Lightning Sensor & Analyzer

User manual

- March 18, 2024 -
Valid from software release 2.0.11773

Lightning
Sensor & Analyzer
Jomitek
Serial # 1114 MAC:00:50:C2:BA:63:66
Relay output J30000001002
June 2023

Contents

1 Introduction to the Lightning Sensor & Analyzer

1.1 The LSA at a glance

The Lightning Sensor & Analyzer (LSA) is a compact lightning detection system for wind turbines designed to detect and process lightning strike characteristics, including reporting on all Lightning Protection Level I thresholds, being Class I compliant across all metrics specified by IEC 61400-24/AMD1 ED2. This functionality is key to determine lightning damage risks, prolong equipment lifetime, as well as ensure timely equipment maintenance.

The LSA can be installed on any wind turbine by placing the sensor box on the exterior of the turbine tower, typically 1m above the door frame. A single IP67 Ethernet cable is used for power and communication.

The distinguishing features of the LSA include:

- Simple retrofit options on existing wind turbines
- Designed from the ground up with long term reliability as a key focus
- Highly accurate charge measurement, due to extremely low sensor noise floor
- Relay as well as multiple communication protocol support for interfacing
- Support for detection of which blade is struck by lightning

For documentation and software, visit the LSA support web site at http://jomitek.dk/en/support/lsa

1.2 First time quick start guide

1. Attach the LSA to a PoE enabled network. A DHCP server is required to assign an IP address to the sensor.
2. Determine the sensor IP address by looking into the DHCP servers client allocation table or by using the Jomitek Device Locator software which can be downloaded from http://jomitek.dk/en/downloads/tools/.
3. Access the graphical user interface through a web browser by navigating to the IP address of the sensor.

1.3 Interface options and requirements in brief

Using a single RJ45 Ethernet connector for both communication and power supply, the sensor may be powered by either a Power over Ethernet (PoE) class 2 device or through 24V or 48V DC power supplied via the Ethernet cable. When connected via Ethernet, it can be accessed through a graphical web interface, IEC 60870-5-104 protocol, FTP, WebDAV, or a Lua or Telnet client, e.g. Putty. Additional web service options can easily by tailored to suit SCADA needs, e.g. using JSON-queries to extract sensor status, lightning event lists, etc..

Using an optional separately sold Power and Interface Box (PIB), basic relay-type interfacing is supported, also providing backwards compatibility to the Classic Lightning Sensor system offered by Jomitek. The PIB provides multiple power redundancy options, including an integrated battery, visual display of active lightning alarm, alarm test, clearing of alarms, and an alarm relay output similar in functionality to that of the Classic system.

1.4 Cyber security in general

The Lightning Sensor & Analyzer (LSA) uses Ethernet for communication. The sensor is an open device for most of the protocols available. The communication is generally not encrypted. For these reasons it is strongly recommended to use a firewall or similar measures, to protect critical parts of the turbine Ethernet network. See additional cyber security options described in section 6.3.

2 System installation & maintenance

Installation of the LSA is simple and requires no calibration. It is attached directly to the outside of the wind turbine tower with permanent magnets ensuring a strong adhesion to the tower. Do ensure that the tower surface is clean before attaching the sensor. Mount a grounding wire to the grounding bolt, if required by the wind turbine vendor, and finally connect the Ethernet cable.

Note that the Ethernet interface (central connection plug) on the LSA must be sealed at all times, either by a termination plug, or by the matched IP67 Ethernet cable included with the sensor. By default, the LSA will be delivered with 4x permanent magnets fitted to the sensor using M6 mounting points, providing a good fit to circular structures with a diameter ranging from 4-6 meters. On request, the sensor casing may also be delivered with a shape providing a good fit for the 6 meter diameter, and above.

Another mounting option is to use the same M6 mounting points to fix the sensor box in place using M6 bolts - note that these bolts must be A2 or A4 class stainless steel. This option is important if the mounting place does not feature a magnetic surface, e.g. if it is a concrete tower.

When using the magnet mounting option, it is recommended to add an adhesive sealant around the magnet pad perimeter. This will guarantee a long term fixed placement. A suggestion for an appropriate sealing is the Sikaflex 291i, typically in the white variant, or a sealant with similar properties. The particular sealant used must be verified with the vendor of the wind turbine.

To ensure measurement accuracy in post-processing, the system must be configured before use. Read about configuring the sensor in section 2.3.

2.1 Installation considerations

The Lightning Sensor & Analyzer measures the magnetic field generated by the lightning current running through the wind turbine tower when struck by a lightning. For optimum sensor performance, it is important to minimize magnetic disturbances close to the sensor. In general, this means that iron and other ferromagnetic materials extending or nearby the tower surface should be avoided within 20 cm of the sensor box in the vertical direction, and at least 100 cm in the horizontal direction along the tower surface. The tower cylinder itself naturally does not pose an issue.

A lightning current may be led through a lightning down conductor inside the wind turbine, placed away from the center axis of the tower, see figure 1. In this case the current peak measurement will only be within the specified measurement accuracy if the LSA is placed in the indicated range, i.e. 45-55 degrees away from the line that can be drawn from the center of the tower out through the lightning down conductor. This translates to 0.44 times the tower diameter. As an example, for a tower with a 6 meter diameter at the height of the sensor installation, this leads to a proper installation point being 2.64 meter either to one or the other side along the perimeter of the wind turbine tower, measured from the point of the tower surface closest to the lightning down conductor. Note, only 1 sensor is needed per tower - but due to tower geometry there are 2 valid options for installation points. It is suggested to use the one closest to the door into the wind turbine.

The Ethernet cable for the LSA is typically routed from inside of the turbine, to the outside position of the LSA. The cable may be subject to significant inductance phenomena, due to lightning strikes, leading to excessive voltage levels. The LSA is hardened against overvoltage events, however the following precautions should still be made:

- If the Ethernet cable is coiled up at any point, fix the coil horizontally, i.e. as if placed laying on a table.
- In support of the previous point, to the extent possible, avoid using an Ethernet cable longer than is needed.
- Avoid routing the Ethernet cable vertically or coiled up in the immediate vicinity of the lightning down conductor inside the tower, i.e. at least with 1m separation.

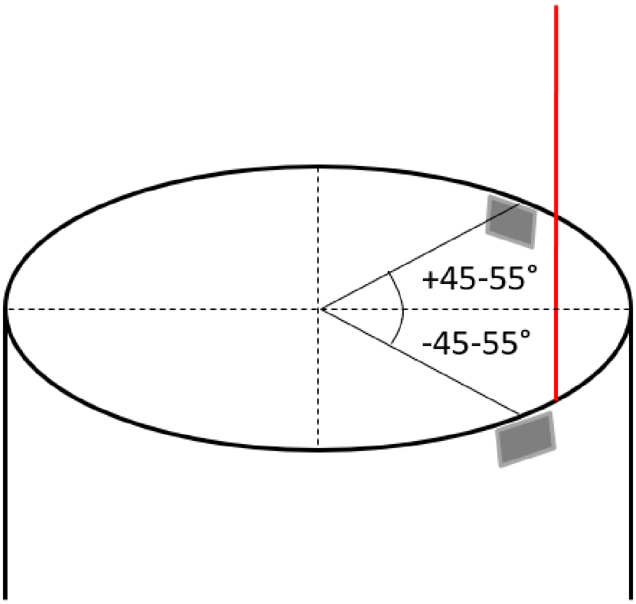


Figure 1: Cross section of a wind turbine tower, indicating proper placement of the LSA , with respect to an off-center internal lightning down conductor

2.2 Power supply and Relay Option

The LSA is powered by Power over Ethernet (IEEE 802.3). The PoE standard specifies two options for selection of wire-pairs with the LSA supporting both options, refer to figure (3) for details. The LSA is characterized as a Class 2 device, drawing power in the range 3.84W-6.49W. Note that the PoE supply must be tested to remain active (supply power) down to 1W power consumption, or be set manually active to ensure sustained PoE. This includes use of PoE injectors.

If the installation does not offer a PoE power supply, an external 24/48VDC supply may be used. This supply has to enter through the Ethernet cable. A special splitter cable making use of the mode B pins 4/5 (DC+) and pins 7/8 (DC-) can be ordered from Jomitek. However, in case of the use of a DC power supply it is recommended to use the Jomitek Power and Interface Box, which will also ensure proper conditioning and isolation of the power input to the LSA .

Note that the power supply for the LSA requires a minimum level of redundancy, ensuring supply for an absolute minimum of 2 minutes after a power failure of the mains supply of the wind turbine. If this criteria is not met, a lightning strike which interrupts the mains supply of the wind turbine will not be recorded, leaving the LSA ineffective. The Jomitek PIB supports the required Uninterruptible Power Supply (UPS) need. It may alternatively be met using a third party UPS / battery bank. For battery dimensioning purposes, note that while the LSA is configured as a Class 2 device, the average power consumption will be less than 2W.

The LSA may be ordered having a relay output for presenting alarms. The relay option uses 2 of the wires, pin 5 and pin 8. In this situation the sensor can get power from either the signal wires (1+2 and 3+6) or the direct wire (pin 4 and pin 7). The power wires used depends on the PoE switch used, weather it uses mode A or mode B. This implies that a special wire splitter is needed in case of relay output and use of a mode B PoE supply. By using the Jomitek Power and Interface Box, interfacing to the relay wires is simplified during installation, and this is the recommended approach. Please observe that the relay output is closed during normal operation. This means that if the interface cable is broken or disconnected, the receiving device (Jomitek PIB or other interface) will see this as a lightning alarm.

The power supply circuit is electrically isolated from the sensor electronics by a 1500V isolating transformer, and is also otherwise EMC hardened using best industry practices.

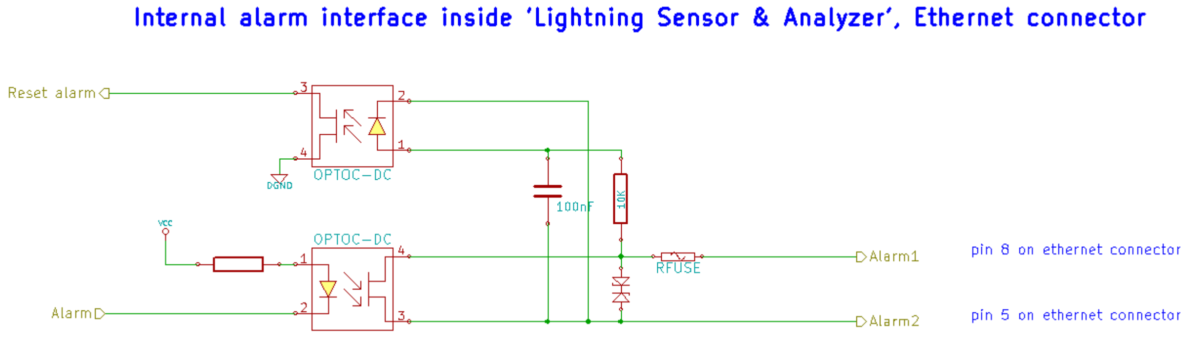
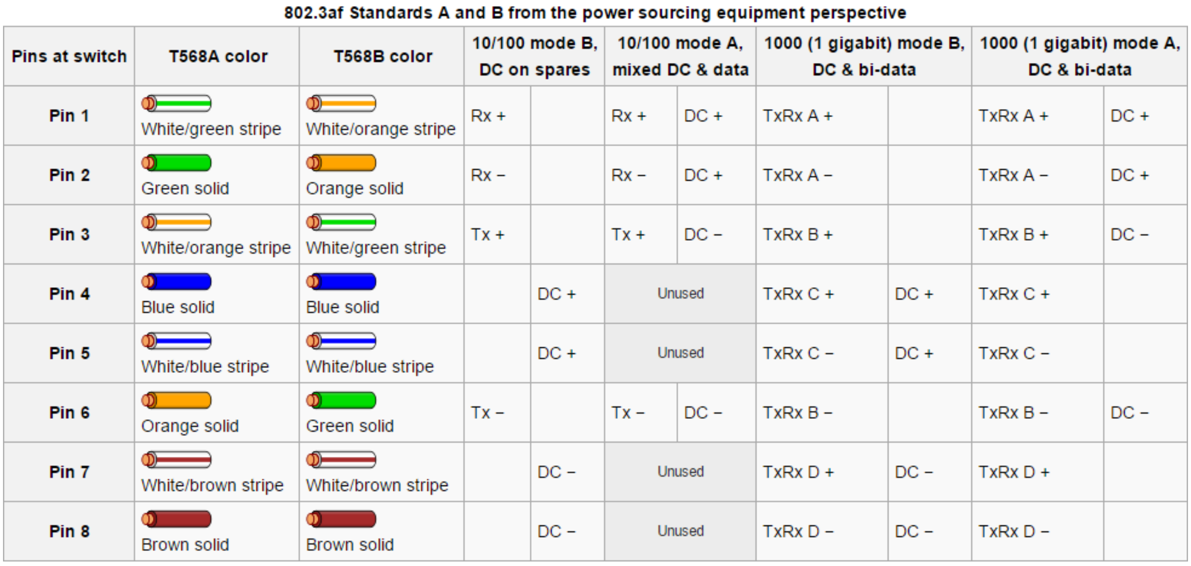

Internal alarm interface inside 'Lightning Sensor & Analyzer', Ethernet connector
Reset alarm
OPTOC-DC
DGND
100nF
10K
VCC
OPTOC-DC
RFUSE
Alarm1
Alarm
Alarm2
pin 8 on ethernet connector
pin 5 on ethernet connector
3
2
4
1
1
4
2
3

Figure 2: LSA Alarm Interface via Ethernet cable



802.3af Standards A and B from the power sourcing equipment perspective

Pins at switch	T568A color	T568B color	10/100 mode B, DC on spares		10/100 mode A, mixed DC & data		1000 (1 gigabit) mode B, DC & bi-data		1000 (1 gigabit) mode A, DC & bi-data	
Pin 1	White/green stripe	White/orange stripe	Rx +		Rx +	DC +	TxRx A +		TxRx A +	DC +
Pin 2	Green solid	Orange solid	Rx −		Rx −	DC +	TxRx A −		TxRx A −	DC +
Pin 3	White/orange stripe	White/green stripe	Tx +		Tx +	DC −	TxRx B +		TxRx B +	DC −
Pin 4	Blue solid	Blue solid		DC +	Unused		TxRx C +	DC +	TxRx C +	
Pin 5	White/blue stripe	White/blue stripe		DC +	Unused		TxRx C −	DC +	TxRx C −	
Pin 6	Orange solid	Green solid	Tx −		Tx −	DC −	TxRx B −		TxRx B −	DC −
Pin 7	White/brown stripe	White/brown stripe		DC −	Unused		TxRx D +	DC −	TxRx D +	
Pin 8	Brown solid	Brown solid		DC −	Unused		TxRx D −	DC −	TxRx D −	

Figure 3: PoE IEEE802.3 Standards A and B. Image source: https://en.wikipedia.org/wiki/Power_over_Ethernet

2.3 Scaling of measurements

To ensure correct scaling of the lightning current measurements, the wind turbine tower geometry must be configured. This is used as input for the post processing, which convert the measured magnetic field to an equivalent lightning current. The parameters to be configured for the structure can be found in the **tower** section, either via the web interface, or in the settings.conf file within the /conf folder using FTP or WebDAV. Note that **especially the tower radius is crucial to set correctly**, so the radius at the point of installation must be determined with diligence:

- height [m]: The height of the wind turbine tower from the tower base (ground or sea level) to the tip of the blade at its highest point during operation.
- sensor_mount_height [m]: The height of the sensor mounting point above ground or sea level.
- radius [m]: The radius of the wind turbine tower.

Additionally, as part of the **measurement** configuration, the following parameters can be adjusted to suit user requirements:

- trigger_level [kA]: The lightning current level used as threshold for triggering the alarm indication, and recording a lightning current time series, including post-processing. The default setting of 4kA is proposed as a reasonable trigger point, which will generally avoid detection of lightning leaders (the early build up phase of a lightning channel), in the cases where the lightning is never fully initiated.
- time_series_length [ms]: The length of the lightning current time series to record specified in milliseconds. It can be specified from 100 to 1000 milliseconds. It is recommended to keep the default setting of 1000ms.

The entity responsible for servicing the turbine may insert service alarm levels (**service_alarm_levels**), to indicate at which level of lightning strike severity a service visit should be triggered. These levels are not actively being used by the sensor post processing. They are intended as a way to indicate such service visit needs in addition to the levels defined as part of the Lightning Protection Level I severity rating of a lightning event. This collection of metrics is intended to support focused service visits, as well as halt of turbine electricity production, only when needed, and in this way lower the overall cost impact of lightning strikes.

2.4 Time synchronization for accurate event time stamps

While the LSA supports a basic time synchronization option, which updates the time of the LSA automatically whenever the web interface is opened, this option is primarily meant for initial setup and test purposes. Relying on this method, should the sensor lose power, the time stamp will not be correct afterwards.

To secure correct time stamps continually, the sensor must have access to an SNTP/NTP server. See section 6.3 for details on NTP server address configuration. In the web interface, the SNTP synchronization state will be clearly marked in the bottom right corner. A red light indicates no connection, while a green light confirm that synchronization via SNTP has been obtained. Note that immediately after rebooting or powering up the LSA , the SNTP indication will remain red for up to 30 seconds. Reload the web page in such case, to confirm that synchronization is obtained. Note that the synchronization state can also be determined based on MODBUS or IEC 104 readouts.

The sensor may operate without an SNTP synchronization source, however this will pose a significant risk of having untrustworthy time stamps of any lightning event recorded.

2.5 Full lightning sensor system test

As a final step during LSA installation, it is strongly recommended to conduct an end-to-end system test. This can be achieved using the Jomitek Lightning Pulse Generator, see figure (4).

The pulse generator is powered by a 9V battery. Always remember to bring a spare 9V battery and a screwdriver to exchange the battery. Remember to power off the device after use, to extend the battery life. If used with care, several hundred lightning discharges can be generated before the battery is drained.

The Lightning Pulse Generator features an On/Off button, LEDs indicating the charge state, and a red button which triggers a current pulse shaped like a standard lightning discharge.

Step-by-step instruction for triggering a lightning test pulse using the Jomitek Lightning Pulse Generator:

- Place the Lightning Pulse Generator centered and immediately above the LSA box, see figure (4)

- Turn it on using the On/Off button. A red LED will then be lit, and after a few seconds it will be replaced by a green LED, indicating that generator is fully charged.
- Perform the test by pressing the red button, which will release a current pulse similar to a lightning.
- Turn off the generator using the On/Off button again.
- Verify that the LSA recorded the pulse - depending on the configuration you may also verify if a physical relay was tripped, or if the wind turbine control was alerted using e.g. Modbus TCP or IEC-60870-5-104. Note that a lightning alarm will be triggered almost instantly, but the key parameter readout, as well as time series measurement will first be available after 2 minutes.

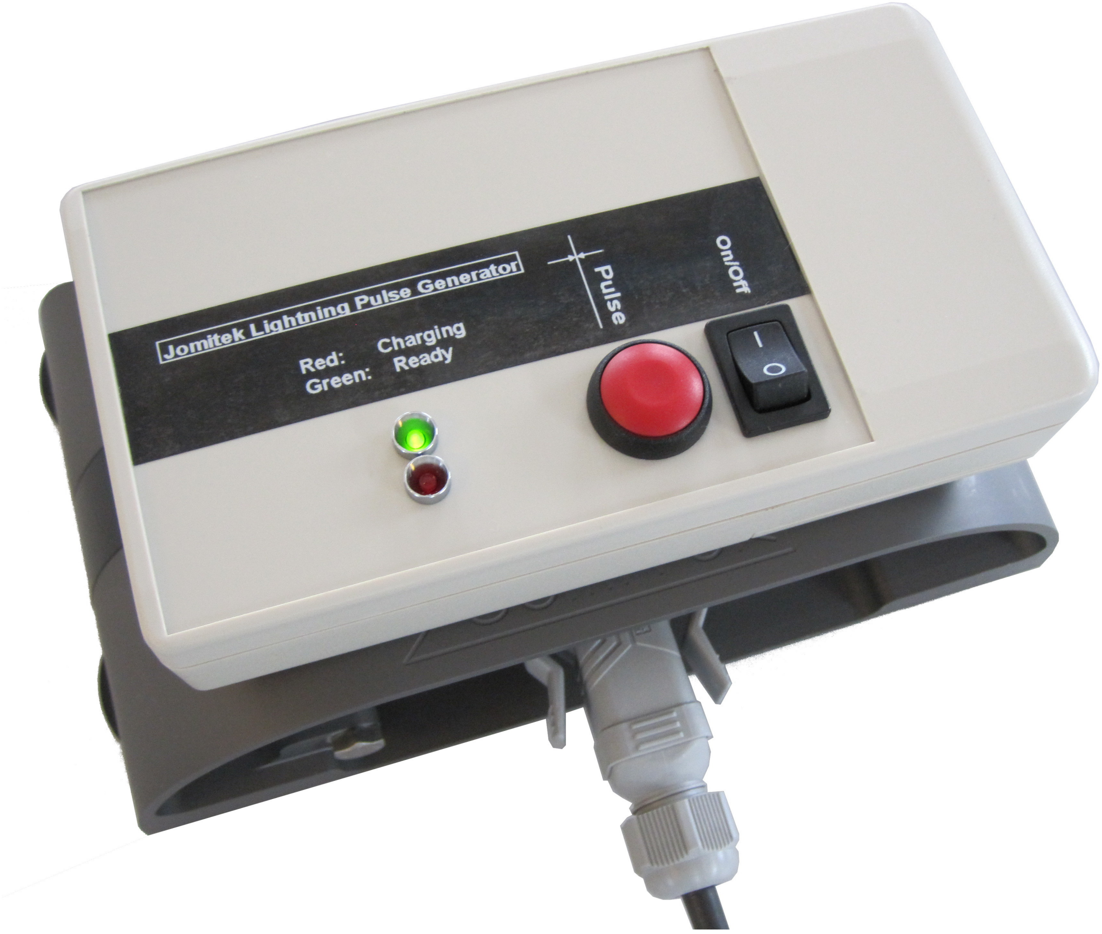


Figure 4: The Jomitek Lightning Pulse Generator must be placed centered and on top of the LSA box, to allow for correct detection of the test pulse.

2.6 Maintenance

The LSA is designed with a focus on very low maintenance requirements. The factory calibration applied lasts the lifetime of the sensor. As part of the continuous measurement flow being processed by the sensor, the sensor confirms the operational state of the internal measurement chain automatically. Should this confirmation fail, an error state warning is flagged e.g. via MODBUS or IEC 60870-5-104 (default address 1102).

The implication of this automatic check, is that scheduled maintenance visits, verifying the operational state of the LSA, can be avoided. This can be a significant factor, when considering the Total Cost of Ownership (TCO) of the sensor system.

3 Lightning strike detection and measurement

3.1 Theory of operation

A lightning striking a tall structure will cause an electrical current to run through the structure. For a wind turbine tower constructed from steel, this lightning current either use a lightning down conductor designed for the purpose, or it may find a way through the tower structure, as this is often the path of least resistance.

Electric current running in a conductor produces a magnetic field arranged in a circular pattern around the conductor. The LSA works by continuously measuring and monitoring the magnetic field strength at the surface of the wind turbine tower. If a lightning strikes the tower, the associated lightning current and magnetic field will be detected by the LSA which will trigger an alarm either via relevant Ethernet protocols, or via the Jomitek Power and Interface Box as a relay signal, and record a timeseries of the magnetic field which will be converted to an equivalent lightning current during post processing within the sensor.

Note that during a lightning event recording (maximum 2 consecutive measurements of 1 second duration each), the sensor enters a dedicated measurement state, which also means that the sensor will halt any Ethernet communication. I.e. if the sensor is begin polled continuously e.g. using IEC-60870-5-104 or MODBUS, a pause in the data flow may be detected. To be clear, the sensor will respond to Ethernet communication during the post processing phase, but not during the actual time spent recording a lightning event.

3.2 Detection of which blade is hit by lightning

The LSA support detection of which blade is struck in 3 different ways with various pros and cons, as highlighted in the following:

1. Relay based
2. Based on MODBUS or IEC 60870-5-104 polling
3. Based on timestamp comparison

- Using a direct analog relay signal from the LSA , and interfacing this to the local turbine control, the turbine control logs the position of the blades at the time the lightning initiates (relay signal is raised within 1 milisecond of the rising edge of a lightning event), to determine which blade is pointing up towards the sky.
- Using the Ethernet connection, the turbine control is configured to poll the LSA on the alarm status using either MODBUS or IEC 60870-5-104, e.g. at an interval of 100ms, resulting in a detection accuracy <150ms, which is sufficient in all practical scenarios.
- Using the Ethernet connection, and based on a local NTP server providing time synchronization between the turbine control and the LSA , the lightning event time stamp is compared to a time stamped log from the wind turbine control, to determine which blade was struck. This method requires that the lightning event data processing is complete, and the time stamp comparison will therefore be delayed by up to 2 minutes (typically 30-40 seconds) from the time of the lightning event.

Using any of these options allow for detection of which blade - or blades, in the case of long duration lightning strikes - are struck. Such detection requires a one-time integration effort with the wind turbine control system, and can therefore be much more cost efficient than the cost of a dedicated sensor system mounted on each blade, including the higher installation cost of such sensors.

The rationale for blade detection - or lack thereof

As a general comment on blade detection, note that the value of such detection of lightning strikes lie mainly in cases with rare and powerful strikes, where it is reasonable to focus inspection efforts on the specific blade affected. This can likely reduce some of the inspection cost, compared to inspection of all 3 blades - though the main cost usually lies in getting on site.

In general, statistically speaking, the majority of cases will see a high likelihood of multiple minor-to-medium strikes on all blades, and it is either the aggregation of lightning events or a single powerful strike which prompts the need for on site inspection. In such cases, while blade specific detection is a nice-to-have, it is prudent to inspect all blades while on site. As such, there is little-to-no effective cost reduction tied to blade specific detection.

In addition, a lightning detection system dedicated to blade specific detection (i.e. one sensor per blade), beside the added cost and installation complexity of such sensors, often lack the fundamental ability to detect lightning strikes which partially or wholly avoid being directed through the blade lightning down conductors. Jomitek simulation estimates, based on real world charge influx measurements on wind turbines, suggests 10-15% of lightning strikes being partially or wholly conducted on the outside of the blade, or directly into the hub or nacelle structure. These cases are equally important to detect, and are supported by the measurement principle of the Jomitek LSA.

3.3 Key lightning parameter output

When the LSA detects a lightning current strength above the user configured threshold, a full lightning current time series is recorded at 1us resolution (1MHz). When the time series has been recorded in internal memory, the data is post processed and related parameters are calculated. The full time series data is converted from the recorded magnetic field strength to the equivalent lightning current and stored in a .wav formatted file. The lightning parameters are stored in a log file, alongside with all past lightning events. The post processed parameter readout include:

- Main stroke peak current [kA]
- Main stroke rise time [μs]
- Main stroke average steepness [kA/μs]
- Main stroke specific energy [kJ/Ohm]
- Subsequent stroke(s) maximum peak current [kA]
- Subsequent stroke(s) minimum rise time [μs]
- Subsequent stroke(s) maximum average steepness [kA/μs]
- Pulse count [#]
- Charge, flash [C]. The total charge delivered by the lightning.
- Charge, long [C]. The maximum charge of any lightning pulse lasting >2ms
- Charge, short [C]. The maximum charge of any lightning pulse lasting <=2ms
- LPL I severity [%]. Relative size of the parameter closest to exceeding LPL I thresholds.
- Inductive energy index [J]
- Total specific energy [kJ/Ohm]
- Receptor mass loss [g]
- Polarity of the lightning pulse. Positive or negative.

Each recorded lightning strike has a timestamp adhering to the nearest ±500μs of the first sequence of three consecutive samples that crosses the user defined threshold in Settings ⇒ lsa ⇒ measurement ⇒ trigger_level. The timestamp is expressed in both local time using the iso8601 format and in UTC time with a relative precision in nanoseconds. Note that the absolute precision of the sensors time stamp is limited by the time-server precision and the method used to synchronise the absolute time with the sensor, usually the absolute time precision is in the milisecond range for NTP time synchronisation.

Note that the relative time precision can be used when comparing the time of two lightning events recorded by the same sensor.

- iso [$\mathrm{YYYY} - \mathrm{MM} - \mathrm{DDThhmmss.sss} \pm \mathrm{hh} : \mathrm{mm}$]. The local time of the strike in iso8601 format including time zone information
- sec[s]. The time expresses in elapsed seconds since January 1, 1970.
- nanoSec [$s \cdot 10^9$]. The nanoseconds part of the timestamp.

Both the time series data and the key parameters can be viewed or downloaded directly from the web interface or by FTP/WebDAV transfer.

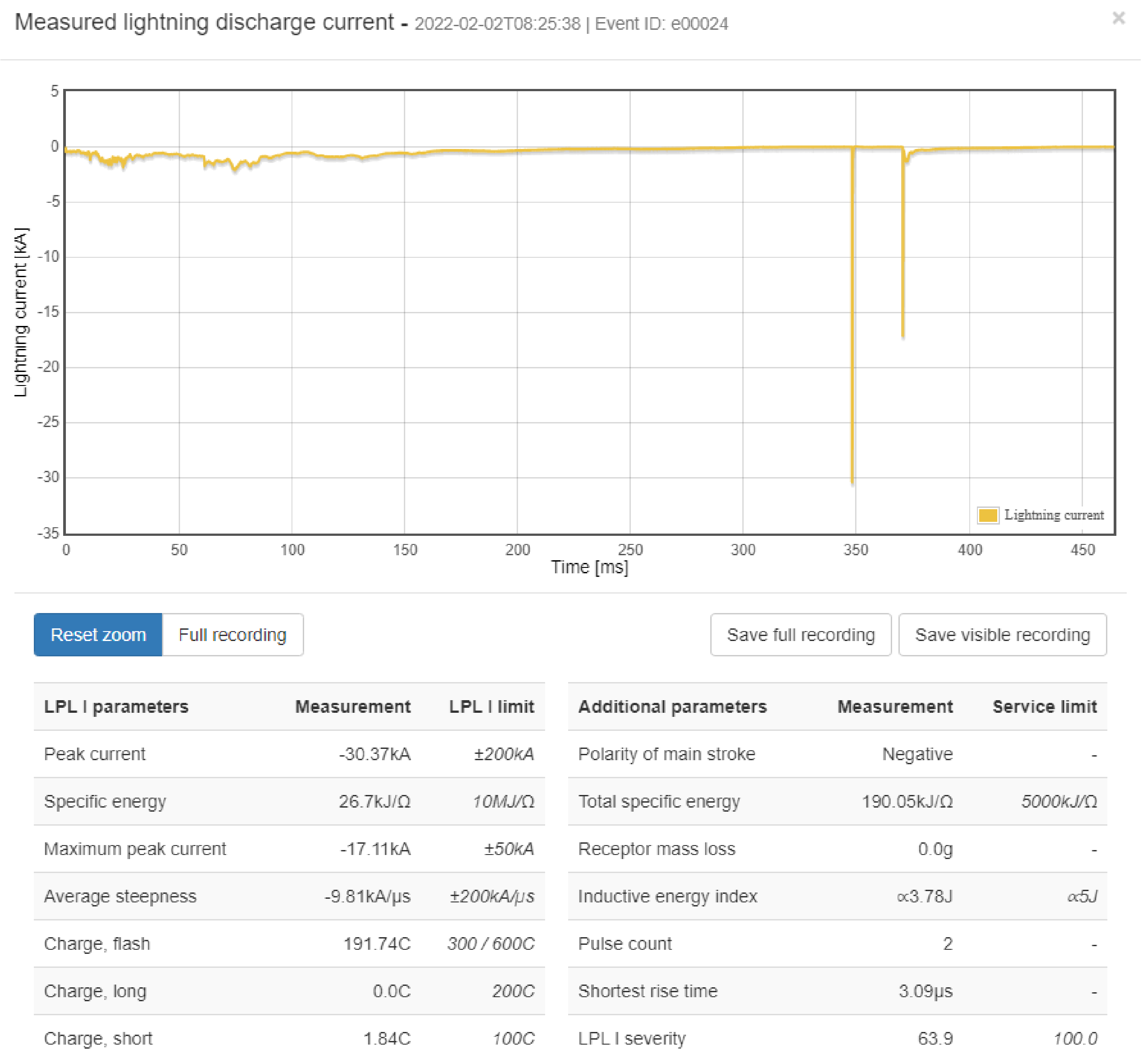
3.4 Receptor damage and replacement need

Based on the key lightning parameters, and as part of this the Jomitek sensor technology properties of a very low signal-to-noise ratio for time series measurements, an additional parameter is produced in the evaluation of a lightning event; Lightning receptor damage. See figure 5 as an example of this feature, in a case where no mass loss is expected.

With a number of base physical properties for stainless steel receptors, in terms of shape, size, heat capacity, melting point, eddy current phenomena etc., the sensor can produce a good estimate for the amount of receptor material which has disappeared due to a combination of resistive heating and atmospheric pressure during a lightning event. Importantly, the evaluation model reflects the fact that relatively 'small' lightning will have no measurable effect on receptor damage, which is a critical aspect of ensuring a good estimate.

The output of the receptor damage assessment is presented as removed mass from the receptors in gram. Customization of the model can be provided on request, in the case of non-standard lightning receptor layout, different metals, different output units or similar.

This output parameter presents the opportunity to lower wind turbine service costs, by avoiding or delaying scheduled receptor inspections, and in stead target inspections for those wind turbines where significant receptor damage is detected based on LSA measurements.



Measured lightning discharge current - 2022-02-02T08:25:38 | Event ID: e00024

LPL I parameters	Measurement	LPL I limit
Peak current	-30.37kA	*±200kA*
Specific energy	26.7kJ/Ω	*10MJ/Ω*
Maximum peak current	-17.11kA	*±50kA*
Average steepness	-9.81kA/µs	*±200kA/µs*
Charge, flash	191.74C	*300 / 600C*
Charge, long	0.0C	*200C*
Charge, short	1.84C	*100C*

Additional parameters	Measurement	Service limit
Polarity of main stroke	Negative	-
Total specific energy	190.05kJ/Ω	*5000kJ/Ω*
Receptor mass loss	0.0g	-
Inductive energy index	∝3.78J	*∝5J*
Pulse count	2	-
Shortest rise time	3.09µs	-
LPL I severity	63.9	*100.0*

Figure 5: Example recording of a real world lightning event. The recording include a listing of the key lightning parameters, as well as the estimated loss of receptor mass caused by the event.

4 Lightning parameter analysis

4.1 How to interpret the lightning parameter output

The core value of the LSA lie in the ability to assign responsibility for lightning related damage or faults, and to significantly optimize the operational costs associated with lightning strikes.

In relation to the question of responsibility, the cost of component failures are most often defined using IEC 61400-24, with the design criteria being the ability to withstand lightning strikes within Lightning Protection Level I limits. If a failure occurs, with LPL I limits exceeded, then the responsibility (cost) most often falls back to the owner of the turbine, whereas faults incurred below these limits are a subject to insurance claims and/or turbine vendor responsibility.

For the purpose of optimizing costs, there are a few elements to consider, looking at a lightning detection system as a whole.

1. Avoidance of wind turbine component failure leading to a prolonged energy production halt
2. Avoidance of halting a wind turbine, when lightning detection is below concerning limits
3. One-off cost of the lightning sensor system itself, as well as for installation and integration
4. Maintenance costs of the lightning sensor system

Items 3 and 4 are addressed by the design principle and functionality of the LSA itself. Items 1 and 2 reflect a need to not only have reliable lightning detection, but also the ability to accurately differentiate between lightning levels of concern, and those that are not a concern. There are real world cases where a turbine on average is struck by lightning more than 10 separate days during a year, which is obviously unsustainable if site visits are triggered every time - in particular when the strikes are not necessarily of concern.

Unfortunately Jomitek has found that the IEC 61400-24 LPL I metrics are not presenting a reference frame easily translated to risk of wind turbine component failure or degradation. As such, additional parameters are introduced for this purpose. The following sections detail both the parameter output in relation to LPL I, as well as the added parameters which may be used to optimize the need for production halt and related service visits.

4.2 Reporting of parameters in relation to Lightning Protection Level I

IEC 61400-24 categorize parameters according to specific parts of a 'standardized' lightning discharge. However, real world lightning discharges exhibit properties which are not always directly translatable to these categories, introducing the need to clarify how such real world events are mapped to the limits of Lightning Protection Level I.

First stroke vs. main stroke

Using figure 5 as a reference, a lightning strike event will often include an initial phase which may span several 100ms indicative of lightning leaders building up an ionized channel for more significant lightning discharges to conduct through later on. As part of this, there are some times minor discharge pulses with rise times in the 1-100us range included as part of the lightning leader phase. LPL I impose limits on the 'first stroke', with different limits and parameters for positive and negative strokes respectively.

Looking at the context of the term 'first stroke', it is evidently not meant to reflect lightning leader discharges. As such the LSA reporting use the term 'main stroke', defined as the discharge reaching the highest absolute peak current value within the time series recording of the lightning. The 'first stroke' limits are related to the LSA 'main stroke'. All other discharge pulses are treated as 'subsequent strokes', even though such a stroke may in some cases include a discharge pulse occurring before the main stroke.

Positive vs. negative stroke

As for the difference in parameters used when the first/main stroke is positive vs. negative, the LSA reports the specific energy and average steepness in both cases, and apply the same limits. The background for this is, that while a positive strike has the highest risk of a significant specific energy output, and the negative the highest risk of a high average steepness, these limiting factors are equally relevant for either stroke polarity.

Time parameters

While the rise time and time parameters in general are part of the LPL I limits, they are to be treated as defining for the pulse time characteristics for lab testing, and not a physically meaningful limit to be evaluated for real world lightning discharges. As such, the rise time is reported, but not used in active evaluation of the LPL I severity level. The physically limiting (damaging) factor in this context is the average steepness.

Charge

The topic of charge measurement and measurement frames is treated on a number of levels for LPL I, of which some are potentially overlapping. It is also the measure which has the highest risk of being exceeded, as long duration low current discharges, which can stack up to levels above the LPL I limits, are fairly common. While the charge of the individual first positive short stroke has a limit of 100C, this criteria is for the LSA being treated for any pulse with a duration <2ms, referred to as 'charge, short'. Any pulse with duration >2ms is treated with the limits of a long stroke, referred to as 'charge, long'. Finally, the charge of the recorded lightning event as a whole is reflected in 'charge, flash', using 300C as the reference limit. Note that this limit may also be set as 600C or higher, depending on the specifications agreed for a particular turbine / turbine model / contract.

Lightning Protection Level I severity

The Lightning Protection Level I parameters, as applied according to the description of the past paragraphs, are evaluated one by one against the limit in question for that parameter. The parameter with the highest relative value to the LPL I limit is used as the LPL I severity indication. The rationale for this parameter, is to present the severity of a lightning event as a single summarized value. In the example of figure 5 the LPL I severity ends up being defined by 'charge, flash' reaching 63.9% of the limiting value.

In summary, all relevant parameters for Lightning Protection Level I is presented for evaluation as part of the LSA output.

4.3 Parameters supporting optimized need for site visits

The need for halting production and/or triggering a site inspection visit rely on an evaluation of the fundamental physical phenomena leading to component failure or degradation. Jomitek operate with 3 main metrics in this context.

1. Absolute peak current
2. Total specific energy (and related receptor mass loss)
3. Inductive energy index

Note that the charge is not included in this list, as it is presently not clear if specific types of lightning damage scale proportionally with the charge. Nonetheless, from an operational viewpoint the amount of charge must still be reacted upon, in relation to the Lightning Protection Limit I criteria.

Absolute peak current

Damage due to the peak current relate to the maximum force exerted on materials due to the Lorentz force, where a force proportional to the current is generated, and depending on the current path and layout of the turbine may rip out, crush, or otherwise compromise the structure of conductors or supporting materials. Also associated with a high peak current, is a high voltage potential leading to arching phenomena, which may burn through materials, or make them brittle, increasing the risk of structural failure.

The nature of damage to look for is equivalent to applying hammer blows or a blow torch to the immediate surroundings of the conduction path, and therefore the state of the lightning down conductor and the blade around the receptors is of particular interest, with less visible areas of interest being the generator or transformer (depending on the turbine layout).

Total specific energy

The specific energy represents the charge squared, integrated over time, which has the unit of Joule per Ohm. In other words, it is a metric for energy dissipation related to a given impedance. The amount of resistive heating of the current path is proportional to the specific energy. The Lightning Protection Level I specification only mention specific energy in the context of the first positive stroke. However, the heat dissipated within a few 100ms is quite limited, and as such, in case of a multiple discharge event, a more meaningful metric is the specific energy of the full lightning discharge recording, i.e. the total specific energy. The total specific energy is used to determine the approximate amount of lightning receptor mass loss as described in section 3.4, which emperically is found to be the type of component seeing the greatest direct impact of the specific energy released during lightning events.

The nature of damage to look for is related to the state of the blade receptors in particular, where molten droplets may also have caused damage to the blade material in the immediate vicinity. Note that degradation is more likely to be caused by multiple lightning over time, than a single lightning event.

Inductive energy index

Lightning Protection Level I treat damage caused by inductive phenomena, as a consequence of the Electromotive force, in the form of the average steepness. Considering lightning events can include 10s of individual strokes, the average steepness as a metric for damage caused by induced energy can easily be off by an order of magnitude, comparing an otherwise similar average steepness of a single stroke lightning, to one with many strokes. As a consequence the LSA presents a more meaningful additional metric, which is the integration of abs(dI/dt) across the entire lightning event. It can be shown that this metric is proportional to the induced energy. The amount of this type of damage can vary widely across turbine models, as it is highly dependent on the placement and orientation of sensitive electronics nearby the conduction path.

The nature of damage to look for is related to low voltage electronic components failing or operating erratically. In particular components containing PCBs, which are otherwise considered well shielded from an EMC viewpoint, will still be subject to induced energy, as the magnetic field is not possible to effectively shield for, apart from distance and orientation with respect to the conduction path.

5 Software and firmware structure

5.1 Microcontroller platform and RTOS

The Lightning Sensor & Analyzer features hardware tailored to meet the measurement capability and processing required to accurately report on any type of lightning discharge event, as well as the component resiliency required to withstand the harsh environment on the outside of an offshore wind turbine, for the lifetime of the turbine. In addition to the computational capabilities based on a custom RTOS (Real Time Operating System), the LSA feature a large onboard memory, designed for event logging during the entire lifetime of the sensor.

The firmware used in the microprocessor can be securely updated over the air using encrypted firmware images, enabling feature addition and improvements after installation.

The LSA firmware include the Lua scripting language which allows for a wide range of customization, including dynamic reconfiguration of the sensor on the fly. This enables easy interfacing to reports, event summaries, etc.. Requests for customization beyond the default capabilities are welcome.

5.2 File system

The LSA platform features storage of non-volatile data on an eMMC with integrated wear leveling. These data include software in the form of Lua scripts and web server content, as well as configuration files, time series recordings in the form of .wav files and other measurement data such as .log files. The eMMC is by default delivered with an 8GB size, which effectively will outlast the lifetime of the sensor and wind turbine. This is based on a lightning event usually consuming <1MB of storage space (automatically .gz compressed), and that at least 4GB of storage is dedicated to receive lightning event data, i.e. more than 4000 lightning strikes can be stored. In the unlikely event that the full memory space is consumed, the oldest time series data will be deleted, while the corresponding log files will remain, and in this way ensure that key data points are retained.

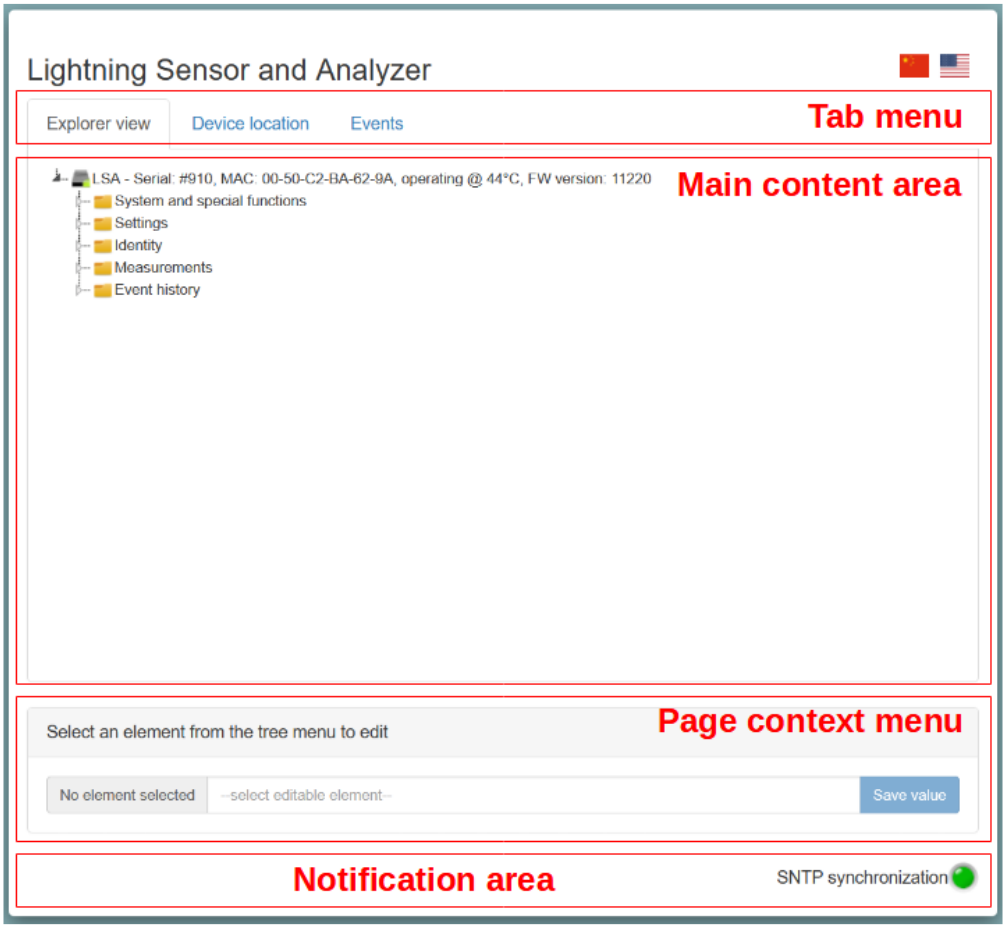
- `/service` - The main folder containing user relevant data, accessible via FTP or WebDAV, see 12.2, 12.3.
- `/service/conf` - System configuration files.
- `/service/log` - Sensor log files.
- `/service/software_update` - Folder for uploading firmware and software updates.
- `/service/data` - Measurement data such as time series and event logs, stored in the /event subfolder.

6 Web interface

6.1 General structure

The web interface is structured around four main components as shown in figure 6, with the following description:

- The *tab menu* for navigating between sub pages.
- The *main content area* for displaying sub page content.
- The *page context menu* for interacting with the currently selected sub page. This menu may not be available on all sub pages.
- The *notification area* for displaying messages as feedback to user actions and input. Notifications will be queued, with the newest notification appearing at the top of the notification area. Notifications will automatically disappear after 20 seconds, or can be manually dismissed. The notification area displays the SNTP (time synchronization) status in the right hand side. A green light confirms synchronization, while a red indicate no synchronization obtained.



Lightning Sensor and Analyzer

LSA - Serial: #910, MAC: 00-50-C2-BA-62-9A, operating @ 44°C, FW version: 11220

Select an element from the tree menu to edit

Figure 6: Overview of the web interface showing the layout of the four basic components.

6.2 Sub pages

6.2.1 Explorer view

The *Explorer view* page provides a quick and direct access to most LSA settings, functions and measurements. All items are arranged in a hierarchical folder structure that can be expanded when clicked. See figure 7.

When a node in the tree is clicked, the *page context menu* will show the node key and value, and if the value is editable, let you enter a new value which can be saved by clicking the *Save value* button.

Depending on the information type, the lowest level expansion will either act as a button executing a command, a link for file download, a link which expands the bottom part of the main page with the requested content or in a pop-up window, or in case of specific parameter values, the value is inserted in an editable text box.

The **main folder** (top level icon) represents the LSA sensor device itself, including a few main status and identification parameters.

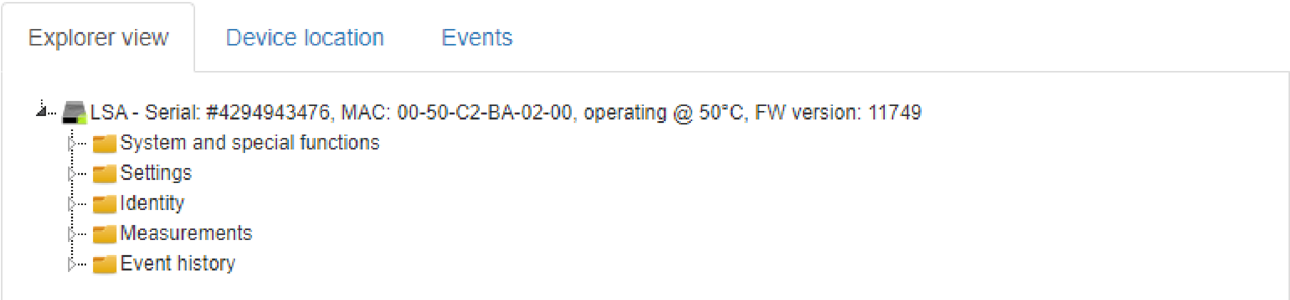
The **System and special function** features **Reboot sensor**; A reboot command is sent to the sensor. The web client will automatically reload the page when the sensor should be up and running again. If this is not the case, please reload the page again, and remember to check that the IP address targeted is still correct after the reboot, as the address may have been manually changed by the user, or reassigned by the DHCP server.

The **Settings** information folder presents a database table as defined by the '*conf/settings.conf*' file. Any web based modication of the parameters will be directly updated in the '*.conf*' file itself. Note that some parameter changes will require a reboot to take effect. This folder (see section 6.3), along with the **Identity** folder (see section 6.4), is a direct mapping of a corresponding data table in Lua. This is the reason why there are no special characters in the subfolder and parameter names.

Note that the majority of the parameters in the **Settings** folder are described by placing the cursor above the parameter in question. The same is the case for many of the parameters included in the other folders.

The **Measurements** folder reflects the relevant parameters of the latest lightning event, as also accessible via the MODBUS or IEC-104 protocols.

The **Event history** provides a full listing of all lightning events, including option for view of the time series and main lightning parameters for the individual events, see the subfolder *eventFiles*. Note that section 6.2.3 describe a more easily accessible overview of the same information using the LSA web interface. Included at the bottom of the event history listing, note the *event_count* parameter which tracks the number of events recorded. Irrespective of specific (or all) events being manually deleted, the *event_count* will remain, to avoid any possible confusion regarding overlapping event IDs from the same sensor.



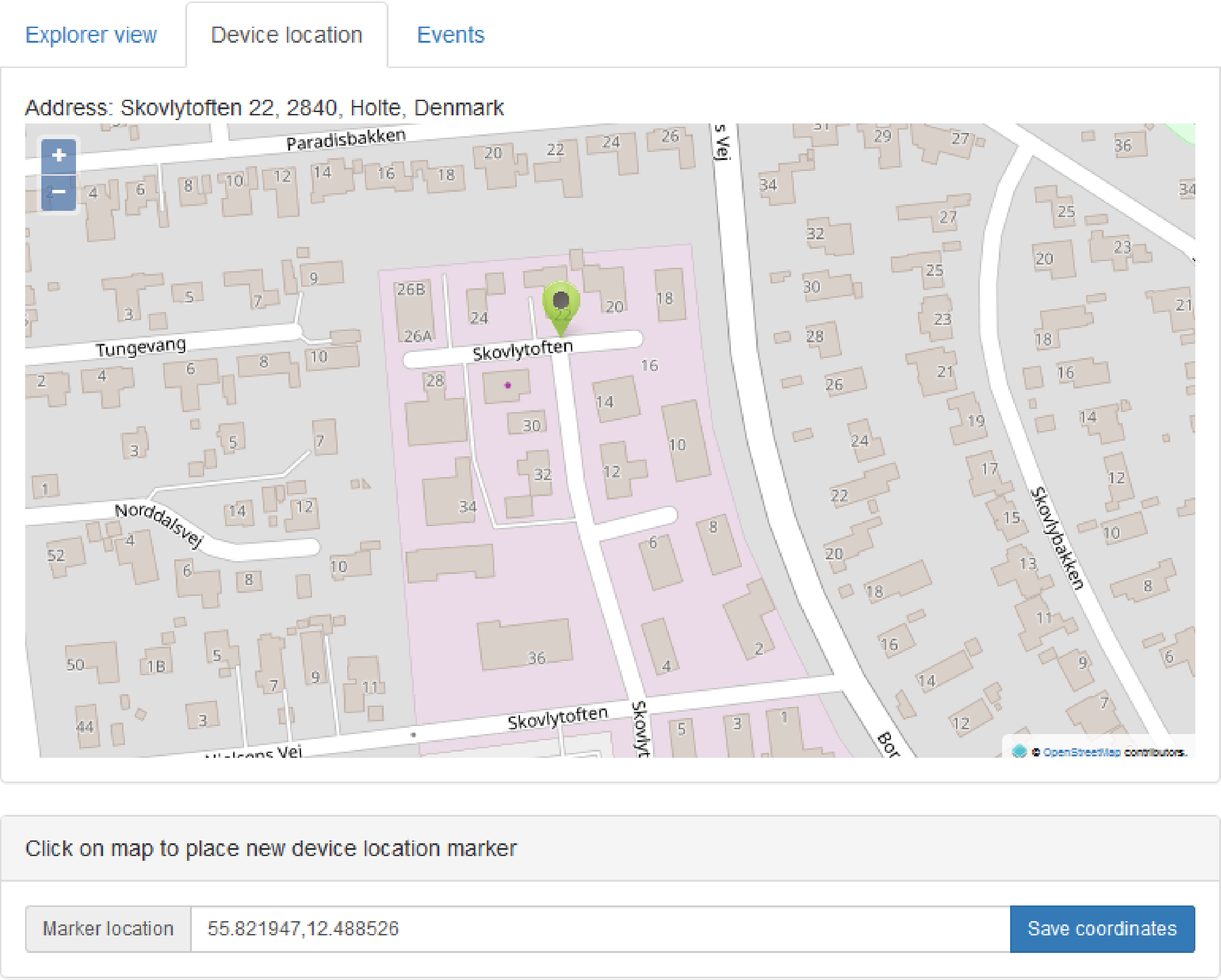
LSA - Serial: #4294943476, MAC: 00-50-C2-BA-02-00, operating @ 50°C, FW version: 11749
- System and special functions
- Settings
- Identity
- Measurements
- Event history

Figure 7: Screen shot from the *Explorer view* sub page listing the main folders.

6.2.2 Device location

The *Device location* page visualizes the geographical sensor installation location on an interactive map. The location coordinates can be edited by clicking the map to place a new marker. Once the new mark has been placed at the desired position, the location coordinates can be saved by clicking the *Save coordinates* button in the *page context menu*.

The device location coordinates can also be set through the *Identity->wgs84_coordinate* node in the *Explorer view* sub page. Note that the map will only load, if the client browser has internet access.



Address: Skovlytoften 22, 2840, Holte, Denmark

Click on map to place new device location marker

Marker location 55.821947,12.488526 Save coordinates

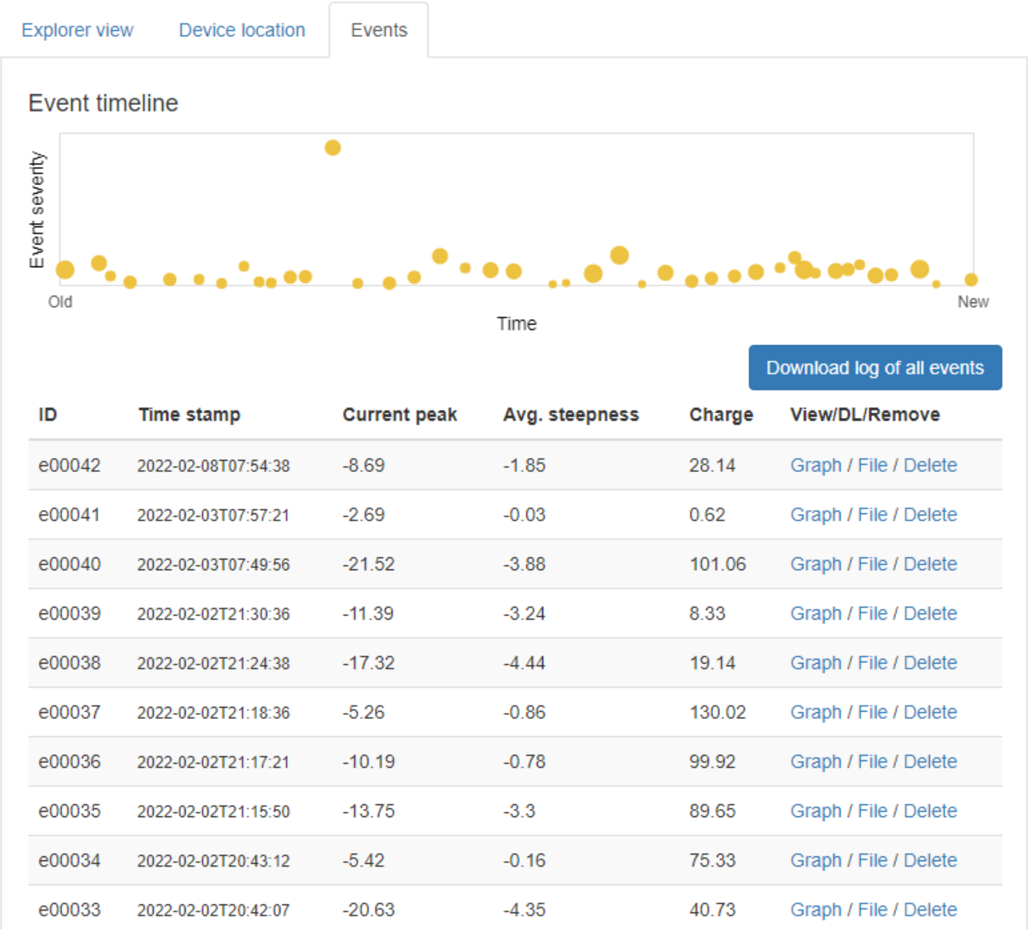
Figure 8: Screen shot from the *Device location* sub page presenting a marker location ready to be saved.

6.2.3 Events

The *Events* page provides an easily accessible overview of the strikes recorded by the LSA, including a graph at the top in chronological order of all recordings, with the size of each circle scaled according to the peak current, the event severity (Y-axis) scaled according to the lightning parameter closest to the respective Lightning Protection Level I level, and a custom log-scaling for the X-axis distance in time between events. See figure 9.

Either by clicking on a circle, or by clicking on the *Graph* link button on the right hand side of the table listing below the graph, an event presentation like shown in figure 5 is shown. With this view, it is also easy to inspect the time series behaviour of individual events using the zoom in and graph reset functionalities.

Using the *Download log of all events*-button, all key lightning parameters of all recorded strikes can be downloaded in a csv file, for easy filtering and analysis.



ID	Time stamp	Current peak	Avg. steepness	Charge	View/DL/Remove
e00042	2022-02-08T07:54:38	-8.69	-1.85	28.14	Graph / File / Delete
e00041	2022-02-03T07:57:21	-2.69	-0.03	0.62	Graph / File / Delete
e00040	2022-02-03T07:49:56	-21.52	-3.88	101.06	Graph / File / Delete
e00039	2022-02-02T21:30:36	-11.39	-3.24	8.33	Graph / File / Delete
e00038	2022-02-02T21:24:38	-17.32	-4.44	19.14	Graph / File / Delete
e00037	2022-02-02T21:18:36	-5.26	-0.86	130.02	Graph / File / Delete
e00036	2022-02-02T21:17:21	-10.19	-0.78	99.92	Graph / File / Delete
e00035	2022-02-02T21:15:50	-13.75	-3.3	89.65	Graph / File / Delete
e00034	2022-02-02T20:43:12	-5.42	-0.16	75.33	Graph / File / Delete
e00033	2022-02-02T20:42:07	-20.63	-4.35	40.73	Graph / File / Delete

Figure 9: Screen shot from the *Events* sub page listing the lightning events registered by the sensor.

6.3 Settings

Below is a description of the different subfolders in the Settings folder, in alphabetical order.

iec104
The iec104 subfolder lists all main parameters used for the IEC 60870-5-104 protocol configuration. See section 8 for additional details.

influxdb
The sensor supports push of a predefined dataset from the sensor to an InfluxDB server (verified to work with InfluxDB 2.1.1). Note that this functionality is inactive, as long as the ***enable_push*** parameter is set to false. Additional customization options may be added in future updates. Should you have a specific request for an InfluxDB configuration or troubleshooting, please contact Jomitek for support.

lsa
The lsa subfolder contains a number of LSA sensor specific configuration options:

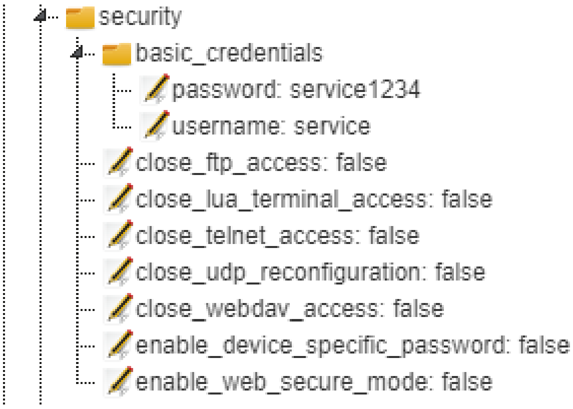
- **alarm_relay** define the settings for the output alarm relay signal used as an indication to external systems that a lightning strike has been detected.

- **measurement** define parameters related to the lightning current trigger level and the length of the time series to be recorded when a strike is detected.
- **service_alarm_levels** lists a set of parameter thresholds for when service visits are warranted. The intent of these parameters are for a wind turbine operator - in particular when a turbine is out of warranty - to determine if an inspection visit is required, based on emperical knowledge. To be clear; The LSA will raise a lightning alarm whenever a lightning event exceeding the ***trigger_level*** is detected. The ***service_alarm_levels*** may in a future update raise a parallel alarm indication whenever either the individual lightning, or the aggregation of lightning events, exceed such empirically determined levels. It is entirely the responsibility of the turbine operator to determine what such levels should be (i.e. what level of risk vs. operational cost is acceptable), however Jomitek is very open to support an expansion and refinement of such an approach in terms of LSA functionality. Note that at present there is no alarm functionality tied to the ***service_alarm_levels*** parameters.
- **tower** define parameters describing the physical geometry of the wind turbine on which the LSA is mounted. Together, these parameters define the magnetic-field-to-lightning-current conversion model. It is important to specify these parameters in order to get the highest level of precision in the post processing, with a particular emphasis on the tower radius at the point of installation.

security
As mentioned in section 1.4 the LSA is generally speaking not able to provide end-to-end encryption, as the sensor makes use of a microprocessor without such capability. Nonetheless, a number of important security measures are supported by the LSA . Part of this security is highlighted in section 5.1, in that only encrypted firmware files created by Jomitek can be used to update the microprocessor. The processor has the hardware pins used for direct programming or program readout disabled. As such, the firmware and any update of this is considered a fully secure aspect of the sensor.

As for the various communication protocols supported by the LSA most of these offer no inherent security features. The exception being the web interface access, which supports login with credentials at several levels. Credential verification happens within the microprocessor (where the firmware is inacessible, even for an attacker with physical access). As one of several measures the credentials are SHA-256 encrypted client side, before being sent to the LSA .

The security concept of the LSA is built on the option of secure access via the web interface, with the *security* section of the Settings folder providing configuration of all relevant security settings. By default none of these options are enabled, to allow ease of initial configuration and integration tests of the sensor.



```
security
  basic_credentials
    password: service1234
    username: service
  close_ftp_access: false
  close_lua_terminal_access: false
  close_telnet_access: false
  close_udp_reconfiguration: false
  close_webdav_access: false
  enable_device_specific_password: false
  enable_web_secure_mode: false
```

Figure 10: Overview of the web interface showing the security settings.

The credentials are supported in two ways; basic credentials, with full customization option, or using a device specific password, with a static password locked to the LSA hardware.

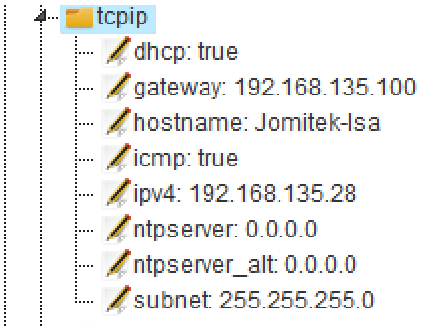
- **basic_credentials->password** is the password used for FTP access in all scenarios. It is also used for login to the web interface, when ***enable_web_secure_mode = true*** and ***enable_device_specific_password = false***. The input is limited to characters a-z, A-Z, 0-9, period and dash, and text length 4 to 24 characters.
- **basic_credentials->username** is the username used for FTP access in all scenarios. It is also used for login to the web interface, when ***enable_web_secure_mode = true***. It is used as username irrespective of the setting of ***enable_device_specific_password***. The input is limited to characters a-z, A-Z, 0-9, period and dash, and text length 4 to 24 characters.
- **close_ftp_access** when set to true, will disable FTP access.
- **close_lua_terminal_access** when set to true, will disable the Lua terminal access.
- **close_telnet_access** when set to true, will disable the Telnet access.
- **close_udp_reconfiguration** when set to true, will disable the Jomitek Device Locator functionality of reconfiguring/recovering the LSA IP settings via UDP.
- **close_webdav_access** when set to true, will disable the WebDAV access.
- **enable_device_specific_password** when set to true, will allow login to the web interface only using the device specific password supplied by Jomitek, when ***enable_web_secure_mode = true***
- **enable_web_secure_mode** when set to true, will require login to the web interface using either basic credentials, or credentials using the device specific password. The device specific password will work in both scenarios, with basic credentials working only if ***enable_device_specific_password = false***.

Note that as a general measure for the security settings, as well as all other reconfiguration of settings, the LSA should be restarted, as many of the changes are put into effect only during boot up.

tcpip (TCP/IP and NTP)
The tcpip setting provides configuration of TCP/IP and (S)NTP settings. The following parameters are available, see figure 11.

- ***dhcp*** a boolean flag for enabling/disabling use of DHCP.
- ***gateway*** The forwarding host e.g. router to other networks used when no other route specification matches the destination IP address of a packet.
- ***hostname*** The hostname of this device.
- ***icmp*** a boolean flag for enabling/disabling the ICMP ping utility for the device.
- ***ipv4*** the IPv4 address of the device, when the sensor is booted with the DHCP flag set to false.
- ***ntpserver*** the IPv4 address of the primary (S)NTP server when the DHCP flag is set to false, set ntpserver to 0.0.0.0 to disable.
- ***ntpserver_alt*** the IPv4 address of the secondary (S)NTP server when the DHCP flag is set to false, the ntpserver_alt address is only used when the ntpserver addess is not 0.0.0.0, set ntpserver_alt to 0.0.0.0 to disable.
- ***subnet*** the subnet mask used when the sensor is booted with the DHCP flag set to false.

The sensor supports SNTP in two ways: By default when the DHCP flag is set to true, the sensor queries the DHCP server for an NTP server address. When the DHCP flag is set to false, or the DHCP server does not respond with an NTP server address, the sensor rely on the user to provide a set of valid NTP server addresses. These addresses are to be typed into the ntpserver and ntpserver_alt fields. For wind turbine farms, an NTP server is often present locally which would then be the preferred source, and otherwise public NTP servers may be used.



tcpip
dhcp: true
gateway: 192.168.135.100
hostname: Jomitek-lsa
icmp: true
ipv4: 192.168.135.28
ntpserver: 0.0.0.0
ntpserver_alt: 0.0.0.0
subnet: 255.255.255.0

Figure 11: Overview of the web interface showing the TCP/IP settings.

As a default DHCP is set to true. The IP and gateway address and the subnet mask is also defined here and is only used when the sensor is booted with the DHCP flag set to false. Note that if the device experiences severe errors during startup, it will revert to the IP configuration defined in the '*conf/panic.ip*' file (default with *dhcp=true*), and if this also fails to load, hardcoded settings will apply, using *dhcp=true*. In DHCP mode, in the case where no DHCP server can be reached, the sensor will automatically choose a random IP address in the range 169.254.1.0 to 169.254.254.255 in compliance with RFC 3927 Section 2.1.

time->timezone
The timezone settings can be found in the **time** folder.

- ***utc_offset_hh*** sets the time offset with reference to UTC in hours.
- ***utc_offset_mm*** sets the time offset with reference to UTC in minutes.

web
The parameters in the web section define which port is used for the web service (default is '80'), and the start page when logging on to the device, with options including 'home', 'geolocation' and 'event'.

6.4 Identity

The Identity folder contains all the location and naming related information for a specific device. It should always be edited, or generated, on an individual basis. The parameters include *address*, *city*, *zip*, *country_state*, *location_name* and *location_description* as identifying text for the location. The location_name could e.g. be the name or reference for a wind turbine, and the *location_description* could detail the wind turbine park name. Furthermore the location may be specified using WGS84 coordinates in a '<latitude>,<longitude>' decimal degrees format. The *serial_number* is the Jomitek device serial number and should not be edited. In this context, note that the only hardcoded identifier of a device is the uniquely assigned MAC address. The *type* parameter will, if left blank, be automatically set during bootup based on a device internal check of the accessible peripherals. Custom naming may be used as an alternative. Note that using the 'Device location' sub page enables manually/visually updating the coordinates of the LSA. When the marker location is saved, it is effectively overwriting the *Settings->wgs84_coordinate* parameter.

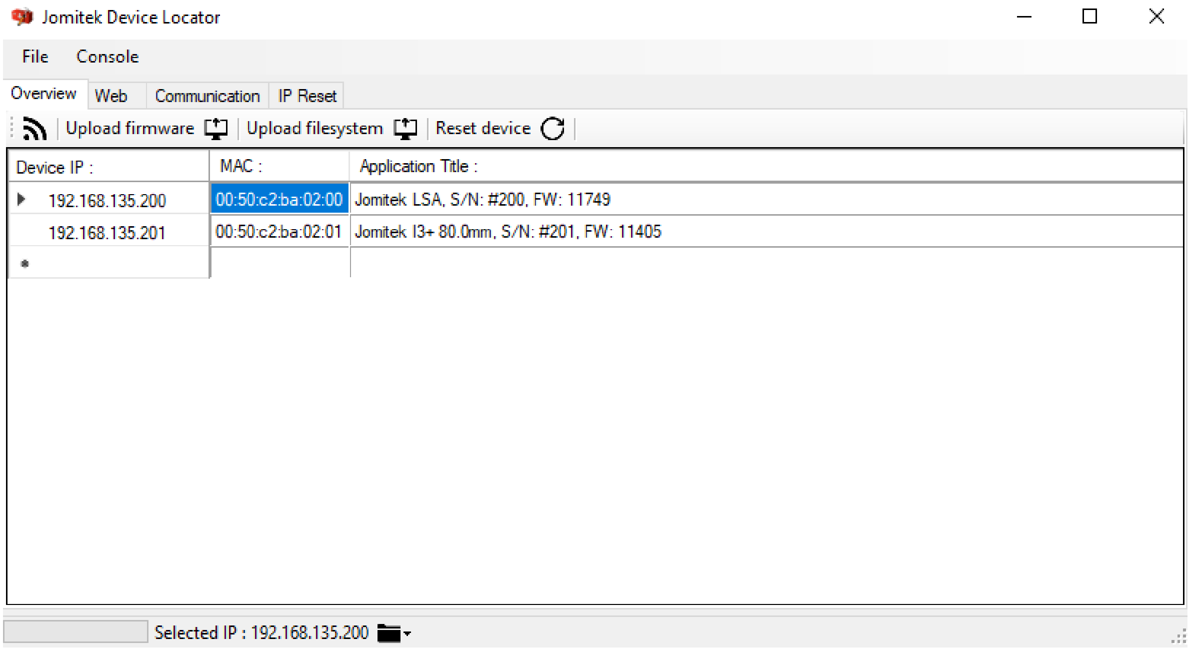
7 Support tools for LSA configuration and updates

On the Jomitek web site various tools are provided to support efficient initial configuration and continued operation of a large amount of sensors. See https://jomitek.dk/en/downloads/tools. Some of these tools, as well as scripting examples, are detailed in the following.

7.1 The Jomitek Device Locator

The Jomitek Device Locator (JDL) offers an all-in-one package in terms of detection and configuration of a Jomitek sensor, based on manual interactions via a GUI. It is a Windows program executable (.exe), tested to work using Windows 10 or later. As such, some organizations may have security policies restricting direct download, or in other ways hindering use of the software. Please reach out to Jomitek, to discuss possible solutions in such cases.

JDL overview



Device IP :	MAC :	Application Title :
192.168.135.200	00:50:c2:ba:02:00	Jomitek LSA, S/N: #200, FW: 11749
192.168.135.201	00:50:c2:ba:02:01	Jomitek I3+ 80.0mm, S/N: #201, FW: 11405

Selected IP : 192.168.135.200

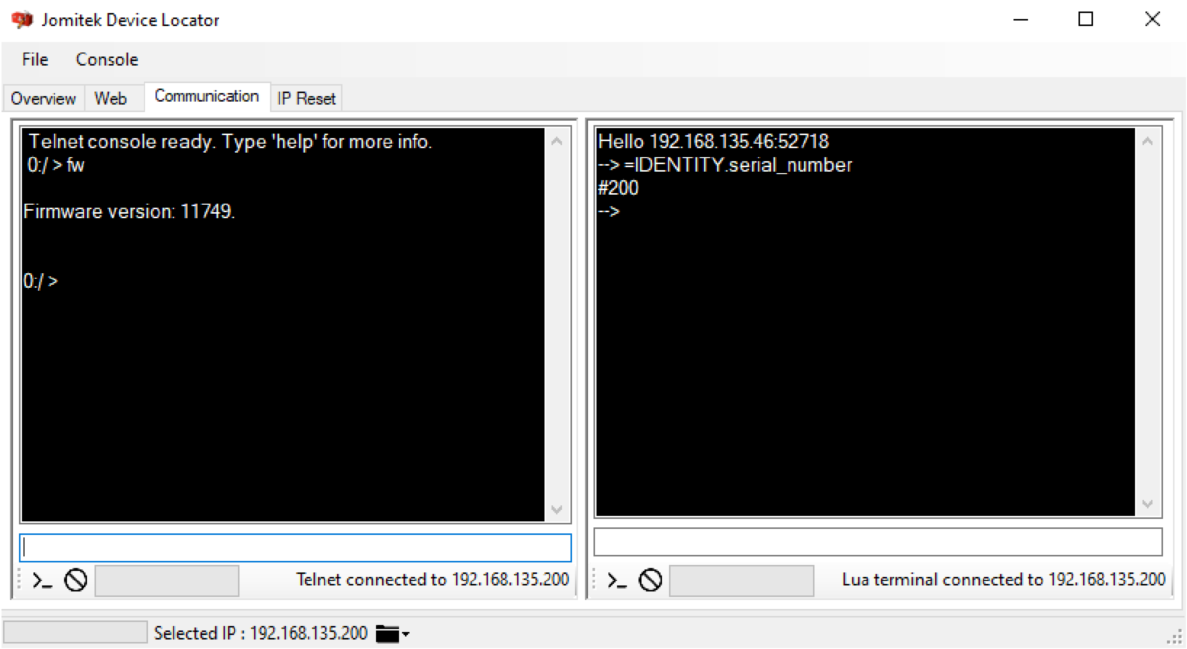
Figure 12: The Jomitek Device Locator overview tab.

Via the overview tab, using broadcast via UDP port 23, the JDL lists all Jomitek sensors reachable from the client PC, including identifying information such as the active IP address of each sensor, the corresponding MAC address, serial number information, type of sensor and the firmware (FW) in active use. See figure 12 for reference. In most cases the sensors use a DHCP server on the network it is connected to, to get an IP address assignment. In this context, the JDL is useful in easily identifying what address was assigned.

Note that use of UDP enables the Locator software to detect sensors that are outside of the IP range / subnet mask used by the client PC. As such, in order to be able to connect to a given sensor, it must be ensured that the client is reachable via the client IP address. This is usually the case if the same DHCP server is used for both sensor and client, and no custom rules are applied for IP assignments.

JDL communication

When marking a sensor in the overview tab, it is automatically selected as the target for the other JDL tabs. The communication tab provides a parallel view with access using Telnet on the left hand side (TCP port 23), see



```
Telnet console ready. Type 'help' for more info.
0:/ > fw

Firmware version: 11749.


0:/ >
```

```
Hello 192.168.135.46:52718
--> =IDENTITY.serial_number
#200
-->
```

Telnet connected to 192.168.135.200

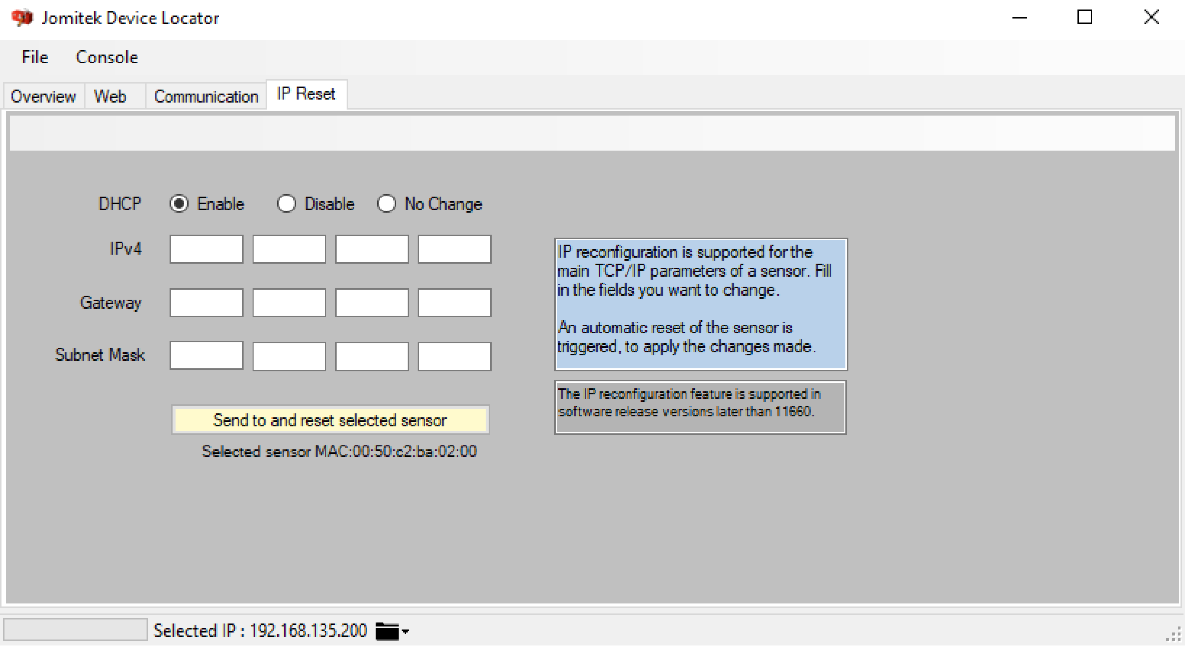
Lua terminal connected to 192.168.135.200

Selected IP : 192.168.135.200

Figure 13: The Jomitek Device Locator communication tab.

connectivity alternatives in section 12.1. The right hand side provides Lua terminal access (TCP port 2840). Both of these access options are primarily meant for super users, and are as such not needed for normal operation.

JDL IP reset



DHCP ● Enable ○ Disable ○ No Change

IP reconfiguration is supported for the main TCP/IP parameters of a sensor. Fill in the fields you want to change.

An automatic reset of the sensor is triggered, to apply the changes made.

The IP reconfiguration feature is supported in software release versions later than 11660.

Selected sensor MAC:00:50:c2:ba:02:00

Selected IP : 192.168.135.200

Figure 14: The Jomitek Device Locator IP reset tab.

The IP reset tab provides a reconfiguration option for the TCP/IP settings for Jomitek sensors, based on UDP port 1342. It is convenient in cases where the client IP settings do not allow direct access to a sensor, and rather than change the client settings, the sensor can be reassigned to be in a reachable IP range using this functionality.

7.2 Mass reconfiguration and updates

Jomitek offers custom configuration of sensors before delivery, with device specific settings if requested. Such custom configuration would usually apply to the parameters described in sections 6.3 and 6.4, which in the sensor is defined in the */conf/settings.conf* and */conf/identity.conf* respectively.

In some cases these parameters are first possible to configure after delivery, prompting the need for an efficient way to perform mass configuration changes of sensors. There are several possible ways to achieve this goal as exemplified in the following.

Reconfiguration via the web interface

While reconfiguration of parameters via the web interface is the most intuitive to use, provides on-mouse-over description of parameters, and feature client side validation of appropriate formatting of parameter input, it is also the least efficient and includes the risk of incorrect manual entries being made. Assuming a large volume of sensor updates (e.g. >10), the web interface is suggested to be used for initial tests only, to provide a valid template for the update need of additional sensors.

Reconfiguration using .reconf files

The *Mass reconf tool* macro enabled Excel document provided by Jomitek can be used as-is, or as an inspiration for similar scripting based sensor updates. See the 'User Manual'-sheet in the document for a detailed description of the functionality. The tool is based on the use of .reconf files (either settings.reconf and/or identity.reconf), which allows for incremental changes of parameters of the parent settings.conf and identity.conf files, without changing the rest of the .conf parameters. It is recommended NOT to overwrite .conf files directly.

The Excel document supports the generation of correctly formatted .reconf files, as well as generation of a transfer script based on FTP transfer via WinSCP.

A *settings.reconf* or *identity.reconf* file transferred to the */conf* folder (using WebDAV or FTP) will automatically be detected and incorporated in the respective .conf file by the LSA whereafter the .reconf file is automatically deleted. This process flow takes less than 10 seconds.

Before mass updates are initiated, it is important to ensure that there are no errors in the input provided, e.g. using a trial sensor, or other easily accessible sensor to validate full functionality. Jomitek is also available to support any validation needed in this context.

Note that updates to *settings.conf* will, in most cases, require a sensor restart before the changes take effect.

Reconfiguration using *curl*

Curl is a command line tool available across all major operating systems, which can be used to automate http interactions. However, note that there may be differences in the syntax used across various implementations. The examples provided in the following applies for Windows 10 with curl 8.4.0. The examples include the most common parameters required to update to configure and identify a sensor.

The parameter value in each case is underlined. To check what parameter values are valid, please test values using the web GUI as a first step. Note that the examples target a sensor with IP address 192.168.135.98. Change this to the relevant address to be updated.

Parameters specified in settings.conf; tower height, radius and sensor mount height respectively

- `curl -d "command=lua_table_update&file_name=settings&lua_table_path=CONFIG.lsa.tower.height&lua_value=80" http://192.168.135.98:80/backendhandler.lua`

- `curl -d "command=lua_table_update&file_name=settings&lua_table_path=CONFIG.lsa.tower.radius&lua_value=2.8" http://192.168.135.98:80/backendhandler.lua`

- `curl -d "command=lua_table_update&file_name=settings&lua_table_path=CONFIG.lsa.tower.sensor_mount_height&lua_value=7.5" http://192.168.135.98:80/backendhandler.lua`

- `curl -d "command=reset_device&reset_type=main" http://192.168.135.98:80/backendhandler.lua`

Note that parameters associated with the settings.conf file, will generally require a sensor reboot command in order to become active, which is included as the last command of the previous example list.

Parameters specified in identity.conf; location coordinates, location name and location description respectively

- `curl -d "command=lua_table_update&file_name=identity&lua_table_path=IDENTITY.wgs84_coordinate&lua_value=55.821925,12.488535" http://192.168.135.98:80/backendhandler.lua`
- `curl -d "command=lua_table_update&file_name=identity&lua_table_path=IDENTITY.location_name&lua_value=T21" http://192.168.135.98:80/backendhandler.lua`
- `curl -d "command=lua_table_update&file_name=identity&lua_table_path=IDENTITY.location_description&lua_value=Wind farm name" http://192.168.135.98:80/backendhandler.lua`

Software updates

Software updates, in the form of a *software.tar.gz* file, are applied by transferring the file to the */software_update* folder, and then triggering a reboot of the sensor. The update is usually completed within 2-3 minutes.

The transfer can be made in a number of ways, e.g. using FTP, WebDAV, and the 'Upload filesystem' button in the overview tab of the Jomitek Device Locator. The *Jomitek mass SW update tool* on the Jomitek website provides an example based on a macro enabled Excel document, which generates a script for software updates via WebDAV, using WinSCP. See the manual provided in the document for additional guidance on this approach.

An example using *curl* to perform a software update is provided in the following. It is assumed that a software file has been acquired, e.g. from the Jomitek software download page (see section 11.2), and that the curl script is being executed from the folder where the relevant software package is located. Note that the filename of the software package uploaded must be *'software.tar.gz'*. The example targets a sensor with IP address 192.168.135.98. Change this to the relevant address to be updated.

Software package upload and application via sensor reboot command

- `curl -d "command=getDeviceInfo" http://192.168.135.98:80/backendhandler.lua`
- `curl -T software.tar.gz http://192.168.135.98/dav/software_update/`
- `curl -d "command=reset_device&reset_type=main" http://192.168.135.98:80/backendhandler.lua`
- `curl -d "command=getDeviceInfo" http://192.168.135.98:80/backendhandler.lua`

The sensor should be expected to be unresponsive for 2-3 minutes during the update process, whereafter the last command can be executed. Note that the first and last commands in the example are optional checks of the pre and post sensor device info, which includes the firmware version in the response. This information can be used to confirm if the update was successful. For firmware prior to release 11773 the getDeviceInfo command will not work, and in such cases the upgrade can be confirmed by the command working post upgrade.

Reconfiguration and updates vs. security settings

As mentioned in section 6.3, no security measures are activated by Jomitek by default (unless specified so by the customer). The intention is to ensure full access for initial configuration and testing. If the customer choose to activate relevant security measures after commissioning of the sensor, note that scripted access, e.g. via FTP, WebDAV or curl commands may no longer work, depending on what has been disabled via the security settings.

The configuration of the security settings can be accomplished using curl commands, including setting *enable_web_secure_mode* to *true*. After a reboot, curl commands will no longer work. As such, to gain access to the sensor again, it must be unlocked manually using the web interface / GUI with appropriate credentials, whereafter scripted commands can be used again. The point of these comments is to make it clear that activation of the security features include a penalty on the complexity in regards to changes to the sensor configuration and software upgrades, as well as the ability to perform automated retrieval of measurement files, event logs, etc..

8 IEC-60870-5-104 configuration

The IEC 60870-5-104 (abbreviated "IEC 104" or "104" in the following) application layer protocol can be used for transmitting sensor data from the sensor to a SCADA system or another data-aggregation device implementing the IEC 104 protocol. The TCP/IP protocol is used to ensure reliable data transfer. Additionally, the 104 protocol supports message sequencing on the application layer. A 104 client connects to TCP port 2404.

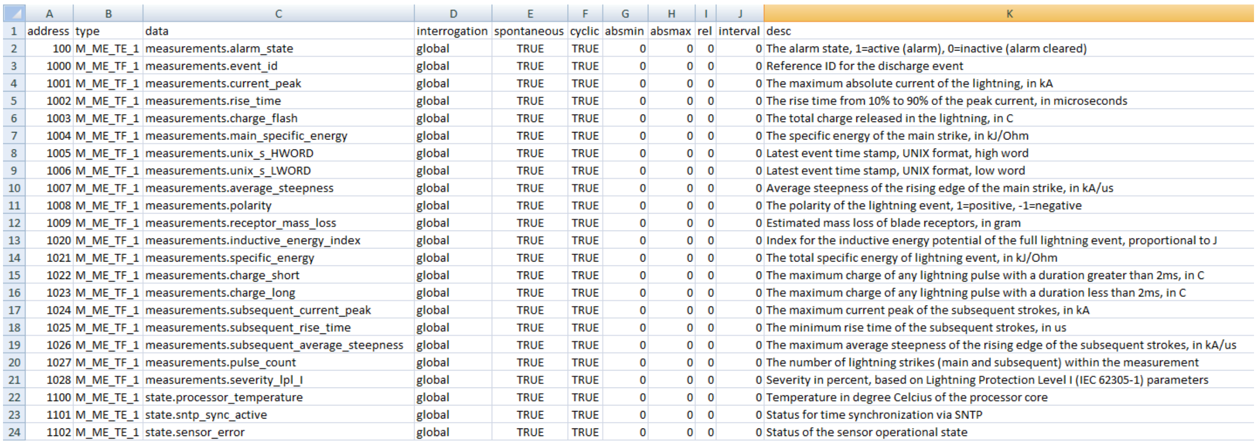
The sensor allows flexible configuration of the protocol settings, and of the data points. The data points can be transmitted based on a variety of triggers, including on-change, periodic, on manual request, or using interrogation commands requesting a larger set of data. The sensor can be configured to use all features defined in the IEC 104 standard, or the sensor can use a small subset for simpler applications.

The 104 protocol settings are found in the settings.conf file under the "iec104" section. These shall match the protocol settings defined in the SCADA client, and must be in compliance with the IEC standard. Interoperability requirements can be documented by a 104 client by filling out Chapter 9 in the IEC 104 standard. An overview of the parameters defined in the sensor is listed in table 1.

Setting	**Meaning**	**Default**
t1	Time-out of send or test APDUs.	16
t2	Time-out for acknowledges in case of no data messages, t2<t1.	11
t3	Time-out for sending test frames in case of a long idle state.	21
k	Maximum difference receive sequence number to send state variable.	8
w	Latest acknowledge after receive w I format APDUs.	12
common_address	IEC 104 address of sensor.	1
background_scan	Interval in seconds between transmission of digital data points.	1800
cyclic	Interval in seconds between transmission of analogue data points.	600
scan	Data change scan interval in milliseconds for sending event-triggered data.	500
clock_validity	Time-tagged client commands validity period in seconds.	600
redundancy	Max number of redundant connections as defined by IEC 104.	2

Table 1: IEC-104 parameters.

Three *.csv* files are used to map sensor measurements to data points accessible by an IEC 104 client. A macro enabled Excel file is used to generate these *.csv* files, and all changes to the data mapping should be applied in the Excel file. There are three sheets in the Excel file, and each generate one .csv file. The sheets are called "iec104_analogue", "iec104_digital" and "iec104_commands", which define analogue and digital measurement mapping to the IEC 104 protocol. An example snapshot of the "iec104_analogue" sheet is shown in figure 15. The "iec104_commands" is currently not used for the LSA , and will not be detailed further.



	A	B	C	D	E	F	G	H	I	J	K
1	address	type	data	interrogation	spontaneous	cyclic	absmin	absmax	rel	interval	desc
2	100	M_ME_TE_1	measurements.alarm_state	global	TRUE	TRUE	0	0	0	0	The alarm state, 1=active (alarm), 0=inactive (alarm cleared)
3	1000	M_ME_TF_1	measurements.event_id	global	TRUE	TRUE	0	0	0	0	Reference ID for the discharge event
4	1001	M_ME_TF_1	measurements.current_peak	global	TRUE	TRUE	0	0	0	0	The maximum absolute current of the lightning, in kA
5	1002	M_ME_TF_1	measurements.rise_time	global	TRUE	TRUE	0	0	0	0	The rise time from 10% to 90% of the peak current, in microseconds
6	1003	M_ME_TF_1	measurements.charge_flash	global	TRUE	TRUE	0	0	0	0	The total charge released in the lightning, in C
7	1004	M_ME_TF_1	measurements.main_specific_energy	global	TRUE	TRUE	0	0	0	0	The specific energy of the main strike, in kJ/Ohm
8	1005	M_ME_TF_1	measurements.unix_s_HWORD	global	TRUE	TRUE	0	0	0	0	Latest event time stamp, UNIX format, high word
9	1006	M_ME_TF_1	measurements.unix_s_LWORD	global	TRUE	TRUE	0	0	0	0	Latest event time stamp, UNIX format, low word
10	1007	M_ME_TF_1	measurements.average_steepness	global	TRUE	TRUE	0	0	0	0	Average steepness of the rising edge of the main strike, in kA/us
11	1008	M_ME_TF_1	measurements.polarity	global	TRUE	TRUE	0	0	0	0	The polarity of the lightning event, 1=positive, -1=negative
12	1009	M_ME_TF_1	measurements.receptor_mass_loss	global	TRUE	TRUE	0	0	0	0	Estimated mass loss of blade receptors, in gram
13	1020	M_ME_TF_1	measurements.inductive_energy_index	global	TRUE	TRUE	0	0	0	0	Index for the inductive energy potential of the full lightning event, proportional to J
14	1021	M_ME_TF_1	measurements.specific_energy	global	TRUE	TRUE	0	0	0	0	The total specific energy of lightning event, in kJ/Ohm
15	1022	M_ME_TF_1	measurements.charge_short	global	TRUE	TRUE	0	0	0	0	The maximum charge of any lightning pulse with a duration greater than 2ms, in C
16	1023	M_ME_TF_1	measurements.charge_long	global	TRUE	TRUE	0	0	0	0	The maximum charge of any lightning pulse with a duration less than 2ms, in C
17	1024	M_ME_TF_1	measurements.subsequent_current_peak	global	TRUE	TRUE	0	0	0	0	The maximum current peak of the subsequent strokes, in kA
18	1025	M_ME_TF_1	measurements.subsequent_rise_time	global	TRUE	TRUE	0	0	0	0	The minimum rise time of the subsequent strokes, in us
19	1026	M_ME_TF_1	measurements.subsequent_average_steepness	global	TRUE	TRUE	0	0	0	0	The maximum average steepness of the rising edge of the subsequent strokes, in kA/us
20	1027	M_ME_TF_1	measurements.pulse_count	global	TRUE	TRUE	0	0	0	0	The number of lightning strikes (main and subsequent) within the measurement
21	1028	M_ME_TF_1	measurements.severity_lpl_I	global	TRUE	TRUE	0	0	0	0	Severity in percent, based on Lightning Protection Level I (IEC 62305-1) parameters
22	1100	M_ME_TE_1	state.processor_temperature	global	TRUE	TRUE	0	0	0	0	Temperature in degree Celcius of the processor core
23	1101	M_ME_TE_1	state.sntp_sync_active	global	TRUE	TRUE	0	0	0	0	Status for time synchronization via SNTP
24	1102	M_ME_TE_1	state.sensor_error	global	TRUE	TRUE	0	0	0	0	Status of the sensor operational state

Figure 15: iec104_analogue.

- **address** The address of the data point, [1-65535].
- **type** The IEC 104 type (see interoperability list in IEC 60870-5-104 chapter 9).
- **data** Internal sensor variable name.
- **interrogation** The interrogation group this data point belongs to. Can be "global" or "groupX", X=[1-16].
- **spontaneous** Set to true if data point should be transmitted on change.
- **cyclic** Set to true if data point should be sent periodically.
- **absmin** Minimum absolute change in data value to trigger spontaneous transmission. This is useful for avoiding sending a data point too often when the value is low.
- **absmax** Maximum absolute change in data value to trigger spontaneous transmission.
- **rel** Relative change in percent of the data value to trigger spontaneous transmission. For example, setting rel = 10 for a data point with value 500 triggers transmission at 450 or 550.
- **desc** A short description of the data point and unit.

Refer to figure 16 for a graphical example of the transmission thresholds absmin, absmax and rel.

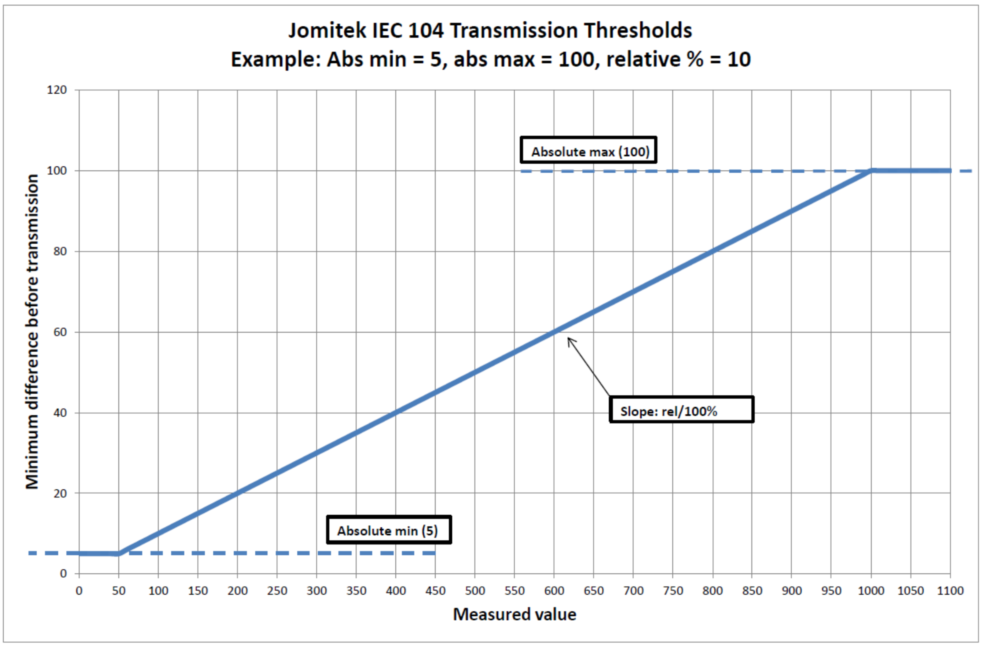


Figure 16: absmin, absmax and rel.

Any change in a digital value triggers transmission given spontaneous is set to true for this data point in the "iec104_digital" sheet. For this reason the "iec104_digital" sheet does not define absmin, absmax and rel columns. Also, the "iec104_digital" sheet replaces the "cyclic" column found in the analogue sheet with "background". The use of the "cyclic" column for analogue values is similar to the use of "background" column because they are both used to trigger transmission at fixed intervals.

Since the IEC 104 protocol uses TCP/IP, it may in some cases be useful to look into the communication stream using Wireshark[1] for troubleshooting purposes.

[1] https://www.wireshark.org/

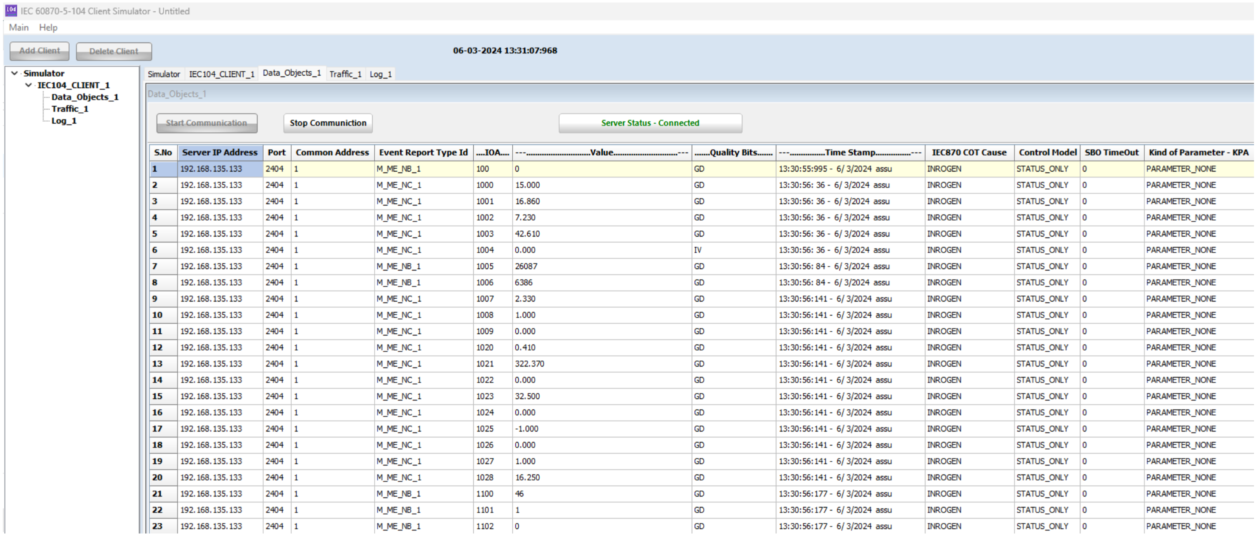
8.1 Time stamp readout and interpretation example

When a strike events occur, the details of the event is calculated (takes 1-2 minutes for a 1000ms recording) and the result can be seen in the web overview. See figure 9 as an example.

The IEC 104 read out always presents the latest recorded strike. As there may be a risk of 2 or more strikes being recorded without reading out the earlier strike via IEC 104, the user can follow the event number of the active strike being displayed on the IEC-104 readout. This makes it possible to check if a readout has been missed. The data can be read out using the web interface, or the full event log file via FTP or WebDAV.

Time is stored in UNIX time format. This is a 32 bit integer. As IEC 104 can read out 16 bit integers, the time is stored in 2 words, a high- and a low word. This is illustrated in the .csv file that defines the IEC 104 variables, see figure 15.

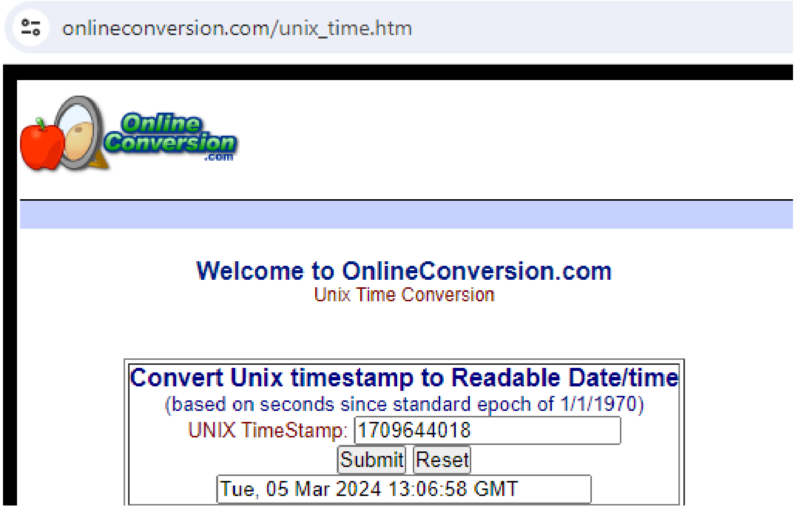
When performing a general interrogation command in IEC 104 the result is shown in figure 17. In this example, the read out of the high word (addr. 1005) is 26087 in decimal format or in hex format, 65E7. The low word (addr. 1006) is 6386(dec) = 18F2 (hex). The combination into a 32-bit hex number is 65E718F2, equal to the decimal number 1,709,644,018.



S.No	Server IP Address	Port	Common Address	Event Report Type Id	....IOA....	---..........Value..........---	.......Quality Bits.......	---..............Time Stamp..............---	IEC870 COT Cause	Control Model	SBO TimeOut	Kind of Parameter - KPA
1	192.168.135.133	2404	1	M_ME_NB_1	100	0	GD	13:30:55:995 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
2	192.168.135.133	2404	1	M_ME_NC_1	1000	15.000	GD	13:30:56: 36 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
3	192.168.135.133	2404	1	M_ME_NC_1	1001	16.860	GD	13:30:56: 36 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
4	192.168.135.133	2404	1	M_ME_NC_1	1002	7.230	GD	13:30:56: 36 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
5	192.168.135.133	2404	1	M_ME_NC_1	1003	42.610	GD	13:30:56: 36 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
6	192.168.135.133	2404	1	M_ME_NC_1	1004	0.000	IV	13:30:56: 36 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
7	192.168.135.133	2404	1	M_ME_NB_1	1005	26087	GD	13:30:56: 84 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
8	192.168.135.133	2404	1	M_ME_NB_1	1006	6386	GD	13:30:56: 84 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
9	192.168.135.133	2404	1	M_ME_NC_1	1007	2.330	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
10	192.168.135.133	2404	1	M_ME_NC_1	1008	1.000	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
11	192.168.135.133	2404	1	M_ME_NC_1	1009	0.000	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
12	192.168.135.133	2404	1	M_ME_NC_1	1020	0.410	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
13	192.168.135.133	2404	1	M_ME_NC_1	1021	322.370	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
14	192.168.135.133	2404	1	M_ME_NC_1	1022	0.000	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
15	192.168.135.133	2404	1	M_ME_NC_1	1023	32.500	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
16	192.168.135.133	2404	1	M_ME_NC_1	1024	0.000	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
17	192.168.135.133	2404	1	M_ME_NC_1	1025	-1.000	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
18	192.168.135.133	2404	1	M_ME_NC_1	1026	0.000	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
19	192.168.135.133	2404	1	M_ME_NC_1	1027	1.000	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
20	192.168.135.133	2404	1	M_ME_NC_1	1028	16.250	GD	13:30:56:141 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
21	192.168.135.133	2404	1	M_ME_NB_1	1100	46	GD	13:30:56:177 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
22	192.168.135.133	2404	1	M_ME_NB_1	1101	1	GD	13:30:56:177 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE
23	192.168.135.133	2404	1	M_ME_NB_1	1102	0	GD	13:30:56:177 - 6/ 3/2024 assu	INROGEN	STATUS_ONLY	0	PARAMETER_NONE

Figure 17: Generel interrogation command result

Entering this decimal number into a UNIX time calculator like: http : //www.onlineconversion.com/unix_time.htm the result shown in figure 18 is seen to match the title line time stamp as presented in the web read out in figure 19.

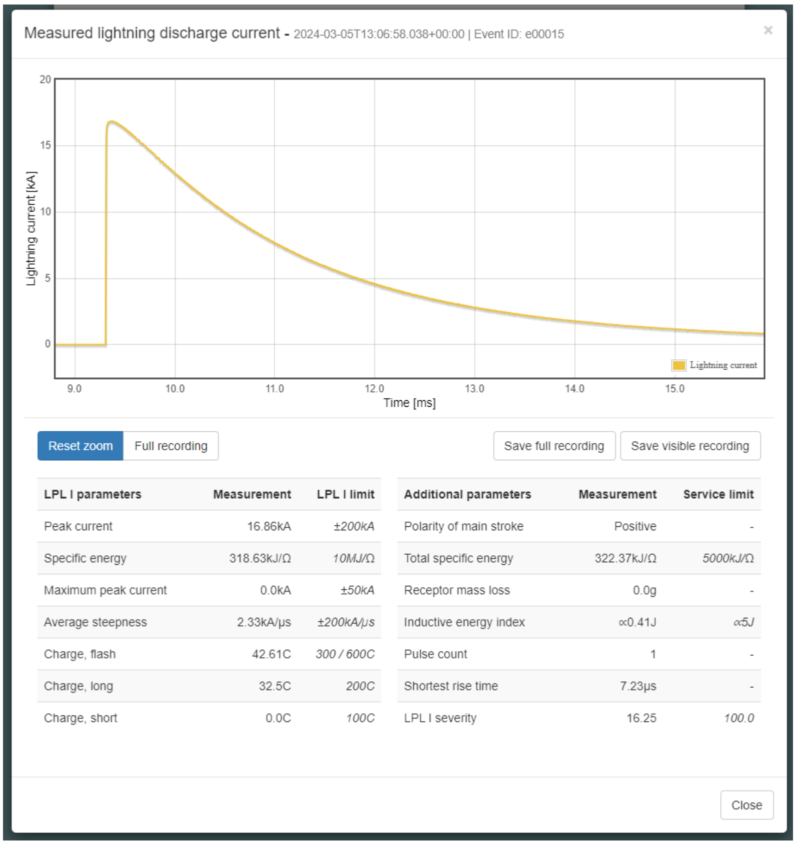


onlineconversion.com/unix_time.htm

Welcome to OnlineConversion.com
Unix Time Conversion

Convert Unix timestamp to Readable Date/time
(based on seconds since standard epoch of 1/1/1970)
UNIX TimeStamp: 1709644018
Tue, 05 Mar 2024 13:06:58 GMT

Figure 18: UNIX time conversion



Measured lightning discharge current - 2024-03-05T13:06:58.038+00:00 | Event ID: e00015

LPL I parameters	Measurement	LPL I limit
Peak current	16.86kA	*±200kA*
Specific energy	318.63kJ/Ω	*10MJ/Ω*
Maximum peak current	0.0kA	*±50kA*
Average steepness	2.33kA/µs	*±200kA/µs*
Charge, flash	42.61C	*300 / 600C*
Charge, long	32.5C	*200C*
Charge, short	0.0C	*100C*

Additional parameters	Measurement	Service limit
Polarity of main stroke	Positive	-
Total specific energy	322.37kJ/Ω	*5000kJ/Ω*
Receptor mass loss	0.0g	-
Inductive energy index	∝0.41J	*∝5J*
Pulse count	1	-
Shortest rise time	7.23µs	-
LPL I severity	16.25	*100.0*

Figure 19: Example event viewed in the LSA web interface

9 MODBUS configuration

As an alternative to IEC 60870-5-104, MODBUS TCP is supported, using the address table below, see table 2:

Description	Unit	Range	Address	MODBUS fct. code
Software version	Number	0-65535	0	4 (read)
Serial number	Number	0-65535	1	4 (read)
Alarm status	Boolean (1=alarm)	0-1	100	4 (read), 6 (write)
Event number	Number	1-65535	1000	4 (read)
Latest peak current	kA	-32768-+32767	1001	4 (read)
Latest rise time	usec	0-65535	1002	4 (read)
Latest charge, flash	C	0-65535	1003	4 (read)
Latest main specific energy	kJ/Ohm	0-65535	1004	4 (read)
Latest event time stamp, HW	Unix time	0-65535	1005	4 (read)
Latest event time stamp, LW	Unix time	0-65535	1006	4 (read)
Latest maximum average steepness	kA/usec	-32768-+32767	1007	4 (read)
Latest polarity	1=pos., -1=neg.	-1 to 1	1008	4 (read)
Latest receptor mass loss	miligram	0-65535	1009	4 (read)
Keep alive counter	Seconds	0-65535	1010	4 (read)
Current time stamp, seconds, HW	Unix time	0-65535	1012	4 (read)
Current time stamp, seconds, LW	Unix time	0-65535	1013	4 (read)
Current time stamp, subsecond	msec	0-999	1014	4 (read)
Latest event time stamp, subsecond	msec	0-999	1015	4 (read)
Time since last alarm	1/10th seconds	0-65535	1016	4 (read)
Time since last alarm	milliseconds	0-65535	1017	4 (read)
Reserved for future use, returns 0	N/A	0	1018	4 (read)
Reserved for future use, returns 0	N/A	0	1019	4 (read)
Latest inductive energy index	$\propto$J	0-65535	1020	4 (read)
Latest total specific energy	kJ/Ohm	0-65535	1021	4 (read)
Latest charge, short	C	0-65535	1022	4 (read)
Latest charge, long	C	0-65535	1023	4 (read)
Latest subsequent current peak	kA	0-65535	1024	4 (read)
Latest subsequent rise time	usec	0-65535	1025	4 (read)
Latest subsequent avg. steepness	kA/usec	-32768-+32767	1026	4 (read)
Latest pulse count	#	1-65535	1027	4 (read)
Latest LPL I severity	%	0-65535	1028	4 (read)
Temperature inside box	Degree C	-200 - 200	1100	4 (read)
SNTP time synchronization	Boolean (1=sync.)	0-1	1101	4 (read)
Sensor error state	Boolean (1=error)	0-1	1102	4 (read)

Table 2: MODBUS address table

The alarm register, 100, will be updated immediately after a strike is detected. The associated lightning event parameters are updated when internal post processing is completed, which for a 1000ms event recording takes 1-2 minutes. Note that register 1016 is valid for 1.8 hours (65535/10 = 6535 seconds), while register 1017 equivalently is valid for 65.535 seconds, after which the register values are automatically reset to 0.

In order to clear an alarm event via MODBUS 0x4341 (17217 decimal) must be written to address 100.

The Unix time stamp should be interpreted similarly to the description in section 8.1. The meaning of 'Latest' in above table is a reference to the latest recorded lightning strike. Data for earlier strikes should either already have been retrieved, or they can be accessed via FTP, WebDAV or the LSA web interface.

An alternative to function code 4 (read register) is function code 3. Function code 16 (write multiple registers), may be used instead of function code 6 (write single register), by specifying a single register in the command.

10 Signal analysis

All time series data files recorded on the LSA are stored as WAV files (file extension .wav). The WAV file format is a lossless and uncompressed format that holds time series meta data such as sampling frequency and sample bit depth as well as the time series measurements stored in a single file.

Additional information describing the type of measurement, scaling, time stamp and similar is contained in the event .log file.

The format structure itself is simple and widely compatible with many software tools relevant for analysis, e.g. Matlab and SciLab. Further information on the format can be found at https://en.wikipedia.org/wiki/WAV.

The web interface of the LSA includes a powerful way to graphically evaluate and analyse lightning recordings, independent of external tools. This option requires web access to the sensor in question.

11 Firmware and software updates

11.1 Boot loading sequence

During startup the LSA checks the `/service/software_update` folder for the presence of a **software update file** or **firmware image file**.

- A **software update file** (`software.tar.gz`) contains a folder structure image that, when unpacked, overwrites the LSA file system. The unpacked file system may include a **firmware image file** in the software update folder.
- A **firmware image file** (`image.bin`) is a binary file which contains the low level functionality needed to run the LSA device.

If a **software update file** is found, it is unpacked and installed automatically, during the next sensor reboot. Such a reboot will therefore often take 2-3 minutes, compared with a standard reboot time of approximately 30 seconds.

If a **firmware image file** is found, the boot loader will search for the presence of a **checksum file** (`checksum.txt`) which is used to verify the integrity of the firmware image. If the calculated checksums match, the firmware is decrypted and its binary instructions copied to the microprocessor which will reboot upon completion, thus finalizing the firmware update process. This process ensures all firmware updates are end-to-end secure, and only updates issued by Jomitek will be possible to load.

After boot loading completes, the system will proceed to initiate further low-level processes after which the Lua scripting engine and web server will be started. At this point the system will be fully operational.

11.2 Sensor updates

The software on the LSA can be updated in four simple steps:

1. Download the newest update file from `http://jomitek.dk/downloads/device_software_update`. The page is password protected, use username: *jomitek* and password: *jomitek*.

2. Connect to the LSA through FTP, WebDAV, using curl or the Jomitek Device Locator, see sections 12.2, 12.3, 7.2 or 7.1 respectively.
3. Transfer the update file, `software.tar.gz`, to the `/service/software_update` directory.
4. Reboot the LSA , e.g. via the web interface, and wait for the boot loading sequence to automatically apply the update.

The LSA will now restart and apply the software update.

For automated mass updates, please refer to `http://jomitek.dk/downloads/tools`, where an Excel and WinSCP-based tool is provided for reference. The mass updates are based purely on WebDAV, i.e. default port 80, which should help avoid many issues in relation to firewall configurations, and related security bottlenecks. Other scripting and file transfer tools may be used based on the example provided, or as otherwise suggested using curl in section 7.2.

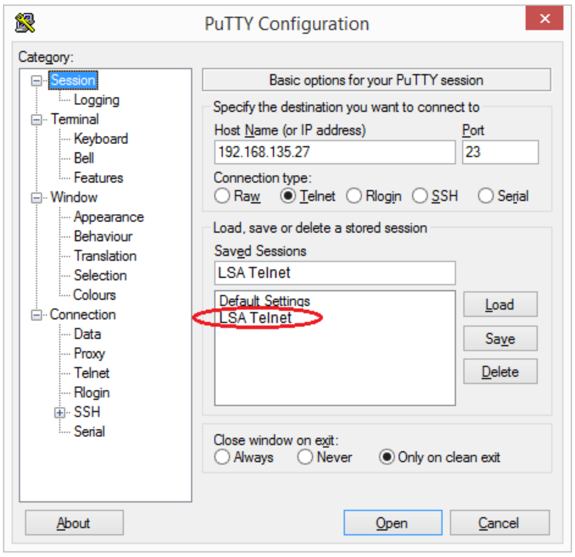
12 Advanced user interfaces

12.1 Telnet command line interface

Meant primarily for super users, the LSA can be accessed and configured via a limited command line interface using Telnet. This interface is accessed by connecting to the sensor IP address on TCP port 23 using a standard Telnet client. It is recommended to use Putty[2] which is open source and free to use.

Be sure to enable the 'Implicit CR in every LF' and 'Implicit LF in every CR' options when configuring Putty.

A list of Telnet commands for the LSA is listed by typing 'help' in a terminal, when connected to a sensor.



Basic options for your PuTTY session

Specify the destination you want to connect to

Host Name (or IP address): 192.168.135.27

Port: 23

Connection type: ○ Raw ● Telnet ○ Rlogin ○ SSH ○ Serial

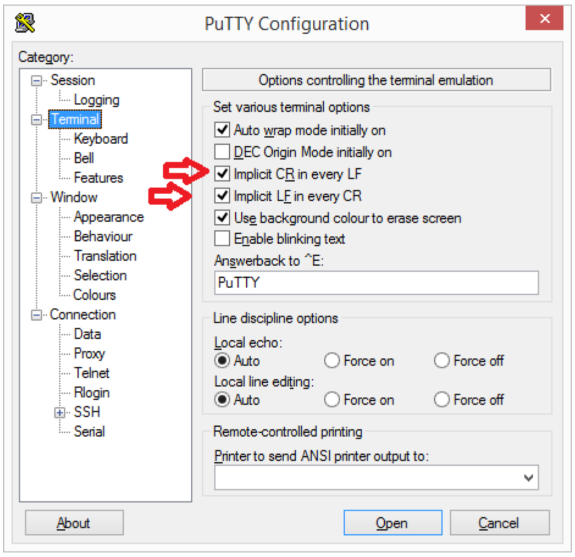
Load, save or delete a stored session

Saved Sessions: LSA Telnet

Default Settings
LSA Telnet

Close window on exit: ○ Always ○ Never ● Only on clean exit

Figure 20: Putty Telnet Session configuration.



Options controlling the terminal emulation

Set various terminal options

☑ Auto wrap mode initially on

☐ DEC Origin Mode initially on

☑ Implicit CR in every LF

☑ Implicit LF in every CR

☑ Use background colour to erase screen

☐ Enable blinking text

Answerback to ^E: PuTTY

Line discipline options

Local echo: ● Auto ○ Force on ○ Force off

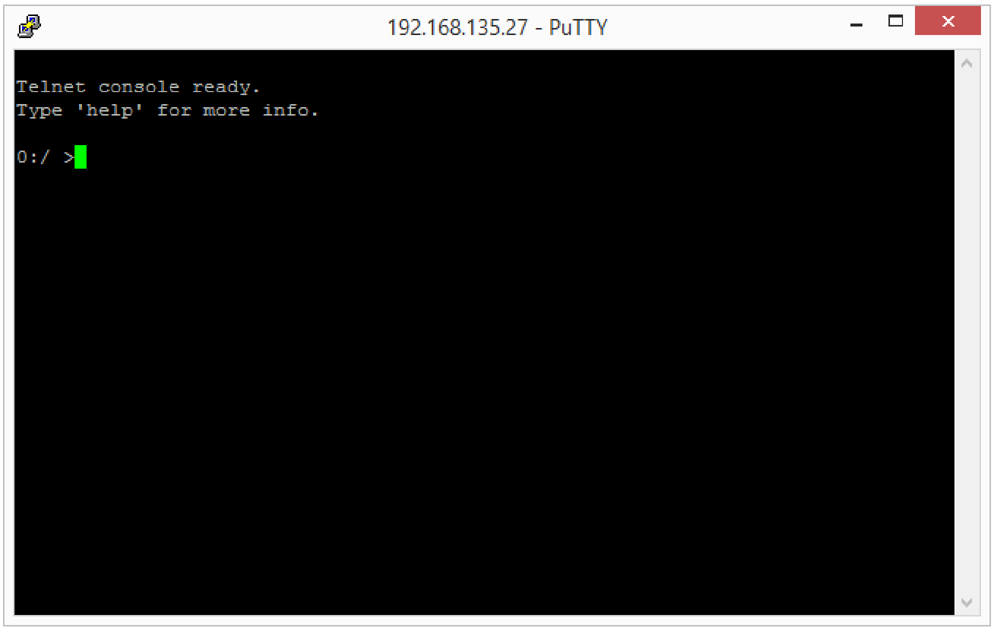
Local line editing: ● Auto ○ Force on ○ Force off

Remote-controlled printing

Printer to send ANSI printer output to:

Figure 21: Putty Telnet Terminal configuration.

[2] `http://www.putty.org/`



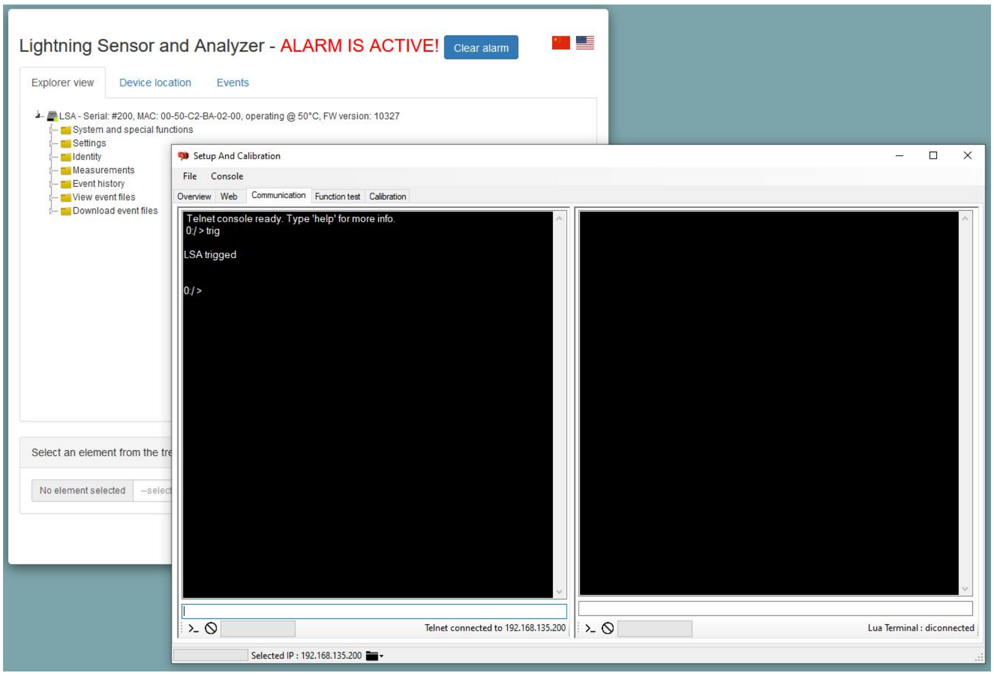
```
Telnet console ready.
Type 'help' for more info.

0:/ >
```

Figure 22: The Telnet command line interface.

The Telnet access may be used for SCADA interface testing, as it is possible to issue a 'trig' command which initiates a lightning event recording, even though the configured trigger level is not exceeded.

As an alternative to a software based test, a simple manual test is to use a fairly strong permanent magnet (e.g. one of those used for mounting). Let it pass over the sensor box by hand, with the pass lasting less than a second. It should then create an event detection, if the trigger level is exceeded. A more controlled and well defined test can be obtained using the Jomitek Lightning Pulse Generator, as noted in section 2.5. Note that the trigger level setting should be <10kA for either the permanent magnet or Jomitek Lightning Pulse Generator to be detected.



LSA - Serial: #200, MAC: 00-50-C2-BA-02-00, operating @ 50°C, FW version: 10327

```
Telnet console ready. Type 'help' for more info.
0:/ > trig

LSA trigged


0:/ >
```

Telnet connected to 192.168.135.200

Lua Terminal : diconnected

Selected IP : 192.168.135.200

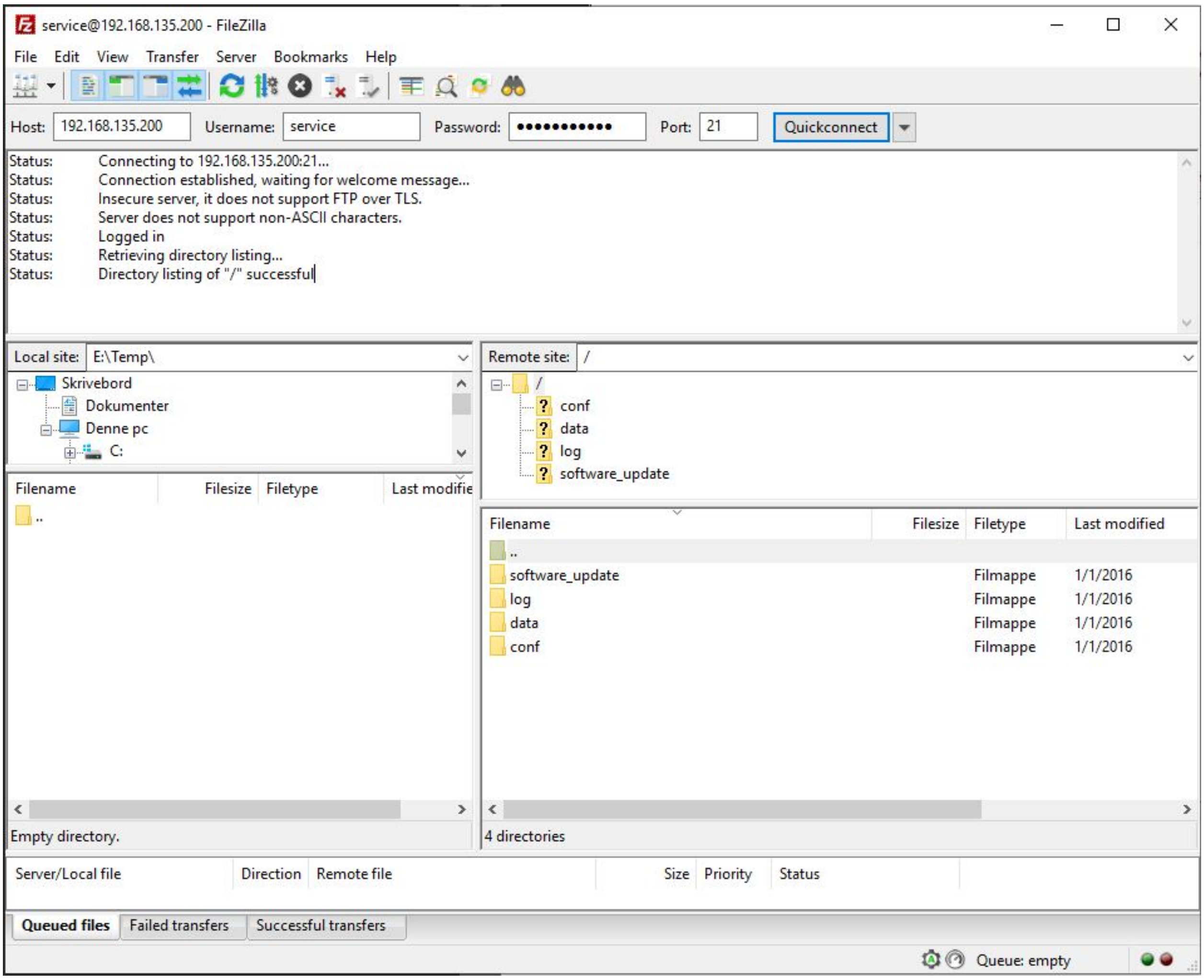
Figure 23: The Telnet 'trig' command.

12.2 FTP file transfer interface

The internal memory on the LSA can be accessed via the FTP protocol on TCP port 21. Use an FTP client program (e.g. FileZilla[3]) and log in with default username: *service* and password: *service1234*.

When connected you will have access to these folders.

- The `software_update` folder where software update files can be uploaded.
- The `log` folder where various log files are placed by the sensor system.
- The `data` folder where all stored measurement data are placed by the sensor system.
- The `conf` folder where configuration files and scripts are stored.



Host: 192.168.135.200 Username: service Password: ●●●●●●●●●●● Port: 21

```
Status:     Connecting to 192.168.135.200:21...
Status:     Connection established, waiting for welcome message...
Status:     Insecure server, it does not support FTP over TLS.
Status:     Server does not support non-ASCII characters.
Status:     Logged in
Status:     Retrieving directory listing...
Status:     Directory listing of "/" successful
```

Local site: E:\Temp\

- Skrivebord
  - Dokumenter
  - Denne pc
    - C:

Filename	Filesize	Filetype	Last modifie
..			

Empty directory.

Remote site: /

- /
  - conf
  - data
  - log
  - software_update

Filename	Filesize	Filetype	Last modified
..			
software_update		Filmappe	1/1/2016
log		Filmappe	1/1/2016
data		Filmappe	1/1/2016
conf		Filmappe	1/1/2016

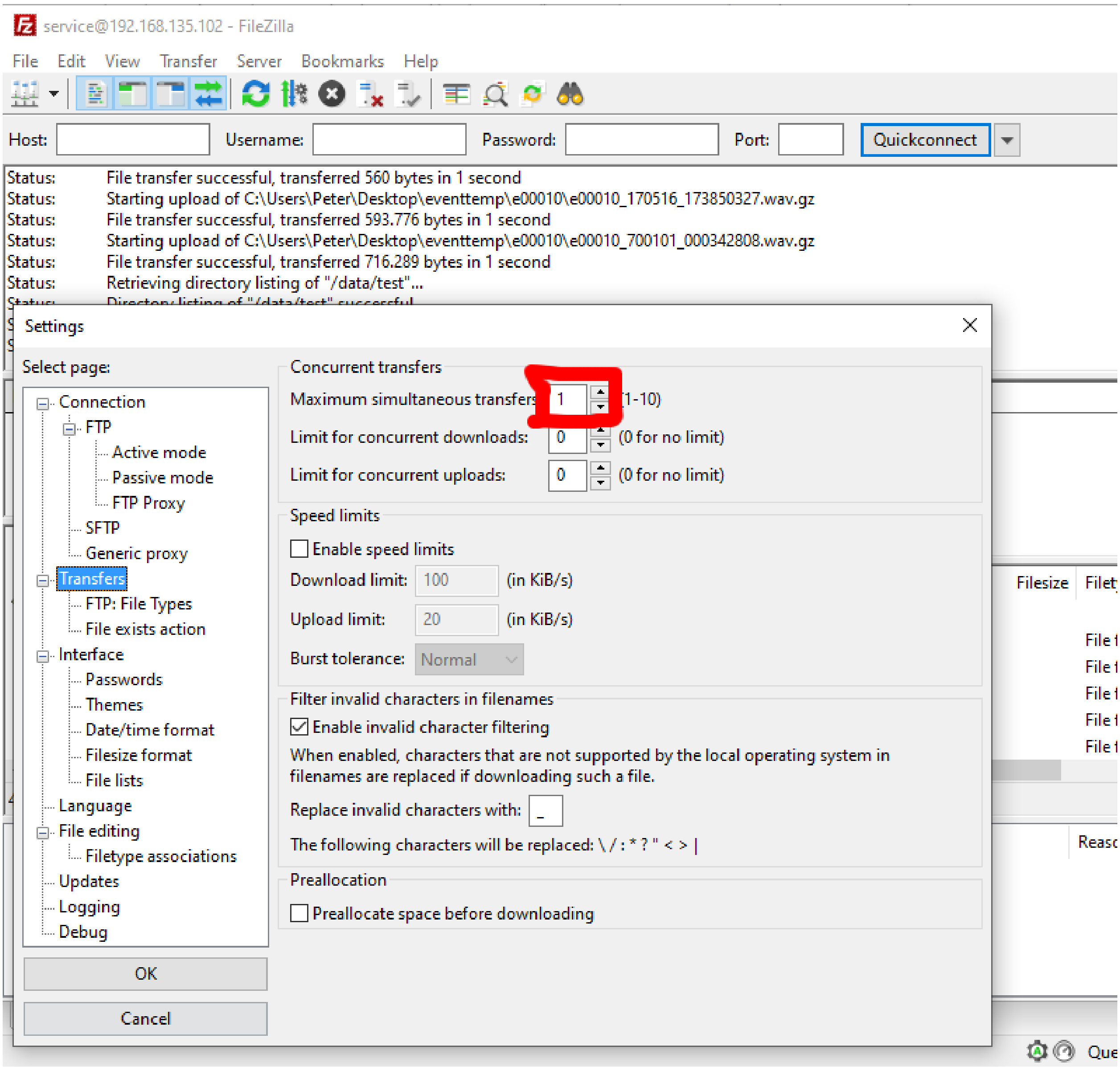
4 directories

Server/Local file	Direction	Remote file	Size	Priority	Status

Figure 24: FTP connection to the LSA shown with the FileZilla FTP client.

[3] `https://filezilla-project.org/`

File Upload is supporting upload one file at a time, so set the sender to non-simultaneous file-transfer



Host: Username: Password: Port:

```
Status:    File transfer successful, transferred 560 bytes in 1 second
Status:    Starting upload of C:\Users\Peter\Desktop\eventtemp\e00010\e00010_170516_173850327.wav.gz
Status:    File transfer successful, transferred 593.776 bytes in 1 second
Status:    Starting upload of C:\Users\Peter\Desktop\eventtemp\e00010\e00010_700101_000342808.wav.gz
Status:    File transfer successful, transferred 716.289 bytes in 1 second
Status:    Retrieving directory listing of "/data/test"...
Status:    Directory listing of "/data/test" successful
```

Concurrent transfers

Maximum simultaneous transfers: 1 (1-10)

Limit for concurrent downloads: 0 (0 for no limit)

Limit for concurrent uploads: 0 (0 for no limit)

Speed limits

□ Enable speed limits

Download limit: 100 (in KiB/s)

Upload limit: 20 (in KiB/s)

Burst tolerance: Normal

Filter invalid characters in filenames

☑ Enable invalid character filtering

When enabled, characters that are not supported by the local operating system in filenames are replaced if downloading such a file.

Replace invalid characters with: _

The following characters will be replaced: \ / : * ? " < > |

Preallocation

□ Preallocate space before downloading

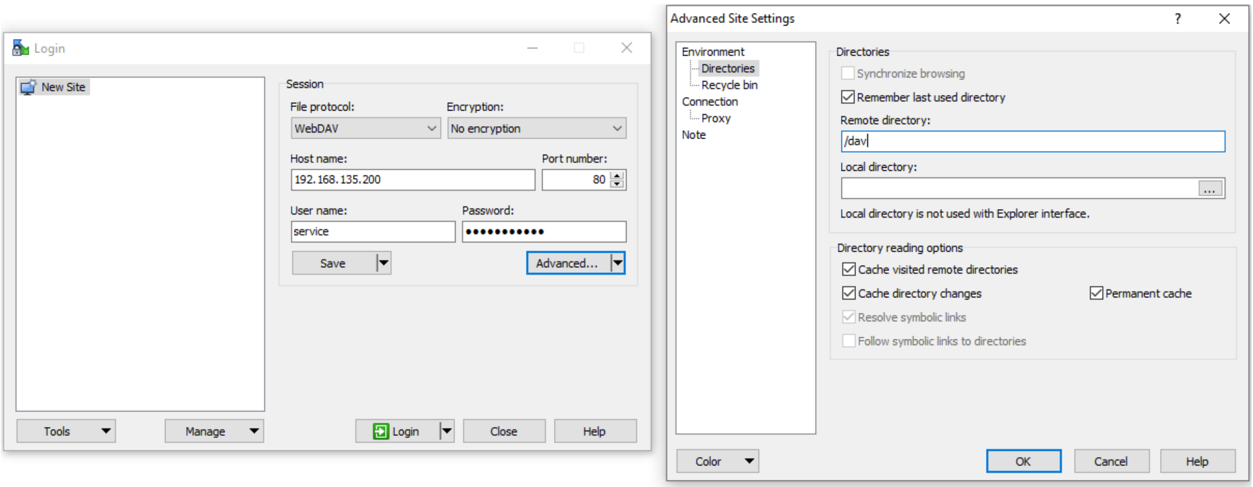
Figure 25: FTP configuration for file upload via FileZilla.

12.3 WebDAV file transfer interface

The LSA can be accessed via the WebDAV protocol on TCP port 80. This presents the advantage, compared to FTP, of using the same default port as is used for web browsing (it is an extension to the HTTP protocol) which simplifies firewall configuration requirements. Use a WebDAV client program (e.g. WinSCP) and log in with default username: *service* and password: *service1234*.

Note, that it is important to connect to the subfolder '/dav' as shown in the figure.

The file structure is equivalent to the description for FTP, see section 12.2.



Login

Session

File protocol: WebDAV

Encryption: No encryption

Host name: 192.168.135.200

Port number: 80

User name: service

Password: ●●●●●●●●●●●

Advanced Site Settings

Directories

□ Synchronize browsing

☑ Remember last used directory

Remote directory: /dav

Local directory:

Local directory is not used with Explorer interface.

Directory reading options

☑ Cache visited remote directories

☑ Cache directory changes

☑ Permanent cache

☑ Resolve symbolic links

□ Follow symbolic links to directories

Figure 26: WebDAV connection setup to the LSA shown with the WinSCP client.