OTT SVR 100 – SURFACE VELOCITY RADAR

WHITE PAPER | For Measuring Open Channel Flow

a brand of OTT HydroMet

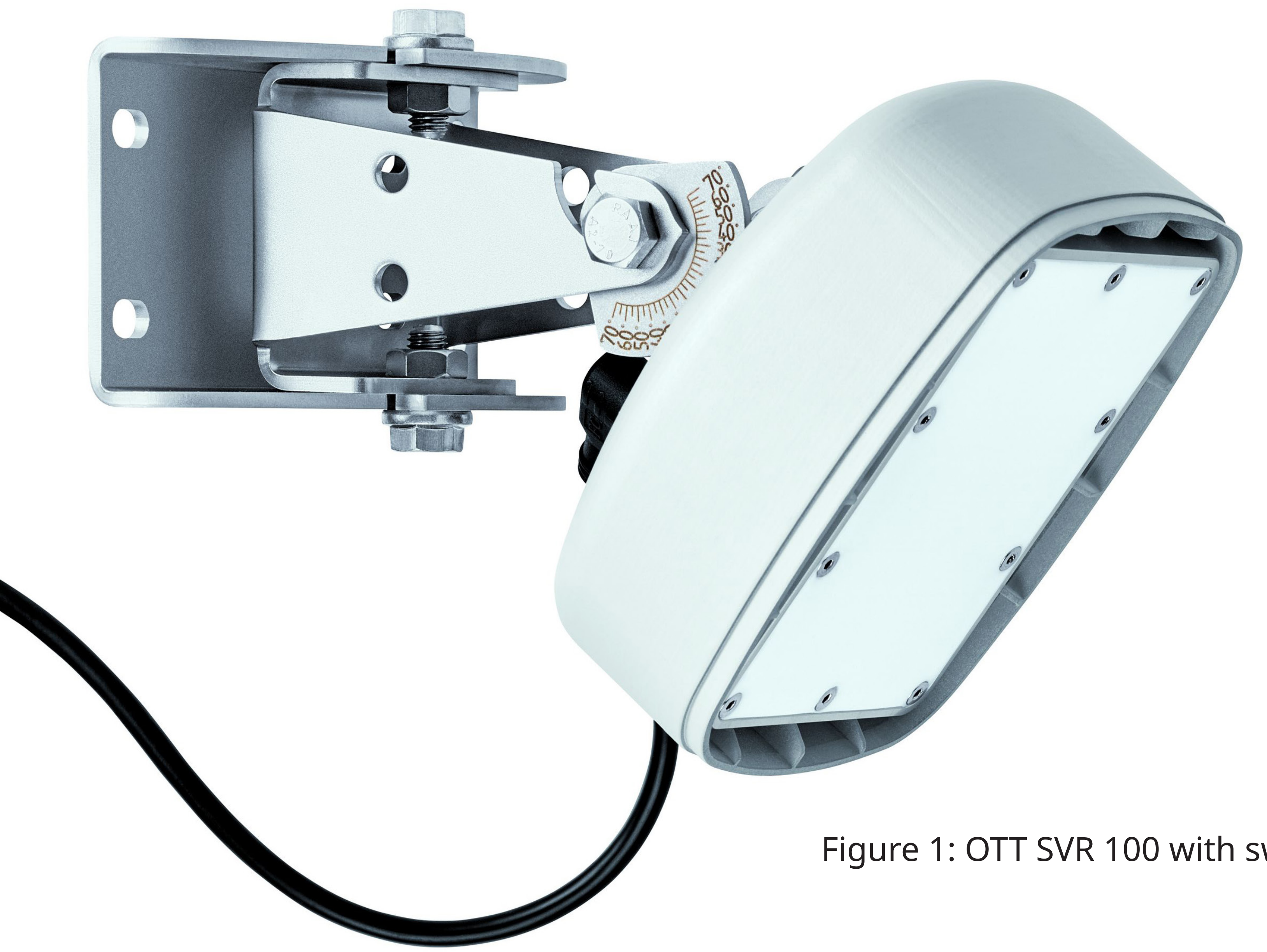

Figure 1: OTT SVR 100 with swivel mount

Introduction

The measurement of water surface velocities to determine discharge in rivers and open channels is one of the oldest measuring methods in hydrometry, well-tried and easy operably since centuries with the aid of floaters. The determination of discharge by surface velocity measurements is also covered by various hydrometric standards and guidelines such as ISO 748 “Hydrometry – Measurement of liquid flow in open channels using current meters or floats”. While floaters are applicable for in-situ measurements only the surface velocity radar provides 24/7 real-time monitoring with high measurement accuracy, low power consumption and minimized maintenance. In addition, contactless measurements benefit from being unaffected by sediments, mud or floating debris in the water.

Velocity Measuring Principle

The OTT SVR 100 is using the latest state-of-the-art radar technology which results in a high precision of measurements that are not affected by outside factors such as temperature, humidity or water density. Oriented parallel to the main direction of flow and tilted at a nominal 30-degree inclination against the water surface it is transmitting and receiving electromagnetic waves. If the water surface is rough and in motion the echo returns with a change in frequency respectively wavelength (Doppler shift). From this the water surface velocity can be derived, refer to Figure 2.

The surface of open channels and rivers commonly always provides a certain degree of roughness. Even miniature waves which possibly can’t be recognized at first sight reflect radar waves back to the sensor. However, a minimum wave height of at least 1 mm is required to provide reliable measurement data.

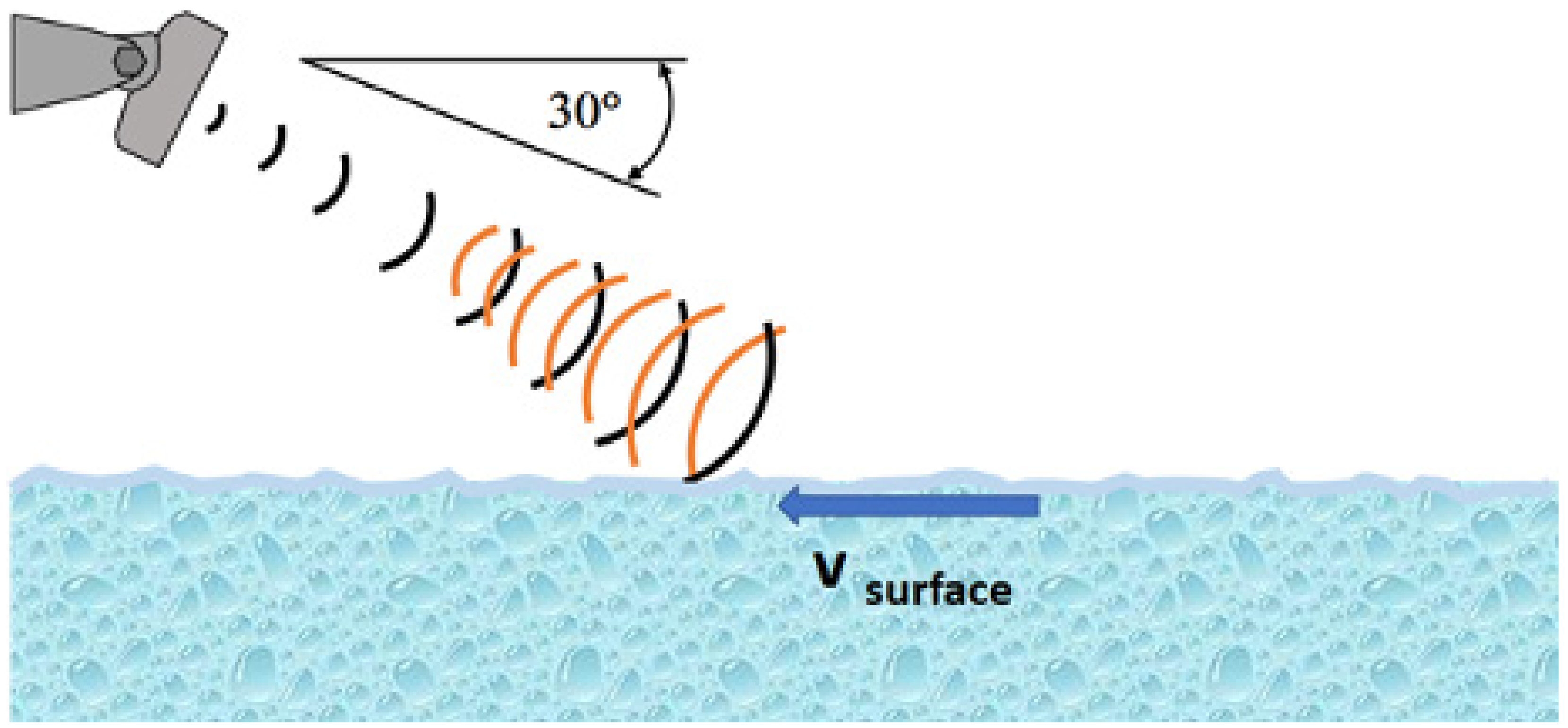

Figure 2: OTT SVR 100 velocity measuring principle

Sensor Orientation, Flow Direction and Area of Measurement

To achieve the specified accuracy, it is important to exercise due care while evaluating and selecting the measurement site and to install the sensor with an appropriate tilt angle. While the tilt angle is adjustable in a range of 20° to 60° (refer to figure 3) the optimal range is between 30° and 45°.

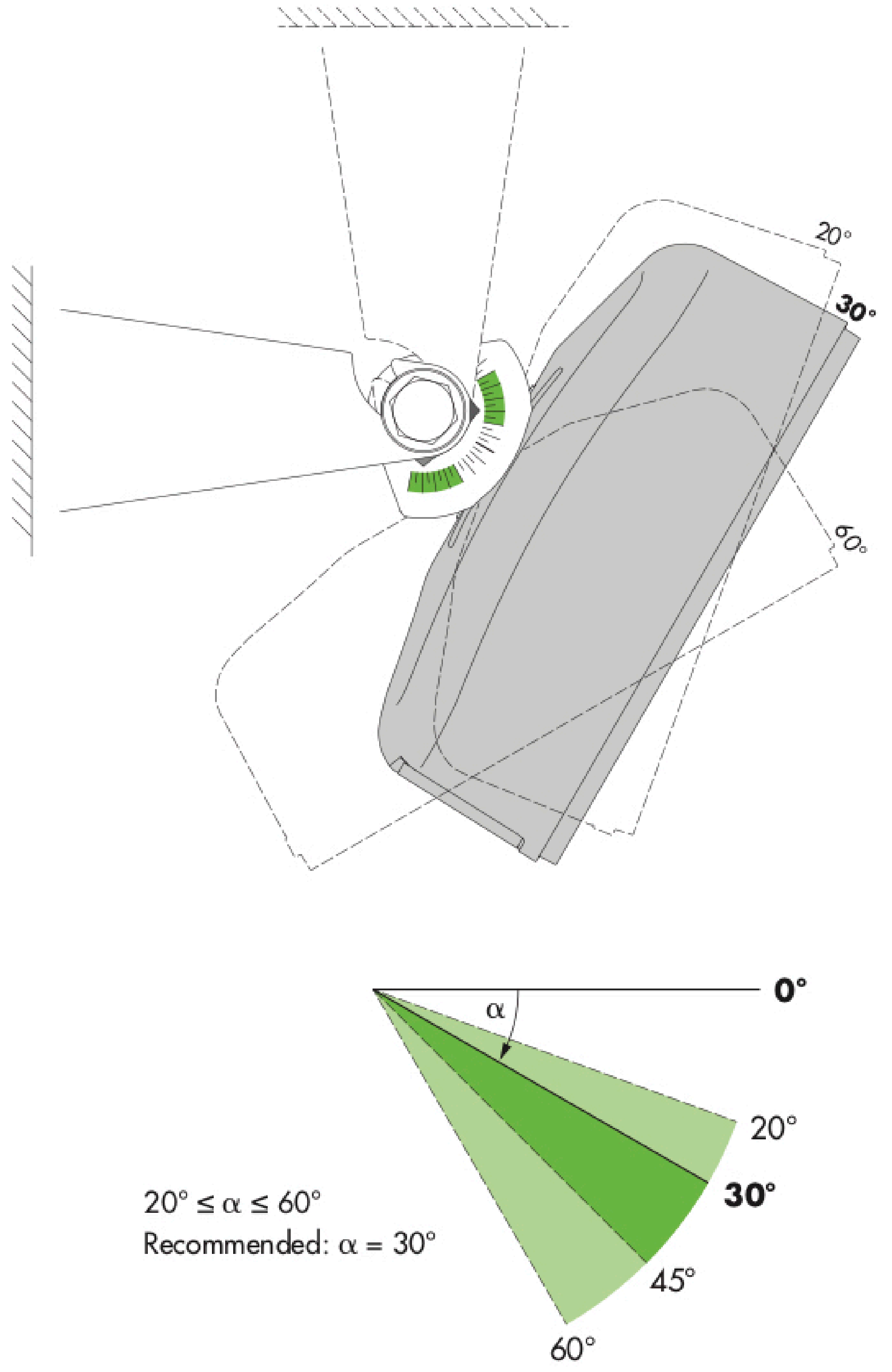

Figure 3: OTT SVR 100 instrument alignment

A graduated scaling at the swivel mount facilitates the sensor alignment on site. Please note, an angle of 30° is recommended and considered as the best setup and performance for most of the applications where the height of the sensor above the water surface is less than 10 m. Nevertheless, good results at 30° inclination can also be expected for sensor heights up to 20 m distance. It is furthermore recommended that the tilt angle does not exceed 45°. The instrument should be oriented in parallel with the main direction of flow and pointed upstream, so that the water flows towards the sensor.

The OTT SVR 100 is equipped with an internal inclination sensor. The measured inclination (tilt angle) is reported by the instrument in the data records with each measured value and will also be displayed in the OTT SVR 100 operating software. It is strongly recommended to check the inclination measured by the instrument itself during the installation on site. The tilt measurement is used internally for automatic velocity cosine compensation.

The height of the instrument above the water surface and the inclination determine the area on the water surface that is covered by the radar beam (footprint). The measurement area should be free of any obstacles. There should be no vegetation between the radar and the measurement area because this could affect the measurement accuracy.

The radar beam will cover an elliptical area on the water surface and will report the average surface velocity of this area. The OTT SVR 100 uses complex Kalman filters with physical modelling of the water flow to give stable measurements even in turbulent conditions. However, if there are too many turbulences in the water flow, fluctuations in measured data could be expected as well as somewhat reduced measurement accuracy. The filter length of the radar should be configured to 120 or more when the water flow at the monitoring station is very turbulent.

Figure 4 illustrates the footprint dimensions depending on sensor height and tilt angle. Calculated values of the footprint dimensions for a variety of most common applications are shown in the table 1.

Angel [°]	30°			45°			60°		
Heigth h [m]	l [m]	d1 [m]	d2 [m]	l [m]	d1 [m]	d2 [m]	l [m]	d1 [m]	d2 [m]
1	1.7	2.0	0.4	1	0.9	0.3	0.6	0.6	0.2
2	3.5	3.9	0.8	2	1.8	0.6	1.2	1.2	0.5
3	5.2	5.9	1.3	3	2.7	0.9	1.7	1.7	0.7
4	6.9	7.9	1.7	4	3.6	1.2	2.3	2.3	1.0
5	8.7	9.8	2.1	5	4.5	1.5	2.9	2.9	1.2
6	10.4	11.8	2.5	6	5.3	1.8	3.5	3.5	1.5
7	12.1	13.8	2.9	7	6.2	2.1	4.0	4.0	1.7
8	13.9	15.7	3.4	8	7.1	2.4	4.6	4.6	1.9
9	15.6	17.7	3.8	9	8	2.7	5.2	5.2	2.2
10	17.3	19.7	4.2	10	8.9	3	5.8	5.8	2.4

Table 1: Dimensions of the radar footprint (a selection)

The water flow at the installation site should be as uniform as possible. Reliable measurements will be obtained if the reach of the stream is straight and the water is flowing parallel to the banks. Rule of thumb: It can be assumed that the water is flowing parallel to the banks if the course is straight over a distance of 5 – 10 times the channel width upstream and twice that downstream.

Rain and Wind

Uniformity of water flow is the most important factor for obtaining accurate and stable measurements. Turbulences, particularly macroturbulences (e.g. vortexes) should be avoided. By adjusting the radar inclination angle and instrument position, it is possible to select the optimal area on the water surface from which the measurements will be taken.

It is important to understand that the water is a very reflective medium for radio waves. When the radar beam hits the water surface, most of the energy of the radar beam will be reflected and scattered in all possible directions but only a small portion of it will return to the radar sensor. This small returning part of waves received by the sensor is used to measure the surface velocity. The amount of energy reflected to the radar sensor depends on the roughness of the water surface. For radar to operate properly, it is required that there are small waves present on the water surface. The OTT SVR 100 requires a minimal wave height of 1 mm only as the instrument uses very sensitive receiving elements in the radar sensor.

The benefit of using high sensitive receivers is the ability to measure low velocities with minimal surface roughness. The downside is that the radar is susceptible to multipath effects that can happen on some specific sites when a part of the radar beam hits the water surface, reflects from the water surface away to another object such as nearby bridge, and is then reflected from the secondary object back to the radar sensor. On majority of installation sites, the multipath effect is non-existent.

The OTT SVR 100 features integrated internal software filters to filter out effects of rain, fog or wind. These filters however have some limitations. Most of measurement inaccuracies caused by environmental factors can be solved by thoroughly sensor installation.

For rain suppression, the most effective solution is to mount the radar so that it points upstream and the water flows towards the radar. As rain falls and the radar is tilted downwards, rain droplets will move away from the radar, while the water flows towards the radar. The radar can then easily distinguish the water movement from rain movement. To further improve rain filtering, the radar should be configured to report only incoming direction of water flow. In this case, the radar will completely ignore all movement with direction going away from the sensor. Of course, it may be possible at some measurement sites that the water will flow in both directions (e.g. tidal rivers). For those sites, the radar sensor should be configured to report both incoming and outgoing flow, by selecting “both direction” setting in the radar sensor.

Additional rain suppression can be implemented by mounting the radar below some structure so that the first 1 to 2 meters in front of the radar are free of rain. As the energy of the radar beam drops exponentially with distance, radar is most sensitive to the rain directly in front of the radar. If the radar instrument is being attached to a bridge, whenever possible, it should be mounted below the bridge instead of on the guard rail or on the bridge head. This way the bridge provides cover from the rain directly in front of the instrument.

Water surface waves respectively velocities are also subject to be disturbed by wind. Depending on the wind direction the water surface velocities can either be accelerated or decelerated. In many cases the influence of wind on the accuracy of measured data is neglectable and can be compensated by extending the averaging time. The only exception is strong wind gradients as those will create surface waves that are traveling in a different direction than the water is flowing.

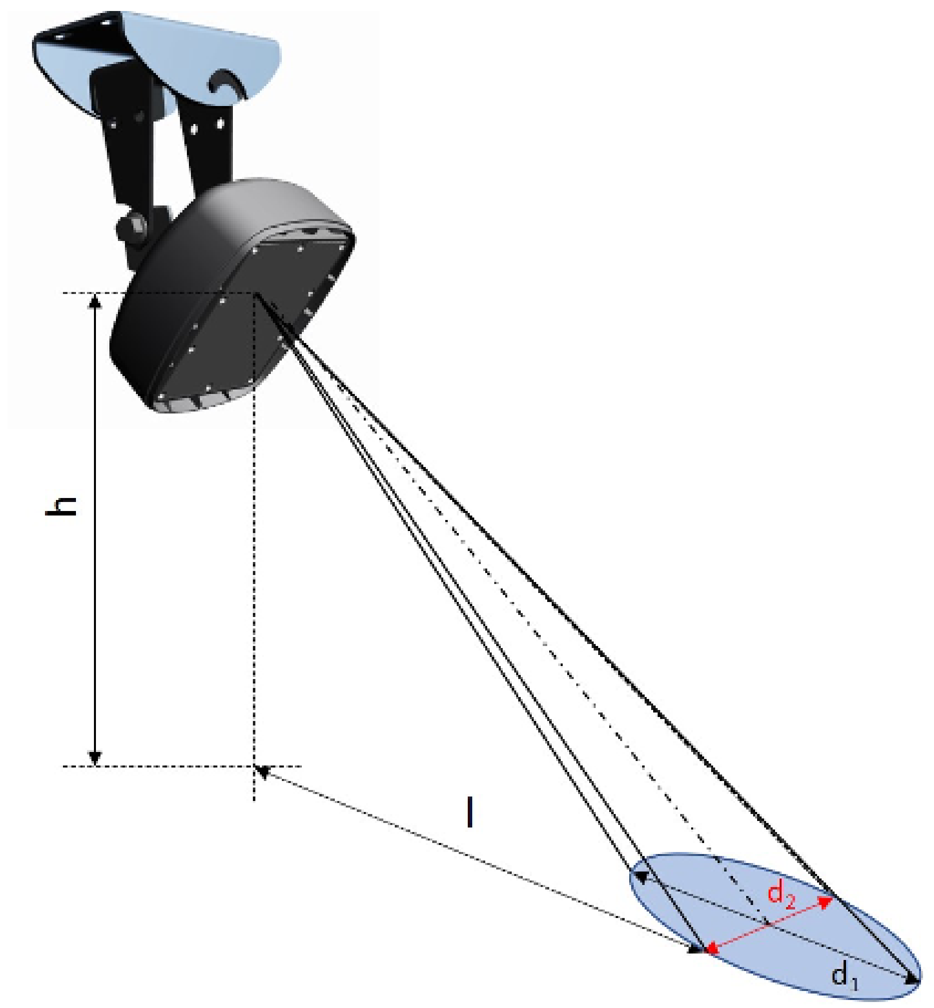

Figure 4: OTT SVR 100 measurement area on the water surface

Vibration Index – Measurement Quality Indicator

Sensor vibrations may affect measurements of any radar sensor attached to a bridge or cantilever and will have a direct influence on the measurement quality. The primary cause of vibrations is wind or traffic. The OTT SVR 100 detects vibrations using an integrated vibration sensor and provides qualitative information whether the sensor is vibrating or not. This data is available via SDI-12 with each measurement. In turn, this indicator can be used to decide if a measurement can be trusted. The vibration index is in range from 0 (no vibrations) to 3 (very strong vibrations – data unacceptable).

For example, when radar is mounted on a railway bridge (one common application), measurements will be of excellent quality most of the time except when train is passing the bridge and the bridge is vibrating extensively. In this case the radar will still report measurements, but the values could be erroneous, and the vibration index will go up to the higher value. It is up to every user to interpret the index - values for their specific application, but a general recommendation is that measurements with a vibration - index value of 3 cannot be trusted, value 2 could be questionable and values 1 and 0 are indicating very little respectively no vibration and are therefore trustable.

Signal Strength

Good signal-to-noise ratio (SNR) is the most important parameter of a radar signal that provides accurate and stable surface velocity measurements. When more radar energy is reflected from the water surface to the radar sensor, the overall signal strength is higher. When less energy is reflected, as it is when the water surface roughness is lower, the signal strength is lower. If the amount of noise present in the signal remains the same, when the surface roughness is lower, SNR will drop. To improve SNR internally, the radar uses low-noise programmable gain amplifier (PGA). If the strength of reflected signal is low, the radar will increase gain level on PGA. If the strength of reflected signal is higher, gain level will be automatically reduced.

The best indication of good signal strength is the PGA value. This value is automatically changed with the AGC (automatic gain control) algorithm in the radar. Minimal possible gain is 1 and maximal possible gain is 200. Best measurement results are obtained when PGA gain level is between 5 and 100; if PGA gain is lower than 5, this means that the reflected signal is very strong, and it can oversaturate the receiver, which could result in reduced accuracy. Gain 200 should be avoided as it is usually indication of very low reflections from the water surface.

The instrument provides a signal quality indicator reported with each measurement. It indicates the signal quality in a range of 0 (good signal) to 3 (very bad signal). The values are corresponding with the measured SNR value. A SNR of greater than 6 represents a good signal quality.

Interference and Multiple Radars

The radar operates in K band, in a frequency range of around 24.125 GHz. Frequency stability and phase noise of the internal oscillator is very good and always trimmed in the factory to precise central frequency but even with the best possible trimming and most stable oscillators it is very unlikely that two devices will be working on the exact same frequency to cause interference. Doppler frequency shift caused by water in speed range up to 15 m/s is measured in kHz frequency shift. Similarly, as interference from two or more OTT SVR 100 radars on the same location it is very unlikely that other radiation sources in K band, like the OTT RLS will affect radar measurements also. It is possible that some wideband radiation sources can introduce small and impulse interference for the short period of time, but this should not, or it is very unlikely to affect measurements reported by radar sensor.

Power Supply and Operation

Power consumption and a wide power supply voltage range of the unit enables battery-powered operation on remote sites where electric grid power supply is not available. The OTT SVR 100 is also designed to be regularly powered-off and powered-on to save power. In power-off and power-on mode of operation the minimal required settling time (time until the first valid measurement value is available) is around 20 s to 40 s, mostly depending on the site characteristics and turbulences on the water surface. This settling time will allow the sensor to tune programable gain, filters, tracking algorithms and all other internal adaptive systems for best SNR and best measurement accuracy. If operating in SDI-12 or SDI-12 over RS-485 mode, the instrument is in power saving mode, will be woken up with an SDI-12 command and returns to power saving mode after measurement.

When combined with a datalogger which completely powers-off the sensor between periodic measurements, the sensor can be operated on battery power and / or solar power supply without difficulties.

Certification of Accuracy

The accuracy of measured velocities has been proven in the laboratory for hydrometry of the Federal Institute of Metrology METAS in Switzerland and in the Brodarski Institute in Zagreb (Croatia). The velocity verification was executed in a rating tank. The OTT SVR 100 mounted on a towed carriage was drawn through stagnant water in the tank in a velocity range from 0.08 m/s up to 2 m/s (METAS) and 2.0 m/s up to 12 m/s (Brodarski Institute). Table 2 represents a section of the METAS verification test results.

Position b [mm]	Date	Start Time	No. of measure	v-ref [m/s]	Object tested Display []	U []	U [%]
2690	18.12.2019	14:18:32	1	1.25130	1.2610	0.00270	0.21
2690	18.12.2019	12:10:48	1	1.25130	1.2860	0.00271	0.21
2690	18.12.2019	12:21:07	1	1.50100	1.4860	0.00278	0.19
2690	18.12.2019	14:53:35	1	1.50100	1.4920	0.00278	0.19
2690	18.12.2019	13:46:57	1	1.50100	1.4920	0.00278	0.19
2690	18.12.2019	14:22:26	1	1.50110	1.5200	0.00279	0.18
2690	18.12.2019	14:26:53	1	2.00000	1.9790	0.00297	0.15
2690	18.12.2019	13:51:16	1	2.00050	1.9770	0.00296	0.15
2690	18.12.2019	12:25:22	1	2.00070	1.9720	0.00296	0.15
2690	18.12.2019	14:57:57	1	2.00080	1.9930	0.00297	0.15

Table 2: Verification of accuracy at METAS (a section)

Date of calibration 18.12.2019

For the measurement Marc de Huu

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