Operating Manual v. 2.0

19-001002
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1 Introduction

Thank you for purchasing the MALÅ Borehole antennas. The MALÅ Borehole system is available in two frequencies, 100 MHz and 250 MHz. The 100 MHz is a so-called slim-hole system, with an outer diameter of only 40mm. Data collection is easily carried out with MALÅ Geoscience software, GroundVison..

We at MALÅ Geoscience welcome comments from you concerning the use and experience of this equipment, as well as the contents and usefulness of this manual. Please take the time to read through the assembling instructions carefully and address any questions or suggestions to the following:

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1.1 Unpacking and Inspection

Great care should be taken when unpacking the equipment. Be sure to verify the contents shown on the packing list and inspect the equipment for any loose parts or other damage. All packing material should be preserved in the event that any damage occurred during shipping. Any claims for shipping damage should be filed to the carrier. Any claims for missing equipment or parts should be filed with MALÅ Geoscience.

1.2 Repacking and Shipping

If original packing materials are unavailable, the equipment should be packed with at least 80mm of absorbing material. Do not use shredded fibers, paper wood, or wool, as these materials tend to get compacted during shipment and permit the instruments to move around inside the package.
2 Description of individual parts

2.1 Antennas

The MALÅ Borehole antennas consist of separate Transmitter (Tx) and Receiver (Rx) antennas. The nominal frequency is either 100 or 250 MHz.

Each antenna consists of outer fibreglass housing. The outer diameter (O.D.) is 40mm for the 100 MHz antenna and 48mm for the 250MHz antenna. These housings are waterproof certified to a water pressure of at least 20 bars.

NOTE! As the tube material is glass fibre one should handle it with caution in order not to break it or damage the housing.

The electronic part is mounted inside the housing. The dipole antennas are placed in the upper part of each housing. The battery pack is mounted in the bottom part of the antenna (see Section Charging Batteries for more information)

The metal bottom part in each probe (Rx and Tx) houses the ON/OFF and battery charging plug where the battery charging cable should be mounted during charging.

In the top part of each antenna, the optical connector(s) for the borehole cable is mounted. The Tx is equipped with one (1) connector, which receives trig signals from the Control Unit (CU).
The Rx is equipped with three (3) connectors at the top that receive trig signals from the CU and sends data back to the CU, respectively. One of the connectors is for the trig signals down to the Tx antenna. These signals are transported through the antenna by a short optical fibre down to the bottom optical connector in the Rx antenna.

The optical connectors are mounted in a bayonet type housing for quick connection.

The borehole antennas are delivered in a shipping case together with all accessories. One shipping case for each antenna frequency exists.

2.2 Cables

Optical data transmission is used for both antennas. The optical cable used is a 4-fiber cable, where:

- Two of them are used for sending the trig signals to the receiving and transmitting antennas.
- One of the fibres is used for returning data and the last fibre is a spare one.

The cable is reinforced with Kevlar strength membranes. The length of the cable is 150m. The cable breaking strength is 650kg. The cablehead is however equipped with a weak point that breaks off at a pulling strength of approximately 200kg.

The cable lengths have been chosen to allow for reflection work down to 150m borehole depth.

In reflection mode, the borehole cable is attached only to the (upper) receiving antenna. The trig signals for the transmitting
antenna are led through the receiving antenna, where it is extracted and transferred to the transmitter via one single optical fibre.

The fibre connectors in the system are of two types: -
   - Pin type as in the MALÅ ProEx system.
   - The probe connector's are a bayonet type (Lemo) that is watertight.

As always, when handling optical devices one should be careful and keep the connectors free from dust and dirt.

The borehole cables are equipped with a mechanical strain relief. This should be attached to either the backpack or to the frame attached on the MALÅ ProEx Control Unit. This construction is shown in Figure 2.1.

![Optical cable termination and strain relief.](image)

2.3 Tripod

For operating the antennas in the boreholes, tripods are used. These are used to feed the optical cable into/out of the borehole.
borehole and to trigger the measurements at preset interval. The tripods are of the "Surveyer`s Tripod" type. The measuring wheel is attached to the top of the tripod using a screw attached to the tripod.

If you are using another type of tripod the attaching screw should of the following type: Thread type = UNC 5/8 -11.

Two types of tripods exist; one with optical encoder of the same type as the Hip-Chain and Measuring Wheel for MALÅ GPR Systems. This type is equipped with a connector for the enclosed orange data cable that should be connected to the MALÅ ProEx Control Unit marked "ENC" in the rear. This tripod is seen in Figure 2.2.
The other type of tripod is equipped with a mechanical encoder to be used for one antenna when performing crosshole measurements. This tripod is not connected to any device but is read manually.

Both tripods are equipped with adjustable legs to accommodate for different casing heights at the boreholes.

**NOTE!** The tripod should be placed behind a dipping borehole in such a way that the borehole cable is easily fed down the borehole. This is shown in Figure 2.2. If placed on the opposite
side there is a risk of the tripod tumbling over and damaging the cable.

2.4 Separators

For separation of the antennas, in singlehole reflection mode, a firm fibreglass tube is used. This tube houses the single optical fibre, which carries the trig signals for the transmitting antenna. The purpose of the separator is to avoid oversaturation of the receiving antenna, which might cause disturbances in the data.

With the equipment a separator is delivered. Depending on antenna frequency, this separator is either 0.5 or 1.2m long. The separators can be used for both antenna frequencies. If e.g. the formation conductivity is high a shorter distance can be used for the 100MHz antennas. If on the other hand the formation conductivity is very low a longer separation might avoid oversaturation of the Rx-antenna thereby avoiding clipping of the first part of the time record.

3 Operating modes of the antenna

3.1 Singlehole reflection mode

In singlehole reflection mode both antennas are operated in the same borehole. They are separated by the fibreglass tube that keeps the antennas at a fixed interval.

Measurements are performed by lowering the antennas into the borehole whereby the optical encoder on the tripod triggers the measurements at the preset depth interval.
The principle is much the same as when performing surface measurements using the Hip-Chain or Measuring Wheel as trigging device.

It is advisable to enter the starting point of the survey into the header file of CrossholeVision while being in the field. When working with GroundVision the start point is always set to 0m.

When performing reflection measurements it should be noted that the measurement point is defined as the midpoint between the antennas. This location depends on the antenna lengths and the separation used.

As a rule, when starting a survey the reference point for "0" is important as the antenna centre is calculated from this position. We recommend you use the position of the optical plate in the Rx antenna as 0-location. This is located at the top of the Rx where the cablehead starts.

Table 1 below gives you the different distances for the different antennas.

### 3.2 Tomographic mode

The purpose of a tomographic or so called Crosshole measurement is to scan the plane between two boreholes. In order to carry out a tomographic survey, the transmitter is used in one borehole and the receiver in the other.

It is required that the boreholes are in the same plane and that careful notice on borehole directions is taken.

The normal procedure for performing tomographic measurements is to have one antenna fixed at a starting
position in the borehole. The other antenna is thereafter moved in the other borehole the whole section length whereby readings are taken at even increments in that section.

When this section if finished the first antenna is moved one position in the first borehole and the procedure with data reading is repeated.

The whole section in the both boreholes is scanned this way, which results in a large amount of cross paths of data.

Tomographic processing software, as WinTomo, is thereafter used to analyse the data with respect to the attenuation and velocity distribution between the boreholes.

The MALÅ Geoscience data acquisition program CrossholeVision includes a function for tomographic measurements. Thereby the measurement direction can be changed when measurements are performed in varying directions. Antenna positions as well as trace numbers are written onto a log-file for importation into the processing software.

3.3 Surface-to-Borehole mode

With the MALÅ GPR system, surface antennas can be used together with borehole antennas.

E.g. a surface transmitter 100MHz can be used with a 100MHz borehole receiver. Normally the receiver is located in the borehole to minimise noise and other disturbances in the recorded data.

The record received from a VRP (Vertical Radar Profile) will show reflecting layers and objects between the surface and
borehole. The analysis of such data is not quite straightforward however. From the raw data record it is possible to extract different layers around the borehole.

By performing multiple VRP with varying offset for the surface antenna from the borehole the data can be treated in a similar way as VSP (Vertical Seismic Profiling) data to study layering in the vicinity of the borehole.

4 Connecting the system

4.1 Mounting the cable to the antenna

Figure 4.1 shows the construction of the cable head of the optical cables and probe top.

Figure 4.1 Optical connectors at probe top (Rx) and cable head.
The cable is moulded into a metal piece where the optical connector piece is mounted. This piece is secured against water intrusion by double sets of O-rings at the rear. The loose metal sleeve located behind the moulding tightens against these O-rings when secured with the 4 screws (see below).

The optical fibres in the cable head are terminated using a type of pin connectors. Four fibres are connected in the cable head; two for the Rx, one for the Tx and one spare fiber. The connector for the Rx probe is also seen in Figure 4.1.

The borehole cable is attached to the Rx antenna by inserting the metal connector into the Rx antenna firmly until a “click” is heard asserting that the locking function is in place. Figures 4.2 shows the different parts. Both the cable head and the antennas are marked with a red dot that should be aligned against each other.

The cable head metal sleeve is then attached over the cable head and fastened with the 4 screws. When mounting the sleeve it should be pushed as long forward towards the antenna until a firm “click” is heard. This ensures that it has passed the two O-rings to tighten the cablehead. This
construction secures the cable head against water intrusion. It also acts as an extra strain relieve for the cable. This is shown in Figure 4.3.

![Figure 4.3](image1.png)

Figure 4.3 Optical cable head connected to probe.

Observe that the cable head metal sleeve is different between the 100 MHz (O.D. 40mm) and the 250 MHz (O.D. 48mm). To use the same borehole cable, replace the 48mm cable head by pull-out the cable and replace it with the 40mm cable head.

The MALÅ BH cable heads are watertight and can be operated in water-filled boreholes down to maximum cable length (150m).

During shipping and when not in, use the metal cover seen in Figure 4.4 should be mounted on the cable connector.

![Figure 4.4](image2.png)

Figure 4.4 Removing the protective cap
To remove this captive cap when connecting the cable to the probes proceed as follows:

- Remove the metal sleeve from the cable head by removing the 4 hex screws.
- Gently pull backwards the metal sleeve to expose the cable head.
- While holding the front cover cap with one hand gently pull the cablehead securing backwards. This is the piece located in front of the O-rings. See Figure 4.4.
- Now the cover cap can be removed by pulling it forward.
- After completed survey the metal cap should be mounted back to protect the optical connectors. The mounting is performed by firmly pressing it onto the cablehead making sure that the red dots on both cablehead and cap are aligned.

The borehole cables are delivered with an attachable "garbage collector" that can be mounted on the cable and fastened at the cablehead top. This is done with the 4 screws that are delivered with the cable. The purpose of this device is to collect falling pieces of rock from the wall when performing surveys in slimholes and in hard rock.

In soft rock this device is not always needed and need not be mounted on the cable.

If the borehole was been drilled using different casings or in cases where one can suspect that the casing might not have been properly installed it is advisable not to use this collector. Otherwise problems might occur when the antennas are being lifted into the casing if there exist any form of edge in the borehole.
Remember to attach the plastic covers to the probes when having disconnected the cable head after a survey.

The borehole cable fibre ends should be attached to the CU at their respectively connector. One spare fiber with connector is available in case any damage appears to any of the other fibers. In order to protect the optical connectors from damage the cable end is equipped with a strain relief that should be attached either to the control unit or to the back pack.

4.2 Connecting the single fibre between the Tx and Rx

The single fiber for the trig signals to the Tx antenna is connected between the Rx and Tx antenna. The fiber is seen in Figure 4.5.

![Figure 4.5 Single fiber connecting Rx to Tx.](image-url)
The Tx and Rx antennas are also inter-connected by one glass fibre tube. The purpose of the separator is to avoid oversaturation of the Rx-antenna performed by increasing the distance between the antenna probes.

The correct procedure for connecting the separator and the single fiber is as follows:
- Insert the single fibre into the glass fibre separator tube.
- Connect the single fibre to the Rx antenna
- Thread the glass fibre tube on the Rx antenna and fasten the four screws
- Connect the single fibre to the Tx antenna
- Thread the glass fibre tube on the Tx antenna and fasten the four screws

Dismantling of the separator is performed in the opposite manner.

The connection of the fiber to the Rx and Tx antenna is performed by simply inserting each of the Lemo connectors into the antenna connectors. The white string is to protect the fibre when disconnecting the glass fibre tube. Attached the fibre connectors firmly until a “click” sound is heard. This ensures that the connectors are firmly attached. The connecting of the fiber to the Rx antenna is shown in Figure 4.6.

NOTE! That the fibre connectors are not identical. The reason for this is that one connector also houses an electric part, which acts as ON-OFF switch for the Rx-antenna electronics.
When the optical fibre is connected and the fibre glass tube is mounted, it is vital that the tube is fastened using the four locking screws at both Tx and Rx as shown in Figure 4.7.
Figure 4.7 Mounting the screws for the glass fibre tube.

**NOTE!** Care should be taken when mounting and dismounting the single fibre. When separating the glass fibre tube from the antenna extra care should be taken not to pull the antenna apart more than the extra length of the optical fibre inside the tube.

When operating the antennas in Crosshole mode the Tx is operated with the second borehole cable. In Crosshole mode, the Tx is attached to the cablehead in the same manner as the Rx antenna. More information in Section Performing boreholes surveys below.

### 4.3 Starting the antennas

The MALÅ BH antennas are equipped with internal batteries. They are mounted inside in the bottom part of each probe to allow for charging and ON-OFF switching.

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The ON-OFF switches for the two antennas consist of "startplugs" that fit into the holes in the bottom of the antennas. The plugs are of different construction.

The following types are used:
- Tx plug that is threaded into the Tx antenna bottom
- Rx plug for reflection work
- Rx plug for tomographic work

For attaching the Tx plug a HEX-key is enclosed in the equipment. The Rx plug is connected direct by inserting the connector firmly into the bottom of the probe.

The Tx antenna should always be equipped with a protection plug on the ON-OFF switch as shown in Figure 4.9 below.

The Rx antenna should in the same manner be equipped with this protection plug then the system is used in tomographic survey mode.

As soon as the plug is attached firmly to the antenna it is ready for operation assuming the optical cable has been mounted correctly.

Running the software (GroundVision or CrossholeVision) is identical as for the surface antennas. You should however remember to import the correct calibration file for the length encoder on the tripod if you are using length triggering through length control.

4.4 Performing borehole surveys

Borehole surveys discussed here are referred to either singlehole reflection or crosshole surveys.
They are described here separate even though many of the procedures are common for both types.

### 4.4.1 Reflection survey

The procedure of performing a reflection survey includes:
- Combining the antennas
- Inserting the antennas into the borehole
- Collecting data
- Lifting and dismounting the antennas
- Disconnecting the start plug in the Tx antenna

**Combining the antennas**
This section has already been covered above.

**Inserting the antennas into the borehole**
Depending on whether the borehole to be surveyed is dipping or is horizontal the procedure for inserting the antennas into the borehole varies.

In a horizontal borehole where the antennas can be arranged to lay still during installation the start procedure is simplified.

In a dipping borehole the mounting of cables to antennas should be carried out on the ground close to the borehole.

When the system is connected it is advisable to perform a system check on the ground to assure the function. Parameter settings and Trig mode should be selected according to antenna frequency and aim of the survey.

When taking a test trace on ground the pulse shape may be heavily distorted depending on antenna coupling to the ground.
The aim of the test is to assure that a pulse is received by the Rx antenna and that the overall trace shape is normal.

The antennas are thereafter lowered into the borehole and should be locked at the casing top using the antenna key, see Figure 4.8.

![Figure 4.8 Borehole locking key mounted at cable head of Rx antenna.](image)

At this stage the cable should be threaded on the tripod and attached as described in section 2.3.

The antennas will now hang free in the borehole as long as the tripod locks the cable.

If the tripod with the digital encoder is used the encoder cable should be connected to the control unit at the port marked "ENC".
A good reference point to start the survey is to level the end of the cable head against e.g. the top of casing (T.O.C.) if such exist. Also Ground Level (G.L.) might be suitable reference if casing is missing.

**NOTE!** As the antenna system consists of separate TX and RX antennas the measurement point is referred to as the midpoint between the antennas.

The location of this midpoint depends on the antenna lengths and the separation used. For the available antennas and common separations the values will be as follows:

Table 1. Antenna distances and midpoints

<table>
<thead>
<tr>
<th>Antenna type</th>
<th>Separator</th>
<th>Antenna center separation</th>
<th>Midpoint from antenna top*</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MHz (O.D. 40 mm)</td>
<td>1.00 m</td>
<td>2.77 m</td>
<td>2.283 m</td>
</tr>
<tr>
<td></td>
<td>0.50 m</td>
<td>2.27 m</td>
<td>2.033 m</td>
</tr>
<tr>
<td>250 MHz (O.D. 48 mm)</td>
<td>0.50 m</td>
<td>1.70 m</td>
<td>1.20 m</td>
</tr>
<tr>
<td></td>
<td>1.00 m</td>
<td>2.20 m</td>
<td>1.50 m</td>
</tr>
</tbody>
</table>

(*= refers to the gap where the borehole key fits in cable head)

**Collecting data**

The data collection procedure itself is much the same as for the surface antennas.

The main difference between operating surface antennas versus borehole antennas is that the borehole antenna
radiates in 360 degrees around the borehole. Therefore reflections will occur from all directions. As the dipole antennas are not directionally sensitive in any way there is no way of orienting the origin of the reflections.

If the operator has any previous information or knowledge about the site he is operating on, orientation can be made. However one should bear in mind that the 2D-image presented on the screen actually represents information from the 3D around the borehole.

Also to note about scanning boreholes is that borehole diameter will have influence on the radar results. Generally speaking the greater the borehole diameter is the worse will the coupling between the antennas to the host rock be. In water filled boreholes this will result in waves starting to propagate along the borehole fluid causing a form of high frequency tube-waves.

This will be seen in the images as a high frequency ringing.

**Lifting and dismounting the antennas**

Once the survey is completed the antenna should be dismounted in reverse as described in the mounting section.

When the antennas are lifted from a vertical borehole, care should be taken when the antenna array is lifted in the free air. A firm grip should be taken at both antennas to avoid breaking of the array.

If a survey has been performed in a water filled borehole it is of importance to drain the cable heads from water and to clean them from e.g. borehole mud or clay before packing the equipment.
4.4.2 Crosshole survey

When planning a crosshole survey layout it is important to recapitulate the basic needs for a successful outcome of a tomographic investigation.

Are the selected borehole well suited for a tomographic survey? Do they form a plane, which is a requirement?

What is the geometry like? As the inversion is based on rays traveling in different directions through a cell this sets some limitations on the distance between the boreholes and the borehole depth. We recommend that if the boreholes are parallel the distance between them should not be greater than the depth of the survey interval. Otherwise the rays tend to be too parallel resulting in bad resolution and in worst cases erroneous tomograms.

On the other hand the distance between the boreholes may not be too short. If the resistivity of the host rock is fairly high this may result in oversaturation of the direct wave at the receiving antenna. Thereby no correct amplitude data can be extracted.

Tomographic surveys are based on the knowledge of the antenna positions during the whole survey. Does the client provide borehole deviation surveys? Are these done with enough accuracy? Have the starting coordinates of the boreholes been measured and then also the heights?

Field work

Planning the actual fieldwork deals with selecting appropriate antenna frequency and measuring parameters.

The antenna frequency should be selected as high as possible to obtain highest possible resolution. On the other hand the range decreases with increasing frequency so this leads to a compromise. Remember that the maximum ray distance does
not necessary have to be recorded in a section in case the range does not cover this distance.

Sampling frequency should also be selected as high as possible to obtain maximum resolution and time accuracy. Make calculations of the travel distance difference between the shortest and farthest ray. Use the velocity in the host rock to convert this into a time difference. Make sure that you select the sampling frequency so that the resulting time window covers this time interval with good margin. Make some test measurements with different ray distance and use little and long stacking time to determine the noise level. This will determine the stacking time.

Finally it cannot be repeated too many times;

- Remember to charge the batteries before use.
- Check the optical communication by test measurements.

**Borehole operations**
In crosshole mode each antenna should be connected to the respective optical borehole cable. In this case the fibreglass tube and single optical fibre from Rx to Tx is not used.

Instead a separate "ON-OFF" switch is connected to the Rx. This connector must be covered by a housing as described in Figure 4.9.
Both borehole cables are attached to the control unit, one to the R and D connectors and the other to the T connector.

At the boreholes both borehole cables should be attached to the respective tripod and the probes aligned in the borehole to adjust the depth position.

In data collection mode one antenna is kept at a fixed position in the borehole while the second antenna is moved continuously collecting data at the preset depth interval. This implies that the moving antenna cable should be mounted to the tripod equipped with the digital depth encoder. These data are transferred to the control unit while the depth data from the tripod with the stationary antenna need to be manually entered in the software CrossholeVision (Note that GroundVision can not be used for tomographic crosshole surveys).
It is very important that the depth data is entered in a correct way, as they will be recorded onto a file that is imported into the tomographic processing software.

Per definition one run in the borehole with one fixed antenna position is referred to as one SCAN. It is advisable that the depth position and depth information is corrected after each double scan that is after each run both downwards and upwards. This can be done by aligning the antennas again relative to the depth reference that was used initially.

It is natural that the depth information will differ slightly after each scan as the cable is stretched differently during runs downwards and upwards.

According to the law of reciprocity the Tx and Rx antennas can be switched between the boreholes without affecting the processed results.

The antenna positions in the borehole need however to be adjusted with respect to the position of the antenna centers relative to the antenna tops.

The following table shows the different distances for the antennas.

**Table 2. Antenna distances and midpoints**

<table>
<thead>
<tr>
<th>Antenna type</th>
<th>Antenna top to antenna center</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MHz (O.D. 40mm)</td>
<td></td>
</tr>
<tr>
<td>Tx</td>
<td>0.695 m</td>
</tr>
<tr>
<td>Rx</td>
<td>0.722 m</td>
</tr>
<tr>
<td>250 MHz (O.D. 48mm)</td>
<td></td>
</tr>
<tr>
<td>Tx</td>
<td>0.325 m</td>
</tr>
<tr>
<td>Rx</td>
<td>0.365 m</td>
</tr>
</tbody>
</table>
5 Charging batteries

The operation length of the battery packs in each antenna is 5-8 hours depending on the mode of operation and how much the data is stacked.

- The 250 MHz batteries consist of one element with 6 x 1.2 Ni-Cd cells. The battery packs for the 250 MHz Tx and Rx probes are identical.
- The 100 MHz Tx battery consist of 7.4 V/3.2Ah Li-ion cell, and the 100 MHz Rx battery consist of 7.4 V/ 6.4Ah Li-ion cell.

For the 250 MHz antennas, the charging is performed by the MALÅ GPR Ni-Cd charger. For the 100 MHz (O.D 40mm) antennas, the charging is performed by the MALÅ GPR Li-ion Battery Charger 21-002367.

Two special connecting cables are supplied to connect the chargers to the two antennas. The cables are different for the Tx and Rx antenna and cannot be connected the wrong way.

When charging we recommend the following procedure:
- Connect the charging cable to each antenna at the bottom plug.
- Connect the charging cables to the battery chargers.
- Connect the chargers to the power outlets.

**NOTE!** It is important to follow this procedure. If the charging cables are first connected to a powered charger before to the battery sparks may be caused when the charging cable is inserted into the antennas. The sparks will not necessary damage the antennas but if repeatedly done the chargers may be damaged.

**NOTE!** The chargers for MALÅ battery chargers can be two types, either for 110V AC or for 220V AC.

When charging, the red light on the charger will show a steady light. When the batteries are fully charged the light will start to flicker. This indicates that the charger is on recovery charging.
The charging time for these types of chargers is 2-3 hours for a fully drained battery.

If you are using a type of charger without the red light the corresponding charging time is 14 hours.

Figure 5.10 shows the charging equipment for the Tx antenna. Figure 5.11 shows the connection of the charging plug to the Rx antenna.

**Note!** The pictures below refer to chargers used for the 250 MHz antenna.
NOTE! The batteries have a lifecycle of approximately 400 chargings. It is highly recommended that the antennas are shipped to MALÅ Geoscience for replacement of the batteries when it’s clear that they can’t keep its voltage.

6 Check trig signals

250 MHz (O.D. 48mm) antenna:
There are two led indicators, one on the Receiver and one on the Transmitter antenna. The led is lighting and starts flashing as an indication of the trig signals. This light-emitting diode is located at the middle of the probe.

100 MHz (O.D. 40mm) antenna:
There are two led indicators on the Receiver, and one on the Transmitter antenna. The led is lighting and starts flashing as an indication of the trig signals. The second led indicator on the receiver starts flashing as an indication of transmitting data. The light-emitting diode is located at the middle of the probe.