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IMPORTANT USER INFORMATION

Reading this entire manual is essential for full understanding of the proper use and safe operation of this product

Should you have any comments on this manual we will be pleased to receive them at:

Kipp & Zonen B.V.
Delftechpark 36 2628 XH Delft Holland
P.O. Box 507 2600 AM Delft Holland
Phone +31 (0)15 275 5210
Fax +31 (0)15 262 0351
Email info@kippzonen.com

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Manual version: 0307
Throughout the manual symbols are used to indicate to the user important information. The meaning of these symbols is as follows:

⚠️ The exclamation mark within an equilateral triangle is intended to alert the user to the presence of important operating, maintenance and safety information
DECLARATION OF CONFORMITY

1401/LASR/EMC

We,

Kipp & Zonen B.V.

(Roentgenweg 1
2624 BD Delft

(Supplier’s name)
(Supplier’s address)

This declaration of
Conformity is suitable
for the European
Standard
EN 45014 General
Criteria for supplier’s
Declaration of
Conformity. The basis
for the criteria has
been found in
international
documentation,
perticularly in ISO/IEC,
Guide 22, 1982,
information on
manufacturer’s
Declaration of
Conformity with
standards or other
technical
specifications

LAS Receiver type LAS-R

Name, type or model, batch or serial number, possible source and number of items.

EN 61326-1:2000
EN 61326-1:2000

The end or number and date of issue of the applied standard(s)

EMC-directive: 89/336/EEC
Amendment to the above directive: 93/68/EEC

Following the provisions of the Directives (if applicable):

These conclusions are based on test reports:

1401/LASR/EMC

ce-test PO box 563 2600 AN Delft

Test report number, date, and name of test house

Delft,

Place and date of issue

May 03/05/27/03

Name of responsible for CE-marking
We,

Kipp & Zonen B.V.

(Raiser’s name)

Rüntgenweg 1
2624 GD Delft

(supplier’s address)

declare under our sole responsibility that the product:

LAS Transmitter type LAS-T

(name, type or model, batch or serial number, possible source and number of items)

to which this declaration relates is in conformity with the following European, harmonized and published standards at date of this declaration:

EN 61326-1:2000
EN 61326-1:2000

(title and number and date of issue of the applicable standard(s))

following the provisions of the Directives (if applicable):

EMC-directive : 89/336/EEC
Amendment to the above directive: 93/68/EEC

These conclusions are based on test reports:

1401/LAST/EMC
ce-test PO box 563 2600 AN Delft

(test report number, date and name of test house)

Delft,

(place and date of issue)

(name of responsible for CE marking)

May 0305/26/03
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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

\( A_T \)  
wavelength dependant constants [-]

\( A_Q \)  
wavelength dependant constants [-]

\( c_p \)  
heat capacity of air at constant pressure [-1005 J kg\(^{-1}\) K\(^{-1}\)]

\( C_n^2 \)  
structure parameter of the refractive index of air [m\(^{2/3}\)] \( (C_n^2 = 10^{(U_{CN2})^{-12}}) \)

\( C_T^2 \)  
structure parameter of temperature [K\(^{2/3}\)]

\( C_Q^2 \)  
structure parameter of humidity [kg\(^{-2}\) m\(^{-6}\) m\(^{-2/3}\)]

\( d \)  
zero-displacement height [m]

\( D \)  
aperture diameter of receiver and transmitter unit [m]

\( f_T \)  
universal stability function [-]

\( g \)  
gravitational acceleration [-9.81 m s\(^{-2}\)]

\( G_s \)  
soil heat flux [W m\(^{-2}\)]

\( H \)  
sensible heat flux [W m\(^{-2}\)]

\( I \)  
signal strength or intensity [V] \( (I = U_{DEMOD}) \)

\( L \)  
path length [m]

\( L_E \)  
latent heat flux (or evaporation) [W m\(^{-2}\)]

\( L_{MO} \)  
Obukhov length [m]

\( \text{Pot} \)  
potentiometer path length setting at Path length knob [-]

\( P \)  
aper pressure [Pa]

\( P_{UCN2} \)  
scaled \( C_n^2 \) [m\(^{2/3}\)] \( (C_n^2 = P_{UCN2} \times 10^{-15}) \)

\( Q \)  
absolute humidity [kg m\(^{-3}\)]

\( Q^* \)  
net radiation [W m\(^{-2}\)]

\( R_d \)  
specific gas constant for dry air [-287 J K\(^{-1}\) kg\(^{-1}\)]

\( R_v \)  
specific gas constant for water vapour [-461.5 J K\(^{-1}\) kg\(^{-1}\)]

\( T \)  
absolute air temperature [K]

\( T^* \)  
temperature scale [K]

\( u \)  
wind speed [m s\(^{-1}\)]

\( u^* \)  
friction velocity [m s\(^{-1}\)]

\( U_{CN2} \)  
\( \log \ C_n^2 \) signal [V] \( (C_n^2 = 10^{(U_{CN2})^{-12}}) \) [-5 V to 0 V]

\( U_{DEMOD} \)  
demodulated signal [V] \( (U_{DEMOD} = I) \) [-1 V to 0 V]

\( U_{TH,R} \)  
thermistor signal receiver unit [V] [0 V to 10 V]

\( U_{TH,T} \)  
thermistor signal transmitter unit [V] [0 V to 10 V]

\( z_{LAS} \)  
(effective) height LAS or XLAS [m]

\( z_0 \)  
aerodynamic roughness length [m]

\( z_u \)  
height wind speed measurements [m]

\( \beta \)  
Bowen ratio [-] \( (\beta = H/L_E) \)

\( \kappa \)  
von Kármán constant (-0.40)

\( \lambda \)  
wavelength of EM radiation (880 nm) [m]

\( \rho \)  
density of air [kg m\(^{-3}\)] [-1.2 kg m\(^{-3}\) (at sea level!)]

\( \sigma^2 \)  
variance

\( \sigma^2_{\ln(I)} \)  
of natural logarithm of intensity fluctuations \( (\ln(I)) \) [-]

\( \sigma^2_{U_{DEMOD}} \)  
of \( U_{DEMOD} \) or intensity \( I \) [V\(^2\)]

\( \sigma^2_{U_{CN2}} \)  
of \( U_{CN2} \) [V\(^2\)]

\( \Psi_m \)  
integrated stability function for momentum [-]
ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>(X)LAS</td>
<td>(eXtra) Large Aperture Scintillometer</td>
</tr>
<tr>
<td>MOST</td>
<td>Monin-Obukhov Similarity Theory</td>
</tr>
<tr>
<td>PBL</td>
<td>Planetary Boundary Layer</td>
</tr>
<tr>
<td>RS</td>
<td>Roughness Sublayer</td>
</tr>
<tr>
<td>SL</td>
<td>Surface Layer</td>
</tr>
</tbody>
</table>

(X)LAS

A relationship describing the vertical behavior of non-dimensionalized mean flow and turbulence properties within the Surface Layer as a function of the Monin–Obukhov key parameters.

PBL

The PBL is the lowest region of the troposphere, which is directly affected by heating and cooling of the earth surface. In general the depth of the PBL varies between 100m to 2000m. The depth of the PBL increases during the day, when the surface is heated by the sun and decreases during the night.

RS

Lowest part of the SL, where the flow is influenced by individual roughness elements. Consequently, the SL can be divided into the Constant Flux Layer and the Roughness Sublayer. The height of the Roughness Sublayer strongly depends on the height (size and form) of the roughness elements, but also on the distribution. Usually, over tall vegetation 3 times the obstacle height is taken as the height of the Roughness Sublayer.

SL

In general in the lowest 10% of the PBL the surface fluxes are constant with height, this part of the PBL is also known as the Constant Flux Layer of Surface Layer (SL). Therefore fluxes measured in the SL can be considered as being representative fluxes for the heat and mass exchange processes between the atmosphere and the surface. In general the SL begins at 3 times the vegetation height and has a typical depth of 20m (at night) to 100m (during daytime conditions).
1. GENERAL INFORMATION

1.1 INTRODUCTION TO THE LAS AND XLAS

The Large Aperture Scintillometer (LAS) and eXtra Large Aperture Scintillometer (XLAS) are instruments designed for measuring the path-averaged structure parameter of the refractive index of air \( (C_n^2) \) over horizontal path lengths from 250 m to 4.5 km \(^1\) (LAS) and 1 km to 8 km \(^1\) (XLAS). Structure parameter measurements obtained with the LAS or XLAS and standard meteorological observations (air temperature, wind speed and air pressure) can be used to derive the surface sensible heat flux \((H)\).

The LAS and XLAS optically measure intensity fluctuations (known as scintillations) using a transmitter and receiver horizontally separated by several kilometers. The scintillations seen by the instrument can be expressed as the structure parameter of the refractive index of air \( (C_n^2) \). The light source of the LAS and XLAS transmitter operates at a near-infrared wavelength of 880 nm. At this wavelength the observed scintillations are primarily caused by turbulent temperature fluctuations. Therefore \( C_n^2 \) measurements obtained with the LAS or XLAS can be related to the sensible heat flux.

Compared to traditional point measurements the LAS and XLAS operate at spatial scales comparable to the grid box size of numerical models and pixels of satellite images used in meteorology, hydrology and water-management studies. The LAS and XLAS have important applications in energy balance and also water balance studies, because the surface flux of sensible heat is linked to evaporation \((L_vE)\).

Some key LAS and XLAS features are:

- Heated transmitter and receiver windows and internal temperature monitoring provide a mechanism to eliminate condensation problems.
- Simple construction using Fresnel lenses for collimation and collection of the light permits path lengths up to 4.5 km (LAS) and 8 km (XLAS) (depending on atmospheric conditions). Unlike mirror-based scintillometers the Fresnel lens avoids obstruction of the beam by the transmitting LED or the receiving detector.
- On-board calibration and reference signals at the receiver electronics allow rapid on-site confirmation of operation. Either the received carrier signal or the reference waveform can be monitored on the rear panel BNC output.
- Surge, over-voltage and lightning protection for both the transmitter and receiver units are standard.
- Eye-safe near-infrared light source.
- 12 Volt DC power for flexibility of use.
- Built-in pan and tilt adjuster for easier alignment.

\(^1\) Depending on atmospheric conditions
1.2 MANUAL

The INSTRUCTION MANUAL is intended for customers who have purchased the LAS or XLAS. It includes all the information necessary to properly install and operate the LAS/XLAS and how to derive the sensible heat flux from the LAS/XLAS measurements. An appendix (appendix I) is added to the manual for users who are interested in the theoretical background on scintillometry and the derivation of the surface sensible heat flux (see also WINLAS help file) and references to scientific papers.
## 2. TECHNICAL DATA

Table 1: Specifications of LAS and XLAS Transmitter.

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<thead>
<tr>
<th>Specifications</th>
<th>LAS</th>
<th>XLAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature</td>
<td>-20 °C to +50 °C</td>
<td>-20 °C to +50 °C</td>
</tr>
<tr>
<td>Humidity</td>
<td>0 - 100% RH (= IP 66)</td>
<td>0 - 100% RH (= IP 66)</td>
</tr>
<tr>
<td>Voltage</td>
<td>12 VDC nominal (V_{min} = 10.5 V; V_{max} = 15 V)</td>
<td>12 VDC nominal (V_{min} = 10.5 V; V_{max} = 15 V)</td>
</tr>
<tr>
<td>Power</td>
<td>0.5 A maximum (path length dependant), ~ 3 A maximum with heater on</td>
<td>0.5 A maximum (path length dependant), ~ 1.7 A maximum with heater on</td>
</tr>
<tr>
<td>Window heater</td>
<td>yes, self-regulating at ~ 55 °C</td>
<td>yes, 14 W (non-regulating)</td>
</tr>
<tr>
<td>Surge protection</td>
<td>power (not heater)</td>
<td>power (not heater)</td>
</tr>
<tr>
<td>Optical wavelength of LED</td>
<td>880 nm (spectral bandwidth at 50% ~ 80 nm)</td>
<td>880 nm (spectral bandwidth at 50% ~ 80 nm)</td>
</tr>
<tr>
<td>Optical power output of LED</td>
<td>maximum 80 mW (I_F = 1 A, I_f = 500 mA, duty cycle 0.5)</td>
<td>maximum 80 mW (I_F = 1 A, I_f = 500 mA, duty cycle 0.5)</td>
</tr>
<tr>
<td>Modulation frequency</td>
<td>~ 7 kHz (duty cycle 0.5)</td>
<td>~ 7 kHz (duty cycle 0.5)</td>
</tr>
<tr>
<td>Beam width</td>
<td>~ 1 m at 100 m distance</td>
<td>~ 0.3 m at 100 m distance</td>
</tr>
<tr>
<td>Aperture diameter</td>
<td>0.152 m (6 inch)</td>
<td>0.328 m (12.9 inch)</td>
</tr>
<tr>
<td>Focal length Fresnel lens</td>
<td>0.152 m (6 inch)</td>
<td>0.610 m (24 inch)</td>
</tr>
<tr>
<td>Effective diameter</td>
<td>0.145 m</td>
<td>0.32 m</td>
</tr>
<tr>
<td>Typical signal 1 (U_{TH,T})</td>
<td>0 V to 10 V</td>
<td>0 V to 10 V</td>
</tr>
<tr>
<td>Typical signal 2 (7 kHz oscillator)</td>
<td>7 kHz, 0.5 duty cycle, Amplitude = - 7.8 V</td>
<td>7 kHz, 0.5 duty cycle, Amplitude = - 7.8 V</td>
</tr>
<tr>
<td>Typical signal 3 (LED pulse, also on BNC)</td>
<td>7 kHz, 0.5 duty cycle, Amplitude = 0 V to 1 V</td>
<td>7 kHz, 0.5 duty cycle, Amplitude = 0 V to 1 V</td>
</tr>
<tr>
<td>Physical dimensions (including pan and tilt adjustment):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>0.37 m*</td>
<td>1.07 m</td>
</tr>
<tr>
<td>Width</td>
<td>0.23 m*</td>
<td>0.43 m</td>
</tr>
<tr>
<td>Height</td>
<td>0.32 m*</td>
<td>0.58 m</td>
</tr>
<tr>
<td>Weight</td>
<td>13.5 kg</td>
<td>35 kg</td>
</tr>
</tbody>
</table>

Kipp & Zonen reserves the right to make changes to the specifications without prior notice. * Excluding sun cover LAS.
Table 2: Specifications of LAS and XLAS Receiver.

<table>
<thead>
<tr>
<th></th>
<th>LAS</th>
<th>XLAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature</td>
<td>-20 °C to +50 °C</td>
<td>-20 °C to +50 °C</td>
</tr>
<tr>
<td>Humidity</td>
<td>0 – 100% RH (≤ IP 66)</td>
<td>0 – 100% RH (≤ IP 66)</td>
</tr>
<tr>
<td>Voltage</td>
<td>12 VDC nominal (V&lt;sub&gt;min&lt;/sub&gt; = 11.3 V; V&lt;sub&gt;max&lt;/sub&gt; = 15 V)</td>
<td>12 VDC nominal (V&lt;sub&gt;min&lt;/sub&gt; = 11.3 V; V&lt;sub&gt;max&lt;/sub&gt; = 15 V)</td>
</tr>
<tr>
<td>Power</td>
<td>0.2 A nominal, ~3 A maximum with heater on</td>
<td>0.2 A nominal, ~ 1.4 A maximum with heater on</td>
</tr>
<tr>
<td>Window heater</td>
<td>yes, self-regulating at ~ 55 °C</td>
<td>yes, 14 W (non-regulating)</td>
</tr>
<tr>
<td>Surge protection</td>
<td>power (not heater)</td>
<td>power (not heater)</td>
</tr>
<tr>
<td>Responsivity of photodiode at 880 nm</td>
<td>0.6 A/W (spectral bandwidth at 50% ~ 60 nm)</td>
<td>0.6 A/W (spectral bandwidth at 50% ~ 60 nm)</td>
</tr>
<tr>
<td>Aperture diameter</td>
<td>0.152 m (6 inch)</td>
<td>0.328 m (12.9 inch)</td>
</tr>
<tr>
<td>Focal length Fresnel lens</td>
<td>0.152 m (6 inch)</td>
<td>0.610 m (24 inch)</td>
</tr>
<tr>
<td>Effective diameter</td>
<td>0.148 m</td>
<td>0.32 m</td>
</tr>
<tr>
<td>Scintillation signal bandwidth of electronics</td>
<td>0.2 Hz to 400 Hz</td>
<td>0.2 Hz to 400 Hz</td>
</tr>
<tr>
<td>Typical value signal 1 (U&lt;sub&gt;DEM&lt;/sub&gt; or signal strength I)</td>
<td>- 0.8 V to 0 V</td>
<td>- 0.8 V to 0 V</td>
</tr>
<tr>
<td>Typical value signal 2 (U&lt;sub&gt;CN2&lt;/sub&gt; or log C&lt;sub&gt;N2&lt;/sub&gt; signal)</td>
<td>- 5 V to 0 V</td>
<td>- 5 V to 0 V</td>
</tr>
<tr>
<td>Typical value signal 3 (7 kHz carrier)</td>
<td>~ 7 kHz, 0.5 duty cycle</td>
<td>~ 7 kHz, 0.5 duty cycle</td>
</tr>
<tr>
<td>Typical value signal 4 (U&lt;sub&gt;TH,R&lt;/sub&gt; Thermistor)</td>
<td>0 V to 10 V</td>
<td>0 V to 10 V</td>
</tr>
<tr>
<td>C&lt;sub&gt;n&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt; turbulent range</td>
<td>&lt;sup&gt;10&lt;/sup&gt;-12 to &lt;sup&gt;10&lt;/sup&gt;-17 m&lt;sup&gt;2/3&lt;/sup&gt;</td>
<td>&lt;sup&gt;10&lt;/sup&gt;-12 to &lt;sup&gt;10&lt;/sup&gt;-17 m&lt;sup&gt;2/3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Noise level of electronics</td>
<td>&lt;sup&gt;10&lt;/sup&gt;-17 m&lt;sup&gt;2/3&lt;/sup&gt;</td>
<td>&lt;sup&gt;10&lt;/sup&gt;-17 m&lt;sup&gt;2/3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Physical dimensions (including pan and tilt adjustment):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>0.37 m*</td>
<td>1.07 m</td>
</tr>
<tr>
<td>Width</td>
<td>0.23 m*</td>
<td>0.43 m</td>
</tr>
<tr>
<td>Height</td>
<td>0.32 m*</td>
<td>0.58 m</td>
</tr>
<tr>
<td>Weight</td>
<td>13.5 kg</td>
<td>35 kg</td>
</tr>
</tbody>
</table>

Kipp & Zonen reserve the right to make changes to the specifications without prior notice. * Excluding sun cover LAS.

Table 3: Operating Specifications of LAS and XLAS System.

<table>
<thead>
<tr>
<th></th>
<th>LAS</th>
<th>XLAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum path length</td>
<td>0.25 km</td>
<td>1 km</td>
</tr>
<tr>
<td>Maximum path length (depends on atmospheric conditions)</td>
<td>4.5 km</td>
<td>8 km</td>
</tr>
<tr>
<td>Minimum height</td>
<td>1.5 m (Important: read section 3.3, appendix II and III)</td>
<td>3 m (Important: read section 3.3, appendix II and III)</td>
</tr>
<tr>
<td>Maximum height for C&lt;sub&gt;n&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt; (or turbulence) measurements</td>
<td>no operational restriction</td>
<td>no operational restriction</td>
</tr>
<tr>
<td>Maximum height for flux (H) measurements</td>
<td>~ 100 m (in Constant Flux Layer, see section 3.3)</td>
<td>~ 100 m (in Constant Flux Layer, see section 3.3)</td>
</tr>
</tbody>
</table>

Kipp & Zonen reserve the right to make changes to the specifications without prior notice.
3. INSTALLATION

The following steps must be carefully taken for optimal performance of the instrument.

3.1 DELIVERY

Check the contents of the shipment for completeness (see below) and note whether any damage has occurred during transport. If there is damage, a claim should be filed with the carrier immediately. In this case, or if the contents are incomplete, the Kipp & Zonen Sales or Services organization should be notified in order to facilitate the repair or replacement of the instrument.

The LAS/XLAS scintillometer delivery will include the following items:

- (X)LAS transmitter (with pan and tilt adjuster)
- (X)LAS receiver (with pan and tilt adjuster)
- 2 × sun / weather cover
- 2 × sighting telescope with detachable mountings
- 2 × 0.1m diaphragms to adjust the LAS for short range applications (plus add. screws, washers and spacers)
- 2 × 5 m cable with 10 lead, fitted with a 10-way circular amphenol plug (male) at one end
- 4 spare bags of silica gel (5 gr. each)
- A CD containing WINLAS and a pdf-file of the LAS/XLAS manual

Any missing parts should be reported to your dealer, who will suggest appropriate action.

Unpacking

Keep the original packaging for later shipments!

Although the LAS/XLAS is weatherproof and suitable for rough ambient conditions, the transmitter and receiver do contain delicate optical and electronic parts. For this type of equipment, keep the original shipment packaging to safely transport the equipment to the measurement sites.
3.2 ORIENTATION PATH / SITE SELECTION

Avoid direct sunlight in both the receiver and transmitter windows to prevent overheating of the LED and permanent damage to the detector. It is recommended to select a path that is approximately parallel to the earth’s surface (i.e. horizontal) and has a north-south orientation to avoid problems caused by low sun angles.

⚠️ **Important:** Exposure to direct sunlight can permanently damage the optical parts (LED and detector).

⚠️ **Important:** Verify that the optical path of the LAS or XLAS is always free from obstacles (e.g. trees, buildings).

3.3 HEIGHT – PATH LENGTH

To be certain that the $C_n^2$ measurements of the LAS/XLAS are reliable and fluxes (of sensible heat $H$ and latent heat $L_E$) can be derived from these measurements it is very important to follow the instructions/recommendations given in the following two sections.

3.3.1 Minimum height – Saturation

When the scintillation intensity rises above a certain limit the theory, on which the scintillation measurement method is based, is no longer valid. When this occurs the relationship between the measured amount of scintillations ($\sigma_n^2$) and the structure parameter of the refractive index of air ($C_n^2$) fails. This phenomenon is known as saturation. In order to prevent saturation, $C_n^2$ must stay below a certain saturation criterion ($S_{\text{max}}$), i.e. the scintillometer can operate only under weakly scintillating conditions. The dependence of $C_n^2$ on the optical wavelength ($\lambda$), the aperture diameter ($D$), the measurement height ($z_{\text{LAS}}$) and the path length ($L$) can be written as follows

$$C_n^2(\lambda, D, z_{\text{LAS}}, L) < S_{\text{max}}.$$  

The path length and the measurement height are the only variables that can be adjusted in order to keep $C_n^2$ below the saturation criterion because the diameter and the wavelength of the LAS and XLAS are constant. A scintillometer installed at a height close the earth’s surface, will see more scintillations than a scintillometer installed high above the surface. As the path length increases more scintillations will be observed. This means that over long distances (~ several kilometres) the scintillometer must be placed high above the surface in order to prevent saturation. Over short distances (~ several hundred meters) the scintillometer can be installed close to the surface. Furthermore, the measured amount of scintillations depends on the surface conditions. Over dry areas the surface sensible heat flux is large, resulting in higher $C_n^2$ values than over wet surfaces where the sensible heat flux is small.

In figure 1a,b the minimum height of the LAS and XLAS are given for different surface conditions as a function of the path length. The path length ranges between 250 m and 4.5 km for the LAS and 1 km and 8 km for the XLAS, respectively. The surface conditions range from very dry ($H \sim 400$ W m$^{-2}$) to very wet ($H \sim 50$ W m$^{-2}$). The area above the curves in the figure is the so-called non-saturation zone. Below the curves saturation will occur. Based on the user’s preferred path length, and the surface conditions of the area of interest, the user must install the LAS and XLAS at a height that lies in the non-saturation zone.
Figure 1a: The minimum installation height of the LAS as function of path length and for different surface conditions. The area above the curves is the non-saturation zone. Below the curves saturation of the signal occurs. In the presence of densely packed roughness elements add the zero-displacement height (see appendix III).

Figure 1b: The minimum installation height of the XLAS as function of path length and for different surface conditions. The area above the curves is the non-saturation zone. Below the curves saturation of the signal occurs. In the presence of densely packed roughness elements add the zero-displacement height (see appendix III).
For example a LAS installed over a relatively wet area ($H \sim 100 \text{ W m}^{-2}$) and a path length of 3 km must be installed at a height of 10 - 12 meters or more, according to Figure 1a.

**Important:** Verify that the LAS and XLAS are operating in the ‘saturation free’ zone.

**Important:** Determine the effective height of beam of the LAS/XLAS ($z_{\text{LAS}}$) along the path precisely as the sensible heat flux derived from the structure parameter data is very sensitive to the height (see appendix I)! When the area is relatively flat and the beam is parallel to the surface the effective height is easy to determine ($z_{\text{transmitter}} = z_{\text{receiver}} = z_{\text{LAS}}$). For situations that the area is NOT flat or slanted paths it is recommend measuring the height of the beam at several points along the path. By weighing the collected beam heights using the spatial weighting function of the LAS/XLAS (see appendix II) the effective beam height can be derived (see e.g. figure 16). In the presence of densely packed roughness elements (e.g. dense crop or forest) one has to account for the zero-displacement ($d$) height also (i.e. add $d$ to the minimum height)!

### 3.3.2 Minimum and maximum height – MOST

In order to derive the surface fluxes of sensible heat from the scintillometer measurements (i.e. $C_n^2$) we use the so-called Monin-Obukhov Similarity Theory (MOST) (see appendix I). MOST is widely used in the meteorology and is usually applied to the Surface Layer (SL) (and hence is sometimes called Surface Layer Similarity). The SL is roughly the lowest 10% of the Planetary Boundary Layer (PBL). The PBL is directly influenced by the earth’s surface and its depth varies between roughly 100 m to 2 km. In general the PBL increases during the day, when the earth’s surface is heated by the sun, and decreases again during the night. In the SL the variation of fluxes (such as the sensible heat flux $H$ and latent heat flux $L_e$) is negligible with respect to the magnitude of their value at the surface. Therefore, fluxes measured at a certain elevation in the SL can be considered as being representative for the exchange processes occurring between the earth surface and the atmosphere.

The SL can be divided again into the Roughness Sublayer (RS) influenced by the structure of the roughness elements (e.g. plants, trees, buildings etc) and the Constant Flux Layer where fluxes are assumed to be horizontally and vertically constant (due to turbulent mixing). This means that measurement techniques that apply MOST for estimating surface fluxes can be applied only in the Constant Flux Layer. Therefore the LAS/XLAS have to be installed at a height such that it is located above the Roughness Sublayer and is measuring within the Constant Flux Layer.

The depth of the SL roughly varies between 20 m to 100 m. The upper level strongly depends on the diurnal cycle of surface heating and cooling (and by the presence of clouds). Like the PBL, the SL increases during the day, as the surface is heated by the sun and is maximum at sun set (~100 m), before is decreases again due to cooling of the surface at night (~20 m). The height of the Roughness Sublayer (and thus lower level of the Constant Flux Layer) depends strongly on the size, form and distribution of the roughness elements. Usually, over tall vegetation, the height of the Roughness Sublayer is taken to be equal to three times the obstacle height (or roughness elements $h$ (see also appendix III)). In case the estimated height of the Roughness Sublayer is smaller than the minimum height of the LAS/XLAS in table 3, take as minimum height the values shown in table 3!

**Important:** Verify that the LAS and XLAS are measuring in the Constant Flux Layer.
3.4 THE MOUNTING SUPPORT

The **LAS** and **XLAS** can only function properly when the transmitter and receiver unit are precisely optically aligned. By mounting the scintillometer on a stable support, signal loss and regular realignment procedures will be avoided. In addition vibrations in the mounting structure must be prevented, which can lead to overestimated $C_n^2$ values.

⚠️ **Important:** *Always place the LAS/XLAS units on a STABLE (vibration free) construction.*

3.5 MOUNTING THE LAS AND XLAS

The pan and tilt adjusters of the **LAS/XLAS** transmitter and receiver are supplied with a bottom flange, which provides simple mounting on the optional tripods (G-3M) using the M16 bolts and washers supplied. The bottom flange can also be fixed to the optional Kipp & Zonen tripod floor stands or to customer-supplied supports using 4× M10 bolts, nuts and washers (not supplied) for each of the transmitter and receiver.

![Example of LAS mounted on the optional tripod floor stand.](image)

3.6 ELECTRICAL CONNECTION

3.6.1 Amphenol socket

The **LAS/XLAS** transmitter and receiver are each provided with a 5 m cable with 10 wires and a shield. At one end of each cable is a 10-way circular Amphenol plug is fitted. These plugs mate with the 10-way circular Amphenol sockets at the receiver and transmitter.

The **LAS/XLAS** can be connected to a computer or data logger. An analogue DC voltage input module with A to D (12 to 16 Bit) converter must be available.

⚠️ **Important:** *Always measure $\log C_n^2$ ($U_{CNO}$) together with the demodulated signal ($U_{DEMOD}$). Although the demodulated carrier signal is not used in the calculations it is an important parameter for monitoring the quality of the $C_n^2$ measurements.*
Table 4: Transmitter cable color code.

<table>
<thead>
<tr>
<th>Pin designation (amphenol plug)</th>
<th>Color code</th>
<th>Transmitter unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Blue</td>
<td>Power GND</td>
</tr>
<tr>
<td>B</td>
<td>Violet</td>
<td>Power 12 VDC, 0.5 A</td>
</tr>
<tr>
<td>C</td>
<td>Red</td>
<td>Thermistor $U_{TH,T}$ (Hi)</td>
</tr>
<tr>
<td>D</td>
<td>Orange</td>
<td>7 kHz oscillator (Hi)</td>
</tr>
<tr>
<td>E</td>
<td>Yellow</td>
<td>LED pulse (Hi)</td>
</tr>
<tr>
<td>F</td>
<td>Black</td>
<td>Not connected</td>
</tr>
<tr>
<td>G</td>
<td>White</td>
<td>Heater, 12 VDC</td>
</tr>
<tr>
<td>H</td>
<td>Grey</td>
<td>Heater</td>
</tr>
<tr>
<td>I</td>
<td>Green</td>
<td>Signals GND (Lo)</td>
</tr>
<tr>
<td>J</td>
<td>Brown</td>
<td>Not connected</td>
</tr>
</tbody>
</table>

Table 5: Receiver cable color code.

<table>
<thead>
<tr>
<th>Pin designation (amphenol plug)</th>
<th>Color code</th>
<th>Receiver unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Blue</td>
<td>Power GND</td>
</tr>
<tr>
<td>B</td>
<td>Violet</td>
<td>Power 12 VDC, 0.20 A</td>
</tr>
<tr>
<td>C</td>
<td>Red</td>
<td>Thermistor $U_{TH,R}$ (Hi)</td>
</tr>
<tr>
<td>D</td>
<td>Orange</td>
<td>$U_{CN2}$ (or $\log C_n^2$) signal (Hi)</td>
</tr>
<tr>
<td>E</td>
<td>Yellow</td>
<td>Not connected</td>
</tr>
<tr>
<td>F</td>
<td>Black</td>
<td>7 kHz carrier (Hi)</td>
</tr>
<tr>
<td>G</td>
<td>White</td>
<td>Heater, 12 VDC</td>
</tr>
<tr>
<td>H</td>
<td>Grey</td>
<td>Heater</td>
</tr>
<tr>
<td>I</td>
<td>Green</td>
<td>Signals GND (Lo)</td>
</tr>
<tr>
<td>J</td>
<td>Brown</td>
<td>Demodulated carrier signal $U_{DEMOD}$ (signal strength) (Hi)</td>
</tr>
</tbody>
</table>

The LAS receiver signals ($C_n^2$ and demod) can be connected to a Campbell or COMBILOG data logger as follows:

**Campbell data logger:**

- $C_n^2$: Orange $\rightarrow$ High $\rightarrow$ Diff channel 1 $\rightarrow$ (Optional with voltage divider)
- Green: Low $\rightarrow$ Diff channel 1 $\rightarrow$ (Optional with voltage divider)
- Demod: Brown $\rightarrow$ High $\rightarrow$ Diff channel 2 $\rightarrow$ (Optional with voltage divider)

**COMBILOG data logger:**

- $C_n^2$: Orange $\rightarrow$ In+ $\rightarrow$ AIN1 $\rightarrow$ (Optional with voltage divider)
- Green: In- $\rightarrow$ AIN1 $\rightarrow$ (Optional with voltage divider)
- Demod: Brown $\rightarrow$ In+ $\rightarrow$ AIN2 $\rightarrow$ (Optional with voltage divider)

1 Must be connected with small wire (Both signals have common signal ground)

### 3.6.2 BNC socket

The control panels of both the **LAS/XLAS** receiver and transmitter can be accessed by removing the rear cover from the housing. BNC sockets allow the user to monitor various signals.
The BNC socket labeled **LED pulse** on the control panel of the **LAS** transmitter can be connected to an oscilloscope to monitor the magnitude of the 7 kHz carrier. This gives an indication of the transmitted waveform and the current being pulsed through the LED emitter. The pulse waveform is square-shaped and is scaled as 1 V equivalent to 1 A. The maximum permissible current is 1 A (when the **Current adjust** knob is set at maximum), which corresponds to an average current of 0.5 A (duty cycle of 0.5).

By connecting an oscilloscope to the BNC socket labeled **Carrier** on the control panel of the **LAS/XLAS** receiver the 7 kHz carrier can be monitored, provided that the switch labeled **Mode** is set at **Signal**. The waveform should be sinusoidal. If the detector becomes saturated the shape of the wave is clipped and becomes saw-tooth like. When this occurs reduce the LED emitter current.

The BNC socket labeled **log Cn** allows the user to monitor $U_{Cn2}$ using a standard DC Voltmeter, provided that the switch labeled **Mode** is set at **Signal**. By applying equation 2 the structure parameter of the refractive index of air ($Cn^2$) can be derived.

### 3.6.3 Protection circuitry and fuse ratings

The 12 VDC power input to the electronic circuits of both the **LAS/XLAS** transmitter and receiver include protection circuitry consisting of a spark gap arrestor, in-line inductance and surge protection to guard against transients. A **2A quick blow fuse** protects the circuitry from current overload. To replace the fuse the control panels must be removed.

The control panels can be accessed by removing the rear cover of the **LAS/XLAS** receiver or transmitter unit. Proceed as follows: switch the power off, disconnect the internal plug and remove the 4 screws on the perimeter of the control panel, gently lift out the control panel and carefully disconnect the wiring harnesses linking the control panel to the printed circuit board behind. The power fuse can be identified and replaced (see figure 3).

Reassemble in the reverse order.

---

**Figure 3:** The location of the power fuse (identified by the arrow) on the receiver (left) and transmitter (right) printed circuit boards.

![Figure 3](image)

**Important:** *Always disconnect power before attempting to replace the fuse.*
3.7 OPTICAL ALIGNMENT

The alignment of the LAS/XLAS at the measurement site is an iterative process for establishing the optimum signal strength for horizontal line-of-sight transmission. The different steps are summarised below. We recommend practice of the alignment procedure at a short range (~ 150 m) first, before proceeding to longer distances. The transmitter and receiver can be rotated around both vertical and horizontal axes. The coarse adjustment of the horizontal alignment (pan) can be done before the bolt(s) that fixes the adjuster bottom flange to the supporting base/structure is (are) completely tightened. Fine pan adjustment can be done with the two horizontal screws with black knobs, which are located just below the case of transmitter or receiver, at the back of the adjuster. For the vertical alignment (tilt), two vertical adjustment bolts are provided, one at the front and one at the rear (see figure 4).

Figure 4: Diagram of pan and tilt adjuster.

Two people should carry out the alignment, one at the receiver and one at the transmitter site. They should be able to communicate either by radio, walkie-talkies or mobile telephones.

The transmitter and receiver are mounted at their respective positions. The bolts used to fix the pan and tilt adjusters of the LAS/XLAS to the supporting structures (either a tripod, or something else) are fastened by hand, so that the LAS/XLAS can still be turned around its vertical axis.

1. The telescopes are mounted to the rails on tops of the transmitter and receiver. Note that the telescopes are factory-aligned for each transmitter and receiver and are marked appropriately with either ‘Transmitter’ or ‘Receiver’.
2. The transmitter is adjusted both horizontally (pan) and vertically (tilt) such that the crosshairs of the telescope are centered on the receiver. The same is done for the receiver, relative to the transmitter. Tighten the bolts fixing the pan and tilt adjusters of the LAS/XLAS to the supporting structures (further adjustments can be done with the pan fine adjustment screws).
3. Remove the rear covers of the transmitter and receiver, connect suitable power supplies to both units and switch on. The Power indicator on each control panel should illuminate. Set the switch labeled Mode at the receiver control panel to Signal. At the transmitter side the current is adjusted to a reasonable value with the Current Adjust knob (the dial runs from 0 to 1000). Full scale is approximately 0.5 A (see table 6). For path lengths of about 1 km the current should lie approximately around 0.15 A, whereas for paths of 4.5 km 0.5 A is required. Note that the received signal strength depends on the visibility. If all is well, the analogue meter (Signal Strength) at the control panel of the receiver should give some signal already (to make the meter ten times as sensitive, it can be switched to long range, rather than short range).
Table 6: Power consumption LAS/XLAS transmitter as a function of Current adjust knob (window-heater not included).

<table>
<thead>
<tr>
<th>Current adjust knob [-]</th>
<th>Power consumption Transmitter [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.02</td>
</tr>
<tr>
<td>100</td>
<td>0.06</td>
</tr>
<tr>
<td>200</td>
<td>0.11</td>
</tr>
<tr>
<td>300</td>
<td>0.17</td>
</tr>
<tr>
<td>400</td>
<td>0.22</td>
</tr>
<tr>
<td>500</td>
<td>0.28</td>
</tr>
<tr>
<td>600</td>
<td>0.31</td>
</tr>
<tr>
<td>700</td>
<td>0.36</td>
</tr>
<tr>
<td>800</td>
<td>0.41</td>
</tr>
<tr>
<td>900</td>
<td>0.47</td>
</tr>
<tr>
<td>1000</td>
<td>0.52</td>
</tr>
</tbody>
</table>

![Important: During the alignment, the transmitter current should be kept constant at all time unless:](image)

- If the analogue Signal Strength meter at the receiver goes over-range, decrease the transmitter current.
- If there is no reading on the analogue Signal Strength meter at the receiver, increase the transmitter current and try again.

Otherwise the transmitter current should be kept constant, since when looking for a maximum signal strength, it only makes sense to compare readings at a given fixed transmitter power.

4. The following steps are intended to find the edges of the beam (use landmarks to locate these edges) at both the receiver and transmitter side and to get a good signal as indicated by the analogue meter on the rear of the receiver (see figure 5). It is very important to follow this procedure because the data is not reliable when the edges of the beam are too close to the receiver or transmitter aperture!

   a. The person at the receiver looks at the analogue Signal Strength meter and communicates the values he/she sees to the person at the transmitter.
   b. The person at the transmitter first turns the transmitter horizontally (slowly) left and right using the adjustment knobs until the optimal signal strength (as given by the person at the receiver) is reached by finding the center of the beam (midpoint between horizontal edges of beam).
   c. Then the transmitter needs to be adjusted vertically (using the two vertical adjustment bolts). The transmitter is turned up-wards and down-wards (slowly) until the optimum reading of the analogue Signal Strength meter at the receiver is reached (again find the midpoint between the vertical edges of beam). The vertical bolts are tightened smoothly by hand, taking care not to change the alignment.
   d. It is possible that the transmitter / receiver is not at the center of the crosshairs of the telescope compared with the center of the beam derived from the field alignment, due to a difference from the range at which they were factory adjusted. If necessary the crosshairs of the telescopes can be adjusted. Therefore never use the telescopes alone during the alignment procedure!

Repeat steps b, c and d for the receiver, while the transmitter is kept at its position. The person at the receiver can turn the receiver both horizontally and vertically, while looking at the analogue Signal Strength meter, to obtain the optimum position (i.e. the center of the beam between the edges) and signal strength.
5. The steps in 4 are repeated until the optimum alignment is reached. Tighten the two horizontal fine-adjustments bolts and the two vertical adjustment bolts at the transmitter and receiver with a spanner. Whilst fastening the bolts make sure that the alignment is not changed. This can be avoided by looking through the telescopes whilst tightening the bolts.

6. Finally, the current of the transmitter should be adjusted such that there is sufficient signal ($U_{DEM}$) at the receiver. At maximum distance (i.e. LAS over 4.5 km and XLAS over 8 km) the signal strength should be approximately −75 mV (transmitter at full power and clear atmospheric conditions). As a rule of thumb we advice to adjust the power of the transmitter such that the analogue meter reads approximately 50 (LAS: for distances longer than 2 km set switch to long range, for distances shorter than 2 km set switch to short range; XLAS: short range < 5 km and long range > 5 km). Typical values of LED current and signal strength for several path lengths are given in table 7.

7. Place the rear covers back on the transmitter and receiver and tighten the fixing screws, ensuring that the ‘o’-rings are in their grooves and not distorted.

8. Remove the telescopes.

9. Install the protective heat shields on top of the transmitter and receiver unit and tighten the fixings.

**Important:** Never (re-) align the LAS/XLAS transmitter and receiver using the telescopes only.

**Important:** Never switch around the transmitter and receiver telescopes.

**Important:** Avoid signal saturation of the detector.

**Note:** When the receiver is positioned too close to the edge of the beam this will result in increased noise and incorrect $C_n^2$ measurements.
Table 7: Typical values for LED current and signal strength as function of the path length (for clear atmospheric conditions).

<table>
<thead>
<tr>
<th>Path length [m]</th>
<th>Current adjust knob [-]</th>
<th>$U_{DEMOD}$ [mV]</th>
<th>An. – meter (short range)</th>
<th>An. – meter (long range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAS 250</td>
<td>&lt; 10</td>
<td>&gt; -600</td>
<td>80</td>
<td>×</td>
</tr>
<tr>
<td>LAS 1000</td>
<td>200</td>
<td>-450</td>
<td>60</td>
<td>×</td>
</tr>
<tr>
<td>LAS 4500</td>
<td>1000</td>
<td>-80</td>
<td>×</td>
<td>30</td>
</tr>
<tr>
<td>XLAS 8000</td>
<td>1000</td>
<td>-80</td>
<td>×</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 8: Relation between the signal strength ($U_{DEMOD}$) and reading of the analogue Signal Strength meter for different signal strengths ($R_{detector} = 8M2 \Omega; R_{meter1} = 560 \Omega; R_{meter2} = 5k6 \Omega; \text{no optical filter}$).

<table>
<thead>
<tr>
<th>An. – meter (short range)</th>
<th>An. – meter (long range)</th>
<th>$U_{DEMOD}$ [DC-mV]</th>
<th>$U_{CARRIER}$ [AC-mV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt; 2</td>
<td>-8</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>-80</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>60</td>
<td>-160</td>
<td>90</td>
</tr>
<tr>
<td>30</td>
<td>90</td>
<td>-240</td>
<td>130</td>
</tr>
<tr>
<td>40</td>
<td>×</td>
<td>-300</td>
<td>175</td>
</tr>
<tr>
<td>50</td>
<td>×</td>
<td>-375</td>
<td>215</td>
</tr>
<tr>
<td>60</td>
<td>×</td>
<td>-445</td>
<td>250</td>
</tr>
<tr>
<td>70</td>
<td>×</td>
<td>-520</td>
<td>290</td>
</tr>
<tr>
<td>80</td>
<td>×</td>
<td>-600</td>
<td>335</td>
</tr>
<tr>
<td>90</td>
<td>×</td>
<td>-680</td>
<td>375</td>
</tr>
<tr>
<td>100</td>
<td>×</td>
<td>-770</td>
<td>415</td>
</tr>
</tbody>
</table>
3.8 SETTING PATH LENGTH POTENTIOMETER

Once the LAS has been installed and properly aligned the Path Length dial knob at the receiver control panel must be set for the correct distance between the transmitter and the receiver. The Path Length dial knob has 10 turns maximum with a vernier counter and a locking mechanism. These graduations are NOT in units of distance! The precise path length must first be converted to a dial knob setting (Pot) using the following relationship for the LAS

\[ Pot_{LAS} = \left( \frac{5475.81}{\sqrt{(4.474D^2L^{-1}0.3314 \cdot 10^{12}) + 5.23}} \right)^{-47}, \]  \hspace{1cm} (1a)

and the XLAS

\[ Pot_{XLAS} = \left( \frac{2737.905}{\sqrt{(4.474D^2L^{-1}0.3314 \cdot 10^{12}) + 2.615}} \right)^{-47}, \] \hspace{1cm} (1b)

where \( D \) is the aperture diameter (LAS: 0.152 m; XLAS: 0.328 m) and \( L \) the distance between the transmitter and receiver (in meters). Calculated values of \( Pot_{LAS} \) and \( Pot_{XLAS} \) for different path lengths can be found in table 9. Note that because of the sensitivity of \( Pot \) to \( L \) and thus also \( C_{\nu}^2 \) to \( L \) the distance must be determined accurately. Also note that it is possible to recalculate incorrect \( C_{\nu}^2 \) data, due to an incorrect path length setting \( Pot \) (and thus \( L \)), afterwards in the WINLAS software (see section 5). However, this correction should be used for small corrections only!

⚠️ **Important:** Path length dial knob units are NOT in units of distance.

⚠️ **Important:** Determine the path length precisely!

(\( \sim < 1 \% \), e.g. 500 m (± 5 m) and 3 km (± 30 m))
Table 9: Path Length (Pot) dial knob setting values for different path lengths between the (X)LAS transmitter and receiver.

<table>
<thead>
<tr>
<th>Path length [m]</th>
<th>PotLAS</th>
<th>Path length [m]</th>
<th>Pot XLAS</th>
</tr>
</thead>
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<td>250</td>
<td>91.9</td>
<td>1000</td>
<td>161.9</td>
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<tr>
<td>300</td>
<td>128.2</td>
<td>1250</td>
<td>223.5</td>
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<tr>
<td>350</td>
<td>164.6</td>
<td>1500</td>
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<td>400</td>
<td>200.4</td>
<td>1750</td>
<td>336.2</td>
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<tr>
<td>450</td>
<td>235.3</td>
<td>2000</td>
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<td>500</td>
<td>269.1</td>
<td>2250</td>
<td>431.4</td>
</tr>
<tr>
<td>550</td>
<td>301.5</td>
<td>2500</td>
<td>472.7</td>
</tr>
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<td>600</td>
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<td>510.1</td>
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</tr>
<tr>
<td>700</td>
<td>390.0</td>
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<td>3750</td>
<td>627.5</td>
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<td>7500</td>
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<td>917.4</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

×

×

×

×
4. OPERATION

After completing the installation the LAS/XLAS (alignment, path length) will be ready for operation.

The $C_n^2$ values can simply be computed from the output signal ($U_{CN2}$) using the following equation

$$C_n^2 = 10^{U_{CN2} - 12}. \quad (2)$$

- $C_n^2$ = structure parameter of the refractive index of air [m$^{-2/3}$]
- $U_{CN2}$ = log $Cn^2$ signal [V]

For example if $U_{CN2} = -4.0$ V, then $C_n^2 = 1 \cdot 10^{-16}$ m$^{-2/3}$.

Because of the non-linearity between $C_n^2$ and the output signal of the LAS/XLAS ($U_{CN2}$), an interval-averaged $U_{CN2}$ (e.g. 10 minutes) will not yield the true interval-averaged $C_n^2$. Therefore we recommend one of the following two options:

1. Measure besides the interval averages of $U_{CN2}$, the variance of $U_{CN2}$ ($\sigma_{U_{CN2}}^2$) and apply the following equation for deriving the correct interval-averaged $C_n^2$

$$C_n^2 = 10^{U_{CN2} - 12 + 1.15 \sigma_{U_{CN2}}^2}. \quad (3)$$

- $C_n^2$ = structure parameter of the refractive index of air [m$^{-2/3}$]
- $U_{CN2}$ = log $Cn^2$ signal [V]
- $\sigma_{U_{CN2}}^2$ = variance of $U_{CN2}$ [V$^2$]

2. Calculate $C_n^2$ immediately after each measurement cycle (e.g. 1 Hz) and derive the interval-averaged $C_n^2$ (e.g. 10 minute averages) from the instantaneous $C_n^2$ values. Because $C_n^2$ values are too small to store in most conventional data acquisition systems (~$1 \cdot 10^{-16}$) multiply the $C_n^2$ values by $1 \cdot 10^{15}$ ($PU_{CN2}$). Whether this option can be applied depends on the capability of the data acquisition systems to perform immediate calculations with the measured data. Afterwards the true $C_n^2$ values can be derived from $PU_{CN2}$ as follows

$$C_n^2 = PU_{CN2} \cdot 10^{-15}. \quad (4)$$

In appendix IV and V examples are shown for Campbell Scientific (Model CR10X) and Theodor Friedrichs & Co data loggers (COMBILOG 1020).
5. WINLAS SOFTWARE

The following sections provide information about the **LAS/XLAS** software: WINLAS. WINLAS allows the **LAS/XLAS** user to derive the surface fluxes of sensible heat from collected LAS data and additional meteorological data, namely air temperature ($T$), air pressure ($P$), wind speed ($u$) and Bowen ratio ($\beta$) data. WINLAS calculates the fluxes according to the theory given in appendix I.

5.1 SYSTEM REQUIREMENTS

The minimum computer hardware requirements for WINLAS is a 100 MHz Pentium computer running Windows 95/98/NT/2000/XP/ME, 16 MB of Ram, 10 MB of free hard-disk space (excluding LAS data) and a mouse.

5.2 INSTALLATION

The WINLAS software consists of four files, namely an executable (WINLAS.exe), an initialization file (WINLAS.ini), a help file (WINLAS.chm) and a data-example file (EXAMPLE.txt), which are supplied on a CD. Once the files are copied to a (sub) directory on the PC, WINLAS can be started by double clicking on WINLAS.exe.

5.3 WINLAS OVERVIEW

Double clicking on WINLAS.exe with the Kipp & Zonen logo will open the software. The buttons in the Main Menu of the WINLAS software provide access to the various pages of WINLAS (see figure 6).

![WINLAS menu options](image-url)
File → Parameters

By selecting menu item Parameters in the File list a new window will appear (see figure 7). In this window named **Input Parameters** specific settings and data files used by WINLAS can set. In this window 6 categories can be seen. Under category **Input file** and **Parameters** the LAS/XLAS user is able to select input files and specify its format (header and separator) and the data columns sequence. In case the data file contains wind speed data the height of the anemometer and temperature sensor must be given. If no temperature and air pressure data is available constant values can be given. Under category **Terrain** the terrain characteristics (i.e. roughness length \( z_0 \) and zero-displacement height \( d \)) where the LAS is installed can be set (see appendix III). Category **LAS/XLAS** is used to specify the path length that is set by the Path length dial knob at the back panel of the receiver, the real path length, the LAS type (either 0.1m-LAS, LAS or XLAS), and its effective beam height (for more information about the effective beam height see appendix II). Note that the path length correction should only be used for small corrections! In case no Bowen Ratio data is available a realistic constant value can be defined in category **Bowen Ratio**. Finally, under category **Minimum signal strength** the minimum signal strength value is set. This value is used to check the validity of the LAS measurements. For situations the signal strength drops below this minimum value WINLAS will reject the \( C_n^2 \) data.

Figure 7: WINLAS Input parameters menu.

File → Run

Menu item Run will start the calculations and write the results to an output file. Before the calculations start the program will check whether the output file already exists. If so, the user is asked to either change the name or to press OK to overwrite the existing file.
File → Exit

The program WINLAS will be closed and its settings will be saved automatically in WINLAS.ini.

View → Input

Once an input file is selected in the Parameter menu, the menu item Input under View is enabled. Clicking this menu item will open the input file for viewing and editing.

View → Output

Once WINLAS has derived the fluxes from an input file the menu item Output is enabled. Clicking this menu item will open the output file for viewing and editing.

5.4 THE INPUT FILE

The data input file should be an ASCII file consisting of columns (with or without a header), which are separated by a comma, semicolon, a space or a tab. The first two data columns should always be a date stamp (or day number, DOY) and a time stamp, followed by LAS/XLAS data (\(C_n^2\) and signal strength) and additional meteorological data (namely \(T\), \(u\), \(P\) and \(\beta\)). Header lines are the number of lines that will be skipped by the program before reading the actual data columns. If there is no header this value should be 0.

⚠️ Important: The maximum allowed number of data columns in the input file is 8, including the Date/DOY and Time columns!

The following LAS and additional meteorological data can be read by WINLAS:

- * \(C_n^2\) [m\(^{-2/3}\)]
- * UCn2 [V] (i.e. \(U_{CN2}\) of the LAS/XLAS) preferably in combination with VarUCn2 [V\(^2\)] (i.e. the variance of \(U_{CN2}\), namely \(\sigma_{U_{CN2}}^2\)) selected in the following data column. \(C_n^2\) is calculated according to equation 3.
- * PUCn2 [\(\cdot\)] (i.e. scaled \(C_n^2\), which is stored by the CR10X Campbell program example shown in appendix IV). \(C_n^2\) is calculated according to equation 4.
- Signal strength [mV] (i.e. \(U_{DEMOD}\) of the LAS/XLAS)
- Air temperature (\(T\)) [°C] (between -30 and +50 °C)
- Air pressure (\(P\)) [hPa] (between 950 and 1080 hPa)
- Wind speed (\(u\)) [m s\(^{-1}\)] (between 0 and 100 m s\(^{-1}\))
- Bowen ratio (\(\beta\)) [-] (between -10 and +10)
- Empty

* CHOOSE ONLY ONE OF THESE THREE OPTIONS!

⚠️ Important: In case of missing or invalid data the following Dummy value should be used in the input file: -9999. Other dummy values are not accepted by WINLAS.
<table>
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<th>Doy</th>
<th>Time [UTC]</th>
<th>$U_{CN2}$ [V]</th>
<th>Demod $[\text{mV}]$</th>
<th>Var $U_{CN2}$ [V$^2$]</th>
<th>PU$_{CN2}$ [\text{m/s}]</th>
<th>$u$ [m/s]</th>
<th>$T$ [°C]</th>
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</table>

Figure 8: example of an input file (contains 10-minute averages of LAS and additional data).

Note that the data file in figure 8 contains two columns with $C_n^2$ information, option 1: column 3 combined with column 5 and option 2: column 6. In this case only one of these two options must be selected in WINLAS and NOT both.

If temperature, air pressure and Bowen ratio data are selected in columns 3 to 8, the input boxes for constant values for temperature, air pressure and Bowen ratio will be disabled. In case no wind speed data is available WINLAS calculates the sensible heat flux using the free convection approach only.
5.5 THE OUTPUT FILE

Once an input file is selected, the output file is given the same name with extension .las. The output file is an ASCII file and contains the following data columns:

- Date or Day number (=DOY)
- Time
- $C_n^2$ [m$^{-2/3}$]
- Demod [mV]
- $H_{\text{unstable}}$ [W m$^{-2}$] (sensible heat flux, unstable (or day-time) solution)
- $H_{\text{stable}}$ [W m$^{-2}$] (sensible heat flux, stable (or night-time) solution)
- $H_{\text{free convection}}$ [W m$^{-2}$] (sensible heat flux, free convection solution)
- Wind speed [m s$^{-1}$]
- $u_{\text{unstable}}$ [m s$^{-1}$] (friction velocity, unstable solution)
- $u_{\text{stable}}$ [m s$^{-1}$] (friction velocity, stable solution)
- $L_{\text{MO, unstable}}$ [m] (Obukhov length, unstable solution)
- $L_{\text{MO, stable}}$ [m] (Obukhov length, stable solution)
- Bowen ratio [-]
- Air temperature [$^\circ$C]
- Relative humidity [%]
- Air pressure [hPa]
- Air density [kg m$^{-3}$]
- Comment saturation (“no saturation”, “-” or “possible saturation”)
6. MAINTENANCE

To be certain that the quality of the data is of high standard, care must be taken with the maintenance of the LAS/XLAS. Regular cleaning of the windows and checking the alignment (using telescopes) will prevent unnecessary signal attenuation and data loss. Also periodically check the condition of all cables and connectors.

**Important:** Always keep power connected and switched on to the LAS/XLAS transmitter and receiver when they are placed outside to prevent condensation.

Periodically check if there is no condensation inside the transmitter and receiver units (see humidity indicator or look at front window for condensation). Follow the instructions given by the humidity indicator, which is visible through the rear window of the back panel of both units. Depending on climate conditions and the number of times the units are opened, the silica gel bags have to be replaced once in a while. We recommend not opening the units unless necessary (e.g. during installation or re-alignment). The LED current of the transmitter, signal strength at the receiver and power indicator can be easily checked via the rear window during periodically checks, without removing the rear panel.

![Humidity Indicator](image)

**Figure 9:** Humidity indicator (Type B2, 30% .. 40% .. 50%).

How to deal with internal condensation? First try to find the leak. Is it the amphenol connector or was the back panel not properly closed? Because the electronics of the LAS/XLAS don’t dissipate enough power internally, one has to dry out the LAS/XLAS (Transmitter and/or receiver) as follows (see also figure 10):

1. Take the LAS/XLAS unit inside.
2. Remove the rear cover.
3. Disconnect the cable connector from the control plate.
4. Undo the 4 screws holding the control plate and carefully pull it out.
5. Disconnect the cables that connect the control plate to the printed circuit board (pcb) behind
6. Remove the six screws at the front holding the window assembly to the housing. Be careful not to lose the screws and the rubber O-rings (6 small and 1 large). For details see figure 10.
7. Gently lift out the lens/heater ring assembly and disconnect the power cable from the heater to the bullet. Do NOT disassemble the housing any further because this might affect the optical alignment of the transmitting LED and/or receiving photo-diode!

Dry the inside of the housing as much as possible and clean off any surface corrosion. Clean the window and Fresnel lens using a dry tissue (and/or dust free blower). If the lens is still dirty then a mild soap solution can be used. The Fresnel lens is a moulded plastic component - do NOT use solvents to clean it!

Leave the housing open to dry for a couple of hours/days (depending on room temperature) and reassemble in the reverse order. Note that the Fresnel lens is mounted with the grooved surface facing outwards towards the window. Clean any hard grease off the o-ring seals and apply silicone grease before reassembly (if not available Vaseline will do). The front and rear covers screw down to make metal-to-metal contact with the housing when the o-rings are properly compressed.

Figure 10: Window - Fresnel - Heating ring assembly.
7. CALIBRATION

7.1 ON-SITE CALIBRATION CHECK

The purpose of the electronics in the LAS/XLAS receiver unit is to provide real-time values for $C_n^2$ but scaled in voltage units, which can be recorded by data acquisition systems. The electronics perform the following steps: detection with feed-back circuit to remove slow ambient fluctuations; demodulation of the carrier signal; low-pass filtering at 400 Hz to remove high-frequency noise; producing the logarithm of the signal intensity; removing any offsets; path length correction (i.e. adjustment of Gain); filtering the scintillation bandwidth between 0.2 Hz and 400 Hz; calculation of the variance of the conditioned signal. In addition to the analogue pre-processing, calibration circuitry provides the user a quick on-site check of the performance of the real-time $C_n^2$ calculations.

By setting the receiver control panel switch labelled Mode to Calibration a reference signal of a known modulation and carrier frequency is sent through the analogue processing circuitry. This reference signal consists of a 7 kHz ($\pm$ 0.7 kHz) square-wave carrier modulated by a 10 Hz ($\pm$ 1 Hz) square-wave with a modulation depth of 50%. This reference signal can be monitored at the BNC socket labelled Carrier with an oscilloscope. Due to additional filters this reference signal is slightly distorted. However, the modulated signal is still recognisable.

By adjusting the Path Length dial knob of the LAS to a setting of 593.5 (equal to $L = 1184$ m) and for the XLAS a setting of 414.1 (equal to $L = 2152$ m), zero volts should be measured at BNC socket $\log C_n^2$. If the signal is not 0 V ($\pm$ 15 mV) after 1 hour of warm-up time, the receiver electronics need to be recalibrated. In table 10 a range of output values are given for different Path Length dial knob settings when set in Calibration mode.

**Important**: When performing a calibration check the LAS/XLAS receiver should be connected to a stable power supply and the environmental temperature must be constant at close to room temperature.

### Table 10: Output signal $U_{Cn2}$ at BNC socket (of LAS/XLAS) as a function of the Path Length dial knob setting (in Calibration mode) at constant room temperature.

<table>
<thead>
<tr>
<th>$Pot_{LAS}$</th>
<th>LAS $U_{Cn2}$ at BNC [mV]</th>
<th>$Pot_{XLAS}$</th>
<th>XLAS $U_{Cn2}$ at BNC [mV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1415</td>
<td>200</td>
<td>813</td>
</tr>
<tr>
<td>300</td>
<td>1004</td>
<td>300</td>
<td>402</td>
</tr>
<tr>
<td>400</td>
<td>650</td>
<td>400</td>
<td>48</td>
</tr>
<tr>
<td>500</td>
<td>316</td>
<td>414</td>
<td>0.0</td>
</tr>
<tr>
<td>594</td>
<td>0.0</td>
<td>500</td>
<td>-286</td>
</tr>
<tr>
<td>700</td>
<td>-398</td>
<td>600</td>
<td>-626</td>
</tr>
<tr>
<td>800</td>
<td>-859</td>
<td>700</td>
<td>-1000</td>
</tr>
<tr>
<td>884</td>
<td>-1415</td>
<td>800</td>
<td>-1462</td>
</tr>
</tbody>
</table>
7.2 RECALIBRATION

The electronics of the LAS/XLAS receiver unit can change with time and with temperature. Therefore periodic checking of the electronic (see Section 6.1) is advised. If the signal is not within ± 15 mV of the values given in table 10 for different Path Length knob settings (check at least 5 different pot settings) the receiver electronics need to be recalibrated.

To return a LAS/XLAS to Kipp & Zonen for recalibration the use of the recalibration form at the end of this manual is strongly recommended.

7.3 CALIBRATION PROCEDURE AT KIPP & ZONEN

7.3.1 Calibration procedure RMS-circuits

The receiver electronics contain two RMS-circuits that operate in logarithmic mode. The purpose of the first RMS-circuit is to obtain the log of the received signal intensity. This circuit is calibrated for an arbitrary zero point (offset) and a fixed gain, using two reference voltages of 1.000 V and 0.100 V.

The purpose of the second RMS-circuit is to calculate the RMS of the amplified and filtered log intensity fluctuations (i.e. the conditioned signal). As the first RMS-circuit, the second circuit also requires calibration for offset and gain.

Because both RMS-circuits operate in log-mode an extra temperature-dependant resistor is added, which compensates for the temperature dependence of the (dB) output of the RMS IC’s. Therefore the electronics require at least 1-hour warm-up time.

7.3.2 Calibration path length

For the calibration of the Path Length dial knob setting an artificial signal is used with a carrier frequency of ~ 7 kHz, which is amplitude modulated with a block signal with a frequency of ~ 10 Hz and a modulation depth of 50%. This signal is directly fed to the demodulator unit (see also Paragraph 7.1).
8. SOLVING PROBLEMS

The LAS/XLAS is designed for both long and short periods of operation with little operator maintenance. However, if a problem occurs that cannot be corrected using the standard operating information supplied in the preceding sections of this manual, use the information in this chapter to identify and solve the problem.

If the problem cannot be corrected after reviewing the information in the following section, contact Kipp & Zonen. When contacting Kipp & Zonen with technical assistance questions, ensure that you have the following information readily available to aid the technician in solving your problem:

- The model number and serial number of the LAS/XLAS. This information is listed on the identification labels, located on the pan and tilt adjusters of the LAS/XLAS transmitter and receiver.

If you cannot solve the problem by the steps on the following pages, please contact Kipp & Zonen.

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8.1 PROBLEM CHECK-LIST

Check the items in the following list. If these do not help, see the following section on troubleshooting.

Check that:

- Power is supplied to both the LAS/XLAS transmitter and receiver unit.
- The data cables are correctly connected to the data logger or data acquisition unit.

8.2 TROUBLESHOOTING

Table 11: Troubleshooting.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Corrective action</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED indicator on back panel is off</td>
<td>Check the power fuse, see Paragraph 3.6.3</td>
</tr>
<tr>
<td></td>
<td>Check wires</td>
</tr>
<tr>
<td>The receiver has no signal</td>
<td>• Check power to transmitter and receiver units</td>
</tr>
<tr>
<td></td>
<td>• Check if windows are clean (and lenses) and there is no internal condensation (see section 6 for instructions)</td>
</tr>
<tr>
<td></td>
<td>• Check alignment (using telescopes)</td>
</tr>
<tr>
<td></td>
<td>• Check for obstacles in the path of the beam</td>
</tr>
<tr>
<td></td>
<td>• Check the performance of the transmitter electronics at the BNC socket labeled LED pulse</td>
</tr>
<tr>
<td></td>
<td>• Check the performance of the real-time $C_n^2$ calculations of the receiver electronics by setting the receiver to Calibration mode</td>
</tr>
</tbody>
</table>
APPENDIX I – THEORY SCINTILLATION TECHNIQUE

When an electro-magnetic (EM) beam of radiation propagates through the atmosphere it is distorted by a number of processes. These processes remove energy from the beam and lead to attenuation of the signal. The most serious mechanism that influences the propagation of EM radiation is small fluctuations in the refractive index of the air \((n)\). These refractive index fluctuations lead to intensity fluctuations, which are known as scintillations.

A scintillometer is an instrument that can measure the ‘amount’ of scintillations by emitting a beam of light over a horizontal path. The scintillations ‘seen’ by the instrument can be expressed as the structure parameter of the refractive index of air \((C_n^2)\), which is a representation of the ‘turbulent strength’ of the atmosphere. The turbulent strength describes the ability of the atmosphere to transport scalars, such as heat, humidity and other species (dust particles, atmospheric gases). For a Large Aperture Scintillometer (LAS/XLAS) with equal transmitting and receiving apertures the relationship between the measured variance of the natural logarithm of intensity fluctuations \((\sigma_{\ln I}^2)\) and the structure parameter is as follows (Wang et al., 1978)

\[
C_n^2 = 1.12 \sigma_{\ln I}^2 D^{7/3} L^{-3},
\]

where \(D\) is the aperture diameter of the LAS/XLAS and \(L\) the distance between the transmitter and the receiver (i.e. the path length). The figure below shows an example of the diurnal cycle of the structure parameter of the refractive index of air derived from a LAS for a sunny day. Typical values of \(C_n^2\) lie between \(10^{-15}\) and \(10^{-18}\) m\(^{-2/3}\).

![Figure 11: Example of diurnal cycle of \(C_n^2\) obtained with a LAS for a sunny day. LAS setup: effective height roughly 40m and the path length 4.4 km.](image)

In figure 11 the \(C_n^2\) values show a distinct drop around 6:00 and 18:00, sunrise and sunset, respectively. Around sunrise the atmosphere changes from stable to unstable conditions and around sunset the atmosphere changes again from unstable to stable conditions.

In the atmosphere temperature \((T)\), humidity \((Q)\) and to a lesser extend pressure \((P)\) fluctuations cause air density fluctuations and with it fluctuations in the refractive index of air \((n)\). Therefore the structure parameter of the refractive index, \(C_n^2\), can be decomposed into the structure parameters of...
temperature $C_n^2$, humidity $C_Q^2$ and the covariant term $C_{TQ}$ as follows (neglecting pressure fluctuations) (Hill et al., 1980)

$$C_n^2 = \frac{A_T^2}{T^2} C_T^2 + \frac{2 A_T A_Q}{TQ} C_{TQ} + \frac{A_Q^2}{Q} C_Q^2. \quad (6)$$

$A_T$ and $A_Q$ are functions of the wavelength and the mean values of temperature, absolute humidity and atmospheric pressure and thus represent the relative contribution of each term to $C_n^2$. In the visible and near-infrared wavelength region of the EM spectrum $A_T$ and $A_Q$ are defined as follows (Andreas, 1988)

$$A_T = -0.78 \cdot 10^{-6} \left( \frac{P}{T} \right) + 0.126 \cdot 10^{-6} R_v Q, \quad (7)$$

$$A_Q = -0.126 \cdot 10^{-6} R_v Q, \quad (8)$$

where $R_v$ is the specific gas constant for water vapour (461.5 J K$^{-1}$ kg$^{-1}$). Typical values for $A_T$ and $A_Q$, for ‘normal atmospheric’ conditions ($P = 1.0 \times 10^5$ Pa, $T = 288$ K and $Q = 0.012$ kg m$^{-3}$), are $-0.27 \cdot 10^{-3}$ and $-0.70 \cdot 10^{-6}$, respectively. Because $A_T$ is much larger than $A_Q$ the contribution of humidity related scintillations is much smaller than temperature related scintillations, i.e. the near-infrared LAS/XLAS is primarily sensitive to temperature related scintillations. Therefore a simplified expression can be derived, which makes it possible to derive $C_T^2$ from $C_n^2$ as follows (Wesely, 1976)

$$C_n^2 \approx \frac{A_T^2}{T^2} C_T^2 \left(1 + \frac{0.03}{\beta} \right)^2 \quad \text{or} \quad C_n^2 \approx \left(- \frac{0.78 \cdot 10^{-6} P}{T^2} \right)^2 C_T^2 \left(1 + \frac{0.03}{\beta} \right)^2, \quad (9)$$

where $\beta$ is the Bowen ratio, which is a correction for term for humidity related scintillations. The Bowen ratio is defined as the ratio between the sensible heat ($H$) and latent heat flux ($L_e E$), i.e. $\beta = \frac{H}{L_e E}$. When the surface conditions are dry $H$ is larger than $L_e E$, resulting in high $\beta$ values (> 3). This means that the correction term in the latter equation is small. Over wet surfaces $\beta$ is small (< 0.5), which means that a significant amount of scintillations are caused by humidity fluctuations, resulting in a large correction. Thus when the surface conditions are very dry, $C_T^2$ is directly proportional to $C_n^2$

$$C_n^2 \approx \frac{A_T^2}{T^2} C_T^2 \quad \text{or} \quad C_n^2 \approx \left(- \frac{0.78 \cdot 10^{-6} P}{T^2} \right)^2 C_T^2. \quad (10)$$

Once $C_T^2$ is known, the sensible heat flux ($H$) can be derived from similarity relationships that have been derived for $C_T^2$ which are based on the Monin-Obukhov Similarity Theory (MOST) (Wyngaard et al., 1971)

$$\frac{C_T^2 \left(z_{LAS} - d \right)^{2/3}}{T^2} = f_T \left( \frac{z_{LAS} - d}{L_{MO}} \right) \quad (L_{MO} < 0), \quad (11)$$

where $d$ is the zero-displacement height (see appendix III), $z_{LAS}$ the effective height of the scintillometer beam above the surface (Hartogensis et al., 2003), $T_*$ is a temperature scale defined as

$$T_* = \frac{-H}{\rho c_p u_*}, \quad (12)$$
and $L_{MO}$ is the Obukhov length

$$ L_{MO} = \frac{u_*^2 T}{g k_v T}, $$

where $\rho$ is the density of air ($\sim 1.2 \text{ kg m}^{-3}$), $c_p$ the specific heat of air at constant pressure ($\sim 1005 \text{ J kg}^{-1} \text{ K}^{-1}$), $k_v$ the von Kármán constant ($\sim 0.40$), $g$ the gravitational acceleration ($\sim 9.81 \text{ m s}^{-2}$) and $u_*$ the friction velocity. The universal stability function $f_T$ is defined as follows for unstable (day-time, $L_{MO} < 0$)

$$ f_T \left( \frac{z_{LAS} - d}{L_{MO}} \right) = c_{T1} \left( 1 - c_{T2} \frac{z_{LAS} - d}{L_{MO}} \right)^{-2/3} (L_{MO} < 0), $$

where $c_{T1} = 4.9$ and $c_{T2} = 6.1$ and for stable (night-time, $L_{MO} > 0$) conditions as

$$ f_T \left( \frac{z_{LAS} - d}{L_{MO}} \right) = c_{T1} \left( 1 + c_{T3} \frac{z_{LAS} - d}{L_{MO}} \right)^{2/3} (L_{MO} > 0), $$

where $c_{T2} = 2.2$ (see Andreas, 1988; De Bruin et al., 1993; Wyngaard et al., 1971).

⚠️ **Important:** There is no consensus about the stability function for stable (night-time) conditions!

In order to derive $H$ from $C_T^2$, the friction velocity ($u_*$) is required. The friction velocity can be obtained from additional wind speed data ($u$) and an estimate of the surface roughness ($z_0$) (Panofsky and Dutton, 1984) (see appendix III)

$$ u_* = \frac{k_v u}{\ln \left( \frac{z_v - d}{z_0} \right) - \Psi_m \left( \frac{z_v - d}{L_{OM}} \right) + \Psi_m \left( \frac{z_v}{L_{OM}} \right) }, $$

where $z_v$ is the height at which the wind speed is measured and $\Psi_m$ is the integrated stability function for momentum defined as (for unstable conditions (day-time))

$$ \Psi_m \left( \frac{z}{L_{MO}} \right) = 2 \ln \left[ \frac{1 + x}{2} \right] + \ln \left[ \frac{1 + x^2}{2} \right] - 2 \arctan(x) + \frac{\pi}{2} (L_{MO} < 0), $$

with

$$ x = \left( 1 - 16 \frac{z}{L_{MO}} \right)^{1/4}, $$

or (stable conditions (night-time))
In summary, $C_n^2$ data together with additional wind speed, temperature data and an estimates of the surface roughness and the displacement height (see appendix III), the sensible heat flux can be determined from equations 11 to 19, which can be solved iteratively (see also figure 13).

For most day-time (unstable) conditions and when the LAS is installed relatively high above the surface ($z_{LAS} > 20$ m) the contribution of the friction velocity is relatively small. For these conditions the free convection method can be applied

$$H_{free} = \rho c_p b (z_{LAS} - d) \left(\frac{g}{T}\right)^{1/2} \left(C_T^2\right)^{3/4},$$

where $b$ is an empirical constant ($b = \sqrt{\frac{1}{C_{T1}^2}} k_c T_2 \approx 0.48$). The latter expression is also known as the free convection approach and provides a simple method to determine $H$ directly from $C_T^2$ without knowing $u^*$. In practical applications the free convection approach can provide accurate fluxes when the scintillometer is installed relatively high above the surface ($z_{LAS} > 20$ m) (see figure 14).

Figure 12: Example of $H$ and $H_{free}$ derived from a LAS (unstable period only).
Finally, when additional net radiation ($Q^*$) and soil heat flux ($G_s$) data are available, the latent heat flux $L_E$ (or actual evaporation) can be estimated applying the surface energy balance equation (see figure 15).
\[ Q^* = H + L_r E + G_s \]  \hspace{1cm} (21)

Figure 15: Example of time series of net radiation, soil heat flux, sensible heat flux and latent heat flux.

Complete list of required data/information for deriving sensible heat fluxes:

- **LAS/XLAS** – mean of \( C_n^2 \) (derived from \( U_{GN2} \))
- **LAS/XLAS** – mean of signal strength (or \( U_{demod} \))
- **LAS/XLAS** – variance of signal strength (or \( U_{demod} \))
- **LAS/XLAS** – path length (\( L \))
- **LAS/XLAS** – average (effective) beam height (\( z_{LAS} \)) (see appendix II)
- Zero-displacement height (\( d \)) (see appendix III)
- Air pressure (\( P \))
- Air temperature (\( T \))
- Wind speed (\( u \))
- Bowen ratio (\( \beta \))
- Height(s) of cup anemometer(s) (\( z_u \))
- Surface roughness (i.e. roughness length) of source area **LAS**/wind speed measurements (\( z_o \)) (see appendix III)

Other useful meteorological data:

- Radiation data (Global radiation, net radiation)
- Soil heat flux data
- Wind direction
- Rainfall
References


APPENDIX II – PATH-WEIGHTING FUNCTION LAS/XLAS

The LAS/XLAS provides a measure of the structure parameter of the refractive index of air ($C_n^2$), weighted over the path length ($L$). For equal sized transmitter and receiver apertures this path-weighting function is symmetrical bell-shaped having a centre maximum and tapering to zero at the transmitter and receiver end (see figure 16). This means that the LAS/XLAS is most sensitive in the middle of its path. In figure 17 an example is shown how the weighting function has to be used in order to estimate the precise height of the beam of the LAS/XLAS above the surface for non-flat areas. For further details the reader is referred to Hartogensis et al. (2003).

Figure 16: The path-weighting function of the (X)LAS.

Figure 17: Example of a LAS setup over a non-flat area. Based on the elevation map and the path-weighting function an effective LAS height of 46 m was found.
APPENDIX III – ROUGHNESS LENGTH & DISPLACEMENT HEIGHT

The roughness length \((z_0)\)

The aerodynamic roughness length or surface roughness \((z_0)\) is an expression for the roughness of the earth’s surface. It affects the intensity of mechanical turbulence and the fluxes of sensible heat \((H)\), latent heat \((L, E)\) and momentum above the surface. The roughness length depends on the surface (or terrain) characteristics. For example a grassy plain has a smaller roughness length than an area with many trees and buildings. The surface roughness is loosely related to the typical height \((h)\) of closely spaced surface obstacles, often called roughness elements (e.g. water waves, trees, buildings, blades of grass). It depends on the distribution as well as the height of roughness elements \((h)\).

\[ \text{DENSE:} \]
- low roughness length \((z_0)\)
- high zero-displacement height \((d)\)

\[ \text{SPARSE:} \]
- high roughness length \((z_0)\)
- low zero-displacement height \((d)\)

Figure 18: Dependence of the roughness length and zero-displacement height on height and density of roughness elements (e.g. trees).

In table 12 eight different terrain classifications are given plus their typical roughness length.

Table 12: Terrain classifications.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Roughness length [m]</th>
<th>Landscape features</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Name</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sea</td>
<td>0.0002</td>
</tr>
<tr>
<td>2</td>
<td>Smooth</td>
<td>0.005</td>
</tr>
<tr>
<td>3</td>
<td>Open</td>
<td>0.03</td>
</tr>
<tr>
<td>4</td>
<td>Roughly open</td>
<td>0.1</td>
</tr>
<tr>
<td>5</td>
<td>Rough</td>
<td>0.25</td>
</tr>
<tr>
<td>6</td>
<td>Very rough</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>Closed</td>
<td>1.0</td>
</tr>
<tr>
<td>8</td>
<td>Chaotic</td>
<td>&gt; 2.0</td>
</tr>
</tbody>
</table>
When the **LAS/XLAS** are installed over natural landscapes, which are mostly heterogeneous (and a path length of several kilometers) we recommend using table 12 for determining a representative roughness length, if necessary focus on the area in the middle of the path of the **LAS/XLAS** (most important area, see appendix II). In case the **LAS/XLAS** are installed over a relative homogeneous area (e.g. a (dense) agricultural field or (dense) forest) it is best to apply a simple rule of thumb:

\[ z_0 = 0.1h \]  

(22)

**The zero-displacement height (d)**

If the area surrounding the **LAS/XLAS** site consists of roughness elements that are packed very closely together like a dense forest or a dense crop, the top of those elements begin to act like a displaced surface, which is known as the zero-displacement height (\(d\)).

It is difficult to determine the zero-displacement height. The only proper way to derive the zero-displacement height is from wind profile data. There is simple rule of thumb to derive the displacement height from the crop height:

\[ d = 0.7h \]  

(23)

However, note that this rule of thumb is not accurate, especially when the crop/forest is not densely packed! In case the roughness elements are not closely packed (see figure 18 (left)) we recommend not using a zero-displacement height (i.e. \(d = 0\)).

**Additional comments/suggestions**

During daytime conditions with high solar insolation and when the **LAS/XLAS** are installed relatively high above the surface (> 20 m) the free convection method can be applied (see appendix I). Under those conditions the importance of the roughness length is small, meaning that the sensible heat flux (\(H\)) is not very sensitive to changes in \(z_0\). However, during nighttime periods the roughness length becomes very important and can have large effects on the sensible heat flux (and also \(L_v E\)).

In case one has to apply a zero-displacement height it might be necessary to spatially weight \(d\) also using the weighting function of the **LAS/XLAS** (see appendix II).

In case the zero-displacement is difficult to determine (as roughness elements are not densely packed), one can minimize the (relative) effect of \(d\) on the sensible heat flux by installing the **LAS/XLAS** higher above the surface.
APPENDIX IV – HEATER AND THERMISTOR

Both the LAS/XLAS transmitter and the receiver units have an integral heater ring for keeping the Fresnel lens and window clear of dew/condensation/snow. The heater of the LAS is self-regulating working to maintain a constant 55 °C temperature the ring will initially draw more than 1A current when first switched on. At around 22 °C room temperature the heater resistance is 17 ohms. Power to the ring is independent of the other electronics and the user can decide whether this higher power demand mode is necessary, particularly if remote site operation is to be considered. The heater of the XLAS is not self-regulating. Instead it constantly draws 1.2A current.

The heater ring is in thermal contact with the Fresnel lens and the front window but electrically insulated from the body of the LAS/XLAS. This assembly connects to the printed circuit boards mounted on the transmitter and receiver bullets. These connectors are 4-way providing an option for signal sensing a thermistor mounted on the heater ring assembly.

Ambient temperature inside the LAS/XLAS receiver and transmitter units are monitored by NTC thermistors connected to the printed circuit boards and in thermal contact with the bullet. This thermistor forms half of a voltage divider and a scaled voltage output is available at the internal and external bulkhead sockets. The calibration formulae for the transmitter and receiver units are as follows

**LAS transmitter:**

\[ T = 71.54 - 20.39U_{TH} + 1.21U_{TH}^2 \]  

(24)

**LAS receiver:**

\[ T = 71.54 - 10.87U_{TH} + 0.35U_{TH}^2 \]  

(25)

For example if the receiver output voltage, \( U_{TH} = 5.0 \) V then from the above equation the ambient temperature is about 26 °C inside the receiver unit. The rubber sealing O-ring between the front cap and the main tube provides a degree of thermal insulation and as the heater ring temperature stabilises a thermal difference is generated across the ring. The ambient temperature inside the tube will be observed to increase preventing the onset of condensation on the optics. Important to note is that the heater power consumption is > 12 Watt. The user can decide by themselves whether to use the heater or not, since the power supply of the heater is independent of the receiver/transmitter electronics (see table 4 and 5).
APPENDIX V – CR10X CAMPBELL PROGRAM

Comments program:

Data logger: CR10X (Campbell Scientific)
Differential channel 1: log Cn2 signal LAS/XLAS (i.e. \( U_{CN2} \)) (including voltage divider)
Differential channel 2: demod signal \( U_{DEMOD} \) or signal strength \( I \)
Sampling rate: 1 Hz
Averaging time: 10 minutes

Because the output signal of the LAS/XLAS \( U_{LAS} \) has a range between –5 V and 0 V, a voltage divider is used to rescale this output signal to –2.5 V and 0 V that can be measured by the CR10X data logger. The program will start measuring when a full 10-minute interval is reached. This means that when the data logger is switched on it will wait until exactly 0, 10, 20, 30, 40 or 50 minutes (and 0 seconds) after a hour before collecting data. After a 10-minute interval the mean values of \( U_{CN2} \), \( U_{DEMOD} \) and \( P_{UCN2} \), the variances of \( U_{CN2} \) and \( U_{DEMOD} \), and a counter \( N \) (should be 600) are stored. To avoid overflow problems in the data logger memory when using processing instruction P62 (for calculating variances) that can be caused by large numbers, the first measurement values of each 10-minute interval are subtracted from the following measurements.

;{CR10X}
*
Table 1 Program
  01: 1 Execution Interval (seconds)
    ; Start measurements at a full 10-minute interval
  1: If time is (P92)
    1: 0 Minutes (Seconds --) into a
    2: 10 Interval (same units as above)
    3: 12 Set Flag 2 High
  2: If Flag/Port (P91)
    1: 22 Do if Flag 2 is Low
    2: 30 Then Do
    3: Beginning of Loop (P87)
      1: 0 Delay
      2: 12 Loop Count
    4: Z=F (P30)
      1: 0 F
      2: 0 Exponent of 10
      3: 1 \( \rightarrow Z \) Loc [ UCN2 ]
    5: Z=F (P30)
      1: 0 F
      2: 0 Exponent of 10
      3: 6 \( Z \) Loc [ N ]
    6: End (P95)
  7: End (P95)
  8: If Flag/Port (P91)
    1: 22 Do if Flag 2 is Low
    2: 0 Go to end of Program Table

; Do measurements of CN2 signal LAS in Volts
9: Volt (Diff) (P2)
  1: 1 Reps
  2: 35 2500 mV 50 Hz Rejection Range (for countries with 60 Hz power grid, use 25)
  3: 1 DIFF Channel
  4: 1 Loc [ UCN2 ]
  5: 0.002 Mult (conversion mV → V and correction for voltage divider)
  6: 0 Offset

; Do measurements of demod (or signal strength) signal LAS

10: Volt (Diff) (P2)
  1: 1 Reps
  2: 35 2500 mV 50 Hz Rejection Range (for countries with 60 Hz power grid, use 25)
  3: 2 DIFF Channel
  4: 2 Loc [ demod ]
  5: 1 Mult
  6: 0 Offset

; At the beginning of each measurement interval the first measurements
; are stored. The initial values are used to subtract the following
; measurements resulting in signals that fluctuate close to zero. These
; small values prevent overflow problems of the data logger.

11: If Flag/Port (P91)
  1: 23 Do if Flag 3 is Low
  2: 1 Call Subroutine 1

; Calculate 10^\(UCN2\)

12: Z=F (P30)
  1: 10 F
  2: 0 Exponent of 10
  3: 3 Z Loc [ Ten ]

13: Z=X^Y (P47)
  1: 3 X Loc [ Ten ]
  2: 1 Y Loc [ UCN2 ]
  3: 4 Z Loc [ PowerUCN2 ]

; Calculate 10^\(UCN2\)*1000

14: Z=X*F (P37)
  1: 4 X Loc [ PowerUCN2 ]
  2: 1000 F
  3: 5 Z Loc [ PUCN21000 ]

; Counter

15: Z=X+F (P34)
  1: 6 X Loc [ N ]
  2: 1 F
  3: 6 Z Loc [ N ]

; Subtract initial values from measurement signals

16: Z=X-Y (P35)
  1: 1 X Loc [ UCN2 ]
  2: 7 Y Loc [ UCN2_c ]
  3: 9 Z Loc [ UCN2_P62 ]

17: Z=X-Y (P35)
1: 2  X Loc [ demod    ]
2: 8  Y Loc [ demod_c  ]
3: 10 Z Loc [ demod_P62 ]

; After 10-minutes write data to final storage.

18: If time is (P92)
   1: 0  Minutes (Seconds --) into a
   2: 10 Interval (same units as above)
   3: 10 Set Output Flag High (Flag 0)

19: Covariance/Correlation (P62)
   1: 2  No. of Input Locations
   2: 00 No. of Means
   3: 2  No. of Variances
   4: 00 No. of Std. Dev.
   5: 00 No. of Covariance
   6: 00 No. of Correlations
   7: 600 Samples per Average
   8: 9  First Source Loc [ UCN2_P62  ]
   9: 11 First Destination Loc [ Var_UCN2 ]

(Instruction 82 can also be used to calculate the standard deviation)

20: Real Time (P77)
   1: 110 Day,Hour/Minute (midnight = 0000)

21: Average (P71)
   1: 2  Reps
   2: 1  Loc [ UCN2      ]

22: Sample (P70)
   1: 2  Reps
   2: 11 Loc [ Var_UCN2  ]

23: Resolution (P78)
   1: 1  High Resolution

24: Average (P71)
   1: 1  Reps
   2: 5  Loc [ PUCN21000 ]

25: Resolution (P78)
   1: 0  Low Resolution

26: Sample (P70)
   1: 1  Reps
   2: 6  Loc [ N         ]

; Set Flag 3 low to store new first values for next interval.

27: If time is (P92)
   1: 0  Minutes (Seconds --) into a
   2: 10 Interval (same units as above)
   3: 30 Then Do

28: Do (P86)
   1: 23  Set Flag 3 Low

29: Z=F (P30)
   1: 0  F
   2: 0  Exponent of 10
   3: 6  Z Loc [ N     ]
30: End (P95)

*Table 2 Program
  02: 0.0000 Execution Interval (seconds)

*Table 3 Subroutines;
1: Beginning of Subroutine (P85)
  1: 1 Subroutine 1

2: Do (P86)
  1: 13 Set Flag 3 High

3: Block Move (P54)
  1: 2 No. of Values
  2: 1 First Source Loc [ UCN2 ]
  3: 1 Source Step
  4: 7 First Destination Loc [ UCN2_c ]
  5: 1 Destination Step

4: End (P95)

End Program

Input Locations CR10X:

1. UCN2 (= \( U_{CN2} \))
2. demod (or signal strength) (= \( U_{DEMOD} \))
3. Ten
4. PowerUCN2
5. PUCN21000 (= \( P_{U_{CN2}} \))
6. N (counter, \( N = 600 \))
7. UCN2_c
8. demod_c
9. UCN2_P62
10. demod_P62
11. Var_UCN2 (= \( \sigma^2_{U_{CN2}} \))
12. Var_demod (= \( \sigma^2_{U_{DEMOD}} \))

Format output file, downloaded from CR10X memory:

Dummy, Doy, Time(HH:MM), UCN2, demod, var_UCN2, var_demod, PUCN21000 (= PUCn2), N

\( C_n^2 \) can be calculated as follows (two options, see paragraph 4):

\[
C_n^2 = 10^{(U_{CN2} -12 +1.15 \sigma^2_{CN2})}
\]

\[
C_n^2 = P_{U_{CN2}} \cdot 10^{-15}
\]

Note: Additional measurement instructions and sensors can be added to program, such as a temperature sensor, cup anemometer, pressure sensor, net radiometer and soil heat flux plates (e.g. a small micrometeorological station). Of course additional meteorological data can be taken from other nearby field stations.

Note: the data file provided by the CR10X contains two Cn2 ‘formats’, which both can be read by the WINLAS software (namely, 1: \( U_{CN2} \) combined with \( Var_{U_{CN2}} \), 2: \( P_U_{CN2} \)).
APPENDIX VI – COMBILOG PROGRAM

Comments program:

Data logger: COMBILOG (Theodor FRIEDRICHS & Co)
Differential channel 1: \( \log \text{ Cn2 signal LAS/XLAS (i.e. } U_{\text{CN2}} \) \)
Differential channel 2: Demod signal \( (U_{\text{DEMOD}}) \) or signal strength \( (I) \)
Sampling rate: 1 Hz
Averaging time: 10 minutes

COMBILOG

Location: Undefined
Filename: LAS_COMBILOG.PRO

Common Data
User Name: LAS
Answer Delay: 1 Char Times
Timeout: 0 s
Filter Freq.: 50 Hz
Config. Date: 26/09/2003 14:55
Auto Off: Disabled
LED: Disabled
Language: English

Serial Interface Funct.
RS485
Baudrate: 19200
Format: 8e1
Module Timeout: 100 ms
RS232
Connection type: Line modem

Alarm settings:
Alarm 1
Condition:
Type: Off

Alarm 2
Condition:
Type: Off

Alarm 3
Condition:
Type: Off

Alarm 4
Condition:
Type: Off

Logger Funct.
Sample Interval: 1 s
Mode: Continuous
Logging Interval: 10 min
Variables to Log:
Internal (Var#): 01,02,03,07,08,09
External (Addr/Var#): None
Special Data
Block 0:   ---
Block 1:   ---
Block 2:   ---
Block 3:   ---
Block 4:   ---
Block 5:   ---
Block 6:   ---
Block 7:   ---

Configuration Data
Variable 1
Type:    Analogue Input
Variable Name:   UCn2
Sensor:    Voltage
Type of Measurement:  Differential
Unit:     V
Field Length:   8
Precision:   1
Conversion Parameter:  Input Units [V]: Engineering Units [V]:
0%:    -5    -5
100%:    0   0
Data Type:   Real
Data Direction:   Input
Min. Value [V]:   -5
Max. Value [V]:   0
On Sensor Failure:  Corresponding Limit
Zero Calibration:  None
Averaging:   Arithm. Averaging
DP Real Config. Data:  93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 2
Type:    Analogue Input
Variable Name:   Demod
Sensor:    Voltage
Type of Measurement:  Differential
Unit:     mV
Field Length:   8
Precision:   1
Conversion Parameter:  Input Units [V]: Engineering Units [mV]:
0%:    -1   -1000
100%:    0   0
Data Type:   Real
Data Direction:   Input
Min. Value [mV]:  -1000
Max. Value [mV]:  0
On Sensor Failure:  Corresponding Limit
Zero Calibration:  None
Averaging:   Arithm. Averaging
DP Real Config. Data:  93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 3
Type:    Arithmetic
Variable Name:   PUCn21000
Unit:     
Field Length:   8
Variable 4
Type: Arithmetic
Variable Name: Std_Cn2
Unit:
Field Length: 8
Precision: 1
Data Type: Real
Data Direction: Input
Reset: None
Formula: SDev(V1)
DP Real Config. Data: 93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 5
Type: Arithmetic
Variable Name: Std_Demod
Unit:
Field Length: 8
Precision: 1
Data Type: Real
Data Direction: Input
Reset: None
Formula: SDev(V2)
DP Real Config. Data: 93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 6
Type: Arithmetic
Variable Name: Std_PUCn21000
Unit:
Field Length: 8
Precision: 1
Data Type: Real
Data Direction: Input
Reset: None
Formula: SDev(V3)
DP Real Config. Data: 93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 7
Type: Arithmetic
Variable Name: Var_Cn2
Unit:
Field Length: 8
Precision: 1
Data Type: Real
Data Direction: Input
Reset: None
Formula: power(V4;2)
DP Real Config. Data: 93h = C: Yes | F: Byte | D: Input | L: 4 Bytes
Variable 8
Type: Arithmetic
Variable Name: Var_Demod
Unit: 
Field Length: 8
Precision: 1
Data Type: Real
Data Direction: Input
Reset: None
Formula: power(V5,2)
DP Real Config. Data: 93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Variable 9
Type: Arithmetic
Variable Name: Var_PUCn21000
Unit: 
Field Length: 8
Precision: 1
Data Type: Real
Data Direction: Input
Reset: None
Formula: power(V6,2)
DP Real Config. Data: 93h = C: Yes | F: Byte | D: Input | L: 4 Bytes

Format output file, downloaded from COMBILOG memory:

Unit, Date, Time(HH:MM:SS), UCN2, Demod, PUCN21000, Var_UCN2, Var_Demod, Var_PUCN21000, N

$C_n^2$ can be calculated as follows (two options, see paragraph 4):

$$C_n^2 = 10^{\left(\frac{U_{CN2} - 12 + 1.15 \sigma_{CN2}^2}{10} \right)}$$

$$C_n^2 = PUCN2 \cdot 10^{-15}$$

Note: Additional measurement instructions and sensors can be added to the program, such as a temperature sensor, cup anemometer, pressure sensor, net radiometer and soil heat flux plates (e.g. a small micrometeorological station). Of course, additional meteorological data can be taken from other nearby field stations.

Note: the data file provided by the CR10X contains two Cn2 ‘formats’, which both can be read by the WINLAS software (namely, 1: $U_{CN2}$ combined with Var_UCN2, 2: $PUCN2$).
APPENDIX VII – DIAPHRAGMS FOR SHORT RANGE APPLICATIONS

In case the LAS is required to operate over very short distances (i.e. at field-scale) the aperture diameter of the LAS can be reduced to 0.1 m using the supplied diaphragms. The LAS equipped with the 0.1m diaphragms (further denoted as 0.1m-LAS) can be used over path lengths of 100 m to 1 km. The 0.1m diaphragms are placed in front of the LAS transmitter and receiver by removing 3 of the 6 retaining screws (see Figure 19). Figure 20 shows the minimum LAS height as function of path length and surface conditions. A typical installation height for such path lengths is 2.5 m.

Figure 19: Diaphragm assembly on the LAS receiver and transmitter.
Table 13: Operating Specifications of 0.1m-LAS.

<table>
<thead>
<tr>
<th>Minimum path length</th>
<th>0.1m - LAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum path length (depends on atmospheric conditions)</td>
<td>1 km</td>
</tr>
<tr>
<td>Minimum height</td>
<td>1.5 m (see also figure 19)</td>
</tr>
<tr>
<td>Maximum height for ( C_n^2 ) (or turbulence) measurements</td>
<td>no operational restriction</td>
</tr>
<tr>
<td>Maximum height for flux ( (H) ) measurements</td>
<td>( \sim 100 ) m</td>
</tr>
</tbody>
</table>

Kipp & Zonen reserve the right to make changes to the specifications without prior notice.

**Important:** As the beam diameter becomes smaller so does the beam divergence. This means that the alignment of the 0.1m-LAS is more critical than for the standard LAS. It is recommended to use very stable mounting constructions.

Once the **0.1m-LAS** has been installed and properly aligned, the **Path Length** dial knob at the receiver control panel must be set for the correct distance between the transmitter and the receiver. Note that the **Path Length** dial knob setting for the **0.1m-LAS** is different from the standard LAS. For the **0.1m-LAS** the following relationship must be used

\[
Pot_{0.1m-LAS} = \left( \frac{5475.81}{\sqrt{(4.474D^2L^30.3314\cdot10^{12}) + 5.23}} \right)^{-47},
\]

where \( D \) is the aperture diameter (i.e. here 0.1 m must be taken instead of 0.152 m) and \( L \) the distance between the transmitter and receiver (in meters). Calculated values of \( Pot_{0.1m-LAS} \) for different path lengths can be found in table 14. Note that because of the sensitivity of \( Pot \) to \( L \) and thus also \( C_n^2 \) to \( L \) the distance must be measured accurately and the potentiometer must be set precisely!

Table 14: **Path Length** (\( Pot \)) dial knob setting values of the 0.1m-LAS for a range of path lengths.

<table>
<thead>
<tr>
<th>Path length [m]</th>
<th>( Pot_{LAS} ) [-]</th>
<th>Path length [m]</th>
<th>( Pot_{LAS} ) [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>15.1</td>
<td>550</td>
<td>422.6</td>
</tr>
<tr>
<td>150</td>
<td>61.7</td>
<td>600</td>
<td>456.5</td>
</tr>
<tr>
<td>200</td>
<td>111.4</td>
<td>650</td>
<td>488.0</td>
</tr>
<tr>
<td>250</td>
<td>161.9</td>
<td>700</td>
<td>517.0</td>
</tr>
<tr>
<td>300</td>
<td>211.4</td>
<td>750</td>
<td>543.8</td>
</tr>
<tr>
<td>350</td>
<td>258.9</td>
<td>800</td>
<td>568.5</td>
</tr>
<tr>
<td>400</td>
<td>304.1</td>
<td>850</td>
<td>591.4</td>
</tr>
<tr>
<td>450</td>
<td>346.4</td>
<td>855</td>
<td>593.6</td>
</tr>
<tr>
<td>500</td>
<td>385.9</td>
<td>900</td>
<td>612.5</td>
</tr>
<tr>
<td>550</td>
<td>422.6</td>
<td>950</td>
<td>632.1</td>
</tr>
<tr>
<td>600</td>
<td>456.5</td>
<td>1000</td>
<td>650.3</td>
</tr>
</tbody>
</table>
Important: Data processing of the 0.1m-LAS requires WINLAS version 2.2 or higher as older versions do not support the 0.1m-LAS.

Figure 20: The minimum installation height of the 0.1m-LAS as function of path length and for different surface conditions. The area above the curves is the non-saturation zone. Below the curves saturation of the signal occurs. In the presence of densely packed roughness elements add the zero-displacement height (see appendix III).
APPENDIX VIII – RECALIBRATION SERVICE

In order to maintain the specific performance of the LAS/XLAS instrument, Kipp & Zonen recommends calibrating the LAS/XLAS instrument when it fails the on-site calibration check (see section 7.1 and 7.2). This can be done at the Kipp & Zonen factory (see section 7.3 for a description of the procedure). Here the calibration procedure can be performed at low cost and can usually be performed within several weeks. If required, urgent calibration can be accomplished in three weeks or less (subject to scheduling restrictions). Kipp & Zonen will confirm the duration of recalibration at all times. Note that special quantity recalibration discounts are available.
NAME : 
COMPANY/INSTITUTE : 
ADDRESS : 
POSTCODE + CITY : 
COUNTRY : 
PHONE : 
FAX :

☐ I would like to receive a price list for recalibration
☐ I would like to submit my LAS instrument(s) for recalibration

<table>
<thead>
<tr>
<th>Type/Model:</th>
<th>Qty:</th>
<th>Requested delivery time:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I intend to send the instrument(s) to Kipp &amp; Zonen on:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>........................./............./.............</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I would like to receive the instrument(s) back on:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>........................./............./.............</td>
</tr>
</tbody>
</table>

Confirmation by Kipp & Zonen

Yes, the dates are acceptable to us.

No, unfortunately the dates do not fit into our calibration schedule. We suggest the following data:

........................./............./.............

Fax +31-15-2620351

or mail to:

Kipp & Zonen B.V.
P.O. Box 507
2600 AM Delft
The Netherlands
Our customer support remains at your disposal for any maintenance or repair, calibration, supplies and spares.

Für Servicearbeiten und Kalibrierung, Verbrauchsmaterial und Ersatzteile steht Ihnen unsere Customer Support Abteilung zur Verfügung.

Notre service 'Support Clientèle' reste à votre entière disposition pour tout problème de maintenance, réparation ou d'étalonnage ainsi que pour les accessoires et pièces de rechange.

Nuestro apoyo del cliente se queda a su disposición para cualquier mantenimiento o la reparación, la calibración, los suministros y reserva.

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