail due to feedback. This case can occur especially with the use of plane mirror interferometers, if absolutely exact adjustment is made. Normally, due to the tolerances of the components and residual errors in the adjustment, the reflecting surfaces are slightly tilted. The occurrence of feedback can be seen by the fact that the display "Laser OK" flickers red or remains completely red.
If feedback should occur, then it is to be stopped by a slight tilting of the causing component.

The "Laser OK" display must no longer be red!

3.12 ZLM 900 LSI electronics unit with ExpressCard and notebook

In the following list, only the error possibilities that do not occur in connection with the notebook used and the software are considered. For further details, refer to the Software manual.

Error	Causes	Action
ZLM 900 LSI is not recognized by the operating system (notebook).	- Windows does not load hardware driver for ZLM 900 LSI	ExpressCard must be plugged in, restart notebook Inform customer service
Control LED - measuring signal Connection side under "Stat" is not illuminated	- Evaluation unit not connected correctly - Evaluation unit defective	Check all connection Inform customer service
Control LED - measuring signal connection side under "Stat" lights up "red". despite connected fiber optic cable	- No light at the fiber optic cable Reference or measuring - insufficient overlap between measuring and reference beam - Evaluation unit defective	See table Laser measuring head Improve overlap adjustment Inform customer service
Control LED - measuring signal connection side under "Stat" flickers during operation	- LWL - cable connection from laser insufficient - fiber optic cable defective - insufficient overlap between measuring and reference beam - evaluation unit defective	Check measuring head cable connections Replace measuring head cable Improve overlap adjustment Inform customer service

Maintenance and care

Cyclic maintenance is not required for the ZLM 900 LSI.

All bare steel parts are made of stainless steel.
The surfaces of the optical components must always be kept clean. Coarse soiling will impair the measuring result. Do not touch optical surfaces with your fingers. Dust should only be removed with a clean brush. Heavy soiling should be removed with a cotton swab moistened in distilled water. In the case of greasy contamination, use purified methylated spirits. To avoid such contamination, unused optical parts should always be covered or stored in the closed storage container.

Fuse replacement is not necessary. The fuses of the laser stabilization are not accessible to the customer and can only be changed by the service department. The AUK does not have any fusible links.

- It is recommended to have the unit checked and calibrated by the manufacturer approx. every 2 years.
- The warranty period for the ZLM 900 LSI is 2 years from the date of delivery.

☝ **Attention** **Electronic Unit ZLM 900 LSI**
AUK
Do n*<u>ot opening</u>*

The warranty claim expires in case of unauthorized opening of the device.

1. Service

For all occurring questions and problems with the handling of the laser displacement measuring system ZLM 900 LSI the employees of JENAer Meßtechnik GmbH are at your disposal at any time.

Service Adresse

JENAer Meßtechnik GmbH
Carl-Zeiss-Promenade 10
D-07745 Jena
Bundesrepublik Deutschland

Tel +49 3641 2153-26
Fax +49 3641 2153-28
Funk 0171 52 26 654

E-mail: info@tjenaer-mt.de

2. Technical Data / operation conditions

5. Technical Specification of ZLM

Mean wavelength of He-Ne laser in vacuum	632,8 nm
Wavelength stability	$8 \cdot 10^{-9}$ für 2 Stunden, $2 \cdot 10^{-8}$ für Lebensdauer
Beam diameter	4 mm
Max. output power of emerging expanded beam	1 mW
Number of measuring axes per laser	640 MHz / Zwischenfrequenz 2,56 GHz
Zahl der Messachsen pro Laser	1 (max 4)
optional	-
Resolution distance measurement	
Cube corner interferometer	2,5 nm
Plane mirror interferometer	1,25 nm
Measuring distance	≤ 20 m
Angle measurement with angle interferometer	
Resolution	$1,25 \cdot 10^{-7}$ rad
Angular range	±8° bis 20m distance
Measuring velocity	≤ 4m/s, optionally 12m/s translatory
	≤ 320rad/s rotatory
Nonlinearly	±0.625nm (2.5nm resolution)
	±0.312nm (1.25nm resolution)
Interfaces	32bit realtime counter signals (15ns)
	AQB counter input for e.g.: Heidenhain-scales (20 MHz)
	AQB counter output for Motion control (10 MHz)
	16 x 12bit ADC - input
	External Trigger in / Trigger out
	External to-zero fill
Operating conditions	15° C till 30° C

10.2 Operating conditions

The ZLM 900 LSI is suitable for use in harsh industrial environments. The optics modules are suitable for use in high vacuum. The transmission of the laser light from the laser to the interferometer, as well as the transmission of the measuring and reference signal from the interferometer optics to the electronic evaluation unit is carried out via fiber optic cables, so that signal interference due to electromagnetic environmental influences is excluded.

For safe operation of the device and to achieve error-free measurement results, the following must be observed:

- The laser head needs a warm-up time of 15 - 20 minutes for wavelength stabilization

- LED of the laser measuring head

Red	**Laser is still unstable**
Green	**Laser is operating stably**

- the correct connection of the fibre optics cables

Mess	↔	**Mess**
Ref	↔	**Ref**

- Keep optical end surfaces of fibre-optic cables and the ghlass surfaces of the optical moduls clean!

- The beam path must be well aligned with the mechanical measuring axis.

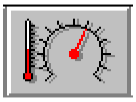
Important

Covering: The same position of measuring- and reference beam in the quadrant field (importantly for perfect interference signal)

)

- LED of evaluation unit

Red	**evalution of the light signals NOT possible**
Green	**Interference signal sufficing**

- enter the correct environmental data via menu items  and 

- no interruption of the beam path during the measuring operation