THE LOW COST MICROWAVE RAIN SENSOR:

STATE CERTIFICATION AND IMPLEMENTATION ON THE OBSERVATIONAL NET.

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ABSTRACT

The low cost rain sensor based on measurements of reflectivity of the drops and their Doppler velocities was developed. The main feature of the rain sensor is in microwave transmitting-receiving module: it is a part of multiply industrially produced microwave security alarm. For that reason the price of the main microwave component is very low, and the total price of the device is twice cheaper then all analogs. The module operates at frequency 10.6GHz in continuous mode. The microwave energy is generated by Gunn diode, reflected by the rain drops and received by mixing diode. The mixing diode output is digitized and fast Furies processing is made by specially pre-programmed processor which is part of the device. On the base of obtained Doppler spectra of the falling drops, the rain drop size distribution (DSD) is calculated. On the base of DSD, which is updated each 10 min, all rain parameters as intensity, accumulation, all momentum of the spectra are calculated in real time. To introduce the new rain sensor on the observation net of State Hydro Meteorological Service of Russian Federation, the certification and inter comparisons with the recent sensors are required. Such comparisons were made with Russian State Etalon for precipitation measurements, which is located on precipitation polygon near Valday Lake (400km north from Moscow). The comparisons were conducted within two summer seasons 2004-2005. As a result the Russian State certificate was obtained in May 2006 and the device is included in Russian State Register of tools for measurements. The procedure of comparisons, algorithms of data processing, and results of it are presented in the current report.

Introduction

The low cost rain sensor (LCR-11) based on measurements of reflectivity of the drops and their Doppler velocities was developed within 2002-2003 (Koldaev at al, 2005). This development was the alternative for the old accumulation type precipitation gages as O-1 (Tretyakov) or P-2. Both these gages were the basic systems in former USSR and are still the same in Russia till now. It is obvious, that current needs in operative information in rain intensity can not be fulfilled with the accumulative devices, where data collection is performed manually and just twice per day. The common view of all three devices is presented at the Fig.1

a)   b)   c)
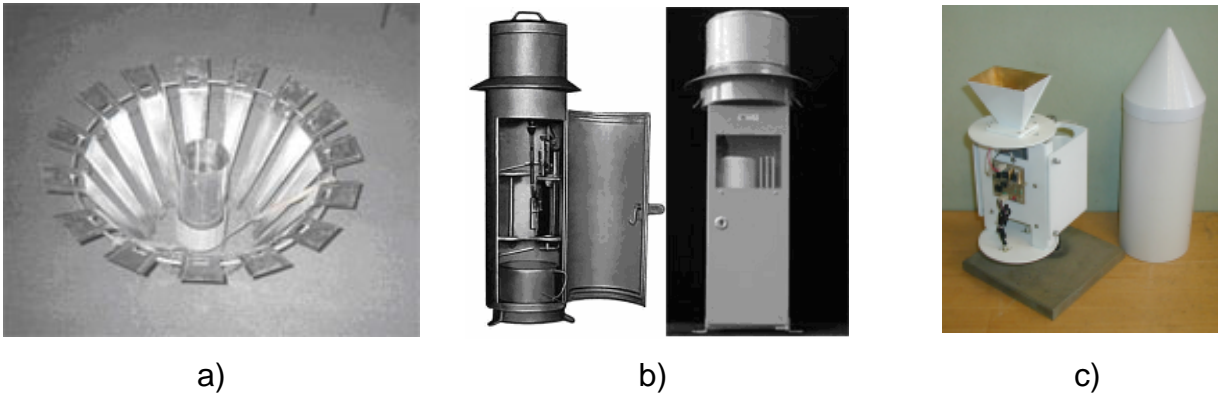
Fig.1 Tretyakov precipitation gage (a), P-2 (b) , LCR-11 (c)

From the other hand, LCR-11 is able to transmit the data about rain intensity each 1 minute with the standard rate of information update each 10 min. In this sense, the replacement of the old rain observational net with the new absolutely unmanned automatic sensors like LCR-11, is not questionable at all. But the problem is in a long term series of observations for precipitation regime in thousands sites of Russian territory. All the models, as well as floating prediction algorithms are based on the many decades measurements with the usage of O-1 or P-2 rain gages. For this reason the basic step use to be made before implementation of the new instruments on the observational net of such a big country like Russia. This step is State certification of the device with the use of State Etalon for precipitation measurements.

The procedure of certification is exactly the same as for O-1 and for P-2. It includes parallel measurements with the Etalon and with the device under comparisons. The statistically valuable data sets use to be obtained for 4(four) intervals of accumulated rain within 12 hours. These intervals are 0.1-0.5mm, 0.5-1.0mm, 1.0-10.0mm,10.0-200.0mm. Of course, it depends on the each individual summer season, and in average about 4 summer season is required to provide enough statistical material. In our case, we were lucky, that two consequent seasons of summer 2004 and summer 2005 were very wet at the experimental site, so enough statistics was achieved. The procedure of measurements, data processing algorithms and the results are presented below.

Principle of operation and features of construction

Theoretical background for the liquid precipitation measurements with the use of LCR-11 was described in the (Koldaev at al, 2005). Principle of measurements is based on the fact that rain drops falling speed is in a definite relation with their size. It means that Doppler spectra of the radio signal reflected by the rain in nadir direction can be definitely converted into drop size distribution (DSD). As soon the drop size distribution is known, the number of drops within any time period can be calculated by using measured radar reflectivity. The radar reflectivity is direct proportional to the production of 6(six) moment of DSD and number of drops within the measured volume.

The main feature of the rain sensor is in microwave transmitting-receiving module: it is a part of multiply industrially produced microwave security alarm. For that reason the price of the main

microwave component is very low, and the total price of the device is twice cheaper then all analogs. The module operates at frequency 10.6GHz in continuous mode. This frequency was chosen specially to provide Relay Law of back scattering: if the frequency would be higher, then the biggest drops will scatter radio waves according to Mee Law and radar reflectivity will not be a linear with number of drops.

The microwave energy is generated by Gunn diode, reflected by the rain drops and received by mixing diode. The mixing diode output is digitized and fast Furies processing is made by specially pre-programmed processor which is a part of the device. On the base of obtained Doppler spectra of the falling drops, the rain drop size distribution is calculated. On the base of DSD, which is updated each 10 min, all rain parameters as intensity, accumulation, all momentum of the spectra are calculated in real time.

The second feature of the device is in the fact that transmitting and receiving horn antenna is the same horn. Such a solution allows us to minimize overall dimensions of the device. But the antenna pattern is still sufficiently wider then it use to be. The problem is in the fact that horizontal drop speed, which is always exist due to wind, has the projection on the direction of radio wave propagation (see Fig.2) If so, the Doppler spectra measured by the device will be disturbed by the horizontal wind and huge errors can be expected for heavy rain with thunderstorm activity. To minimize these errors the antenna pattern use to be as narrow as possible.
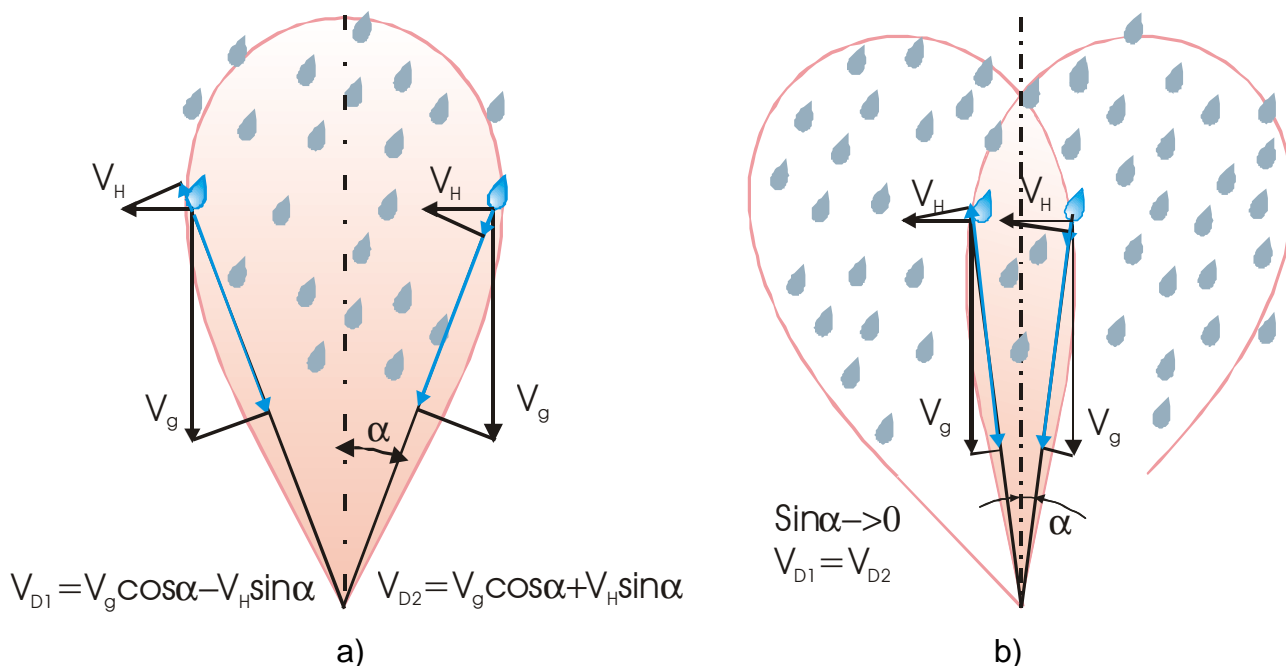

$$V_{D1}=V_g\cos\alpha-V_H\sin\alpha \qquad V_{D2}=V_g\cos\alpha+V_H\sin\alpha$$

a)

$$\text{Sin}\alpha\!\rightarrow\!0$$
$$V_{D1}=V_{D2}$$

b)

Fig.2 Influence of horizontal wind due to antenna pattern: (a) –common case; (b) intersection of antenna patterns in case of LCR-11.

Only two ways are known to get narrow antenna beam: or you have to use higher frequency of radio waves, or just increase the geometrical sizes of the antenna. Higher frequency is not the way in our case because of retrieving principle described above. Increasing of the antenna size means increasing the final cost of the device , what is opposite the main goal of all development.

In this complicated situation we have sacrificed by the energy optimization in favor of narrow antenna beam. The point is that transmitting and receiving sections of waveguide are in a different phase centers while they are working via the same horn antenna. It means that transmitting and receiving antenna patterns will be different with the narrow joint area of intersection. Due to such construction, the big portion of the transmitted energy will not be received by receiver, but the resulted antenna pattern (intersected one) will be much narrow then the separate transmitting and receiving patterns.

Field comparisons

As it was mentioned above, the main job is in certification and inter comparisons with the recent sensors. Otherwise the introduction of a new rain sensor on the observation net of State Hydro Meteorological Service of Russian Federation is just impossible. Thus the certification procedure was carried out at State Hydrological Experimental Site (HES), which is located at Valday Lake, Novgorod Reg. (400km to North from Moscow).
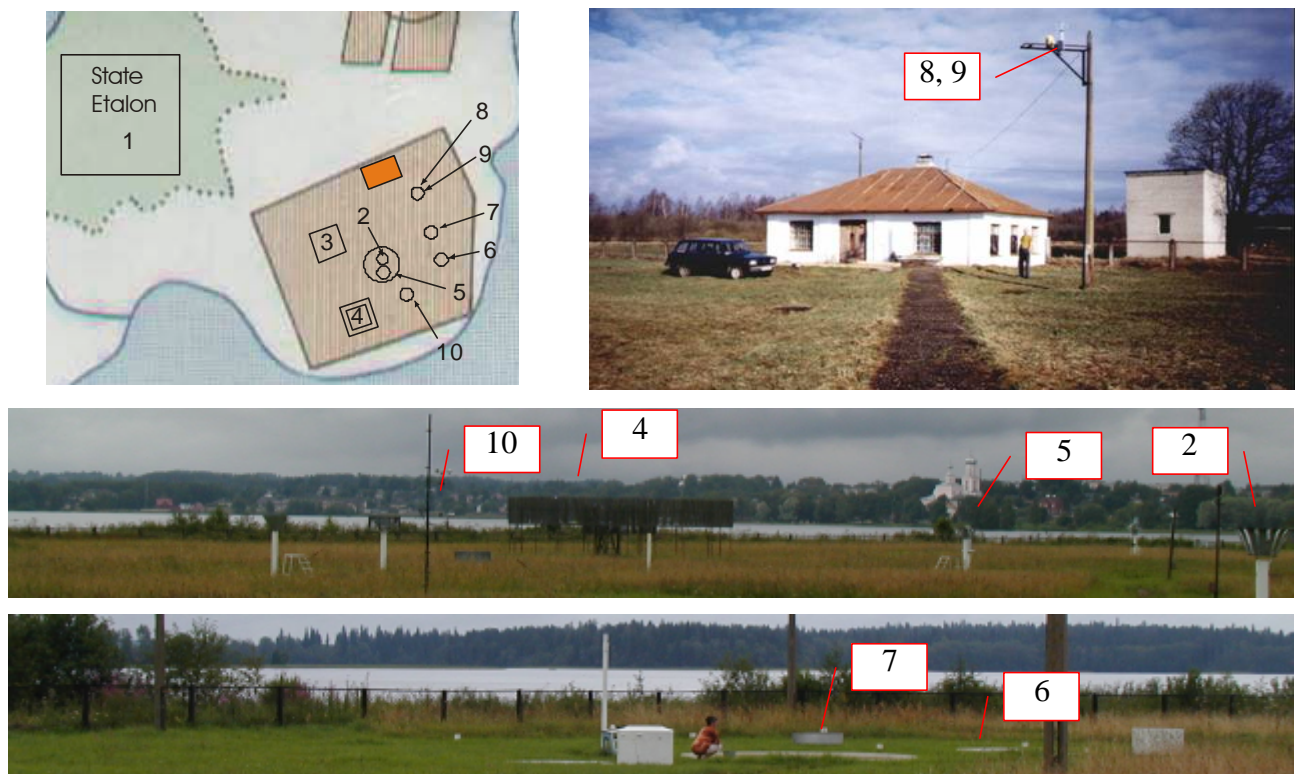

Fig.3 The scheme of State Hydrological Experimental Site at Valday Lake.

1) *State etalon,*
2) *Tretyakov type,*
3) *Tretyakov type with single fence,*
4) *Tretyakov type with double fence,*
5) *accumulation type with the mechanical recorder inside (well known as P-2),*
6) *surface mounted Tretyakov type,*
7) *pit mounted Tretyakov type,*
8) *LCR-11,*
9) *mast with mechanical wind sensors,*
10) *ultra sonic wind sensor.*

Hydrological Experimental Site is the basic Russian polygon for measurements of precipitation and evaporation. It occupies the area of about 200m by 300m at the flat shore of Valday Lake. On the territory of the polygon there are about 20 precipitation gages of different type. Among them are: Tretyakov type, Tretyakov type with single fence, Tretyakov type with double fence, accumulation type with the mechanical recorder inside (well known as P-2), surface mounted Tretyakov type, pit mounted Tretyakov type. The scheme of the different rain gages locations is presented on the Fig. 3.

The data from each type of rain gages were collected and processed. However, the principal comparisons were made with Russian State Etalon for precipitation measurements. State Etalon is located a little bit apart from precipitation polygon. I fact it is a composition of three (3) Tretyakov type rain gages, but the location of it plays the key role. All three instruments are installed at the height 2m above the ground at the angles of triangle with the side 2m also. This triangle is located at the brush-wood garden, which is cut everyday to be at the same level as rain gages. The trees, which surround the brush-wood garden, are cut to be about 4m tall (twice higher then brush-wood). It was proven, that average from three these gages corresponds to the real rain accumulation with maximum accuracy. The accuracy, that were achieved for the State Etalon are presented in the Tab.1.

Range of accumulating [mm]	Absolute accuracy [%]
0.1-0.5	38
0.5-1.0	15
1.0-10.0	6
10.0-200.0	<2

Tab.1 The accuracy of Russian State Etalon for liquid precipitation measurements in real conditions. (State Certificate # 2421637-04; re-confirmed 16 March 2004, valid until 16 March 2009)

These accuracy just means that the rain, in real conditions, has very sufficient natural variability, and specially at the lower values.

It is easy to understand that all these special requirements to installation site are corresponding to the general idea to reduce impact of wind on the rain accumulation measurements. It is decided that the wind impact is fully compensated for the State Etalon, but the rain gages of the polygon still require wind correction. For this reason the polygon was equipped with three mechanical wind sensors, which are installed at the different heights to provide with a kind of wind profile at nearest 10 m to the ground. Specially for the needs of LCR-11 testing we have added the ultra sonic anemometer to measure more accurate horizontal wind pulsation and vertical air motions if such will appear.

The technology of field tests conducting was the next:

a) The data from all Tretyakov type rain gages (including State Etalon) were collected twice a day with 12 hours interval within the period from May to November in 2004 and 2005. The output data was just water accumulation in mm within definite 12 hours interval.

b) The records of P-2 rain gage were collected and processed every day from May to October 2004 and 2006. The output data was: time of each rain beginning and end, accumulation in mm for each rain, average intensity for each rain, 10 min average intensity within the rain with duration more then 20 min, accumulation for 12 hours, which corresponds to the item a) above.

c) The data from LCR-11 were collected in digital files with the rate of sampling 8 Doppler spectra each second. On the basis of this set of data all parameters according to item a) and b) above were calculated in the real time.

d) The data from three mechanical wind sensors were manually recorded every 3 hours in the standard meteorological time (the data about air temperature and humidity, as well as surface temperature and water temperature were recorded at the same time also)

e) The data from ultra sonic wind sensor were recorded in the digital files with the rate of sampling 1 measurement per second.

f) At the end of each month and at the end of the seasons the data were processed according to the same algorithm as it is described at the next section.

It is necessary to emphasize, that all the rain gages were visually and mechanically inspected at least once per day during all the period of observation. In cases with heavy rain and strong wind, the inspections were conducted every hour. The reason for such special attention is that any blowing lives from the trees can led to mechanical closing of the accumulative type gage funnel.

Data processing and results

The procedure of data processing was the next:

a) Quality Control.

The quality control was made in two stage. On the first stage all the data from LCR-11 was compared with the data from P-2 for the same time. If any non corresponding in time of the rain records was observed, thus the data was disqualified. The reasons for such non-corresponding could be in power consumption problem, computer hang-up due to lighting activity, or even direct impact of thunderstorm on all electronic equipment of the polygon. As a total about 15% of the data was disqualified due to this first stage control.

On the second stage, the data from State Etalon was compared with P-2 accumulation within the 12 hours period. If the difference were exceeded the absolute error of Etalon in two times, the

rain was decided as very non homogeneous, and the comparisons were not made also. The reason for such cases was in space separation of Etalon and other gages (about 500m). Thus, during local heavy rains from Cu clouds, it was observed few cases when the difference between Etalon and P-2 was more then 5 times. About 5% of the data was disqualified due to this reason.

b)   Data sorting

All the data, that was accepted as good enough for the final processing, were divided on four group. These groups are according to the ranges of accumulated precipitation as it was described in Tab.1 above for the State Etalon. For each group of the data the same procedures as stated below were executed.

c)   Calculation of the State Etalon value.

The simple arithmetical mean value from three Tretyakov gages, which composes State Etalon, was calculated. And this average was decided as a reference value.

d)   Calculation of LCR-11 value for the same period as in item c) above.

Calculation of the LCR-11 data was made on the base of algorithms described in (Koldaev at al, 2005)

e)   Horizontal wind impact control

The horizontal and vertical wind records obtained from ultra sonic anemometer was analyzed within every time while rain events was observed. It was not observed (within two summer seasons) no any case when vertical wind would exceed 0.5m/sec. If horizontal wind have exceed 3m/sec, then the precise analysis of LCR-11 Doppler spectra data was performed. The subject of this analysis was in detecting of specific disturbances of the Doppler spectra, which can be expected due to known antenna beam width. We should say, that up to 7m/sec horizontal wind, (was observed just once) we have not distinguished any change in the Doppler spectra shape. So, at the moment we can say that up to 7m/sec, LCR-11 data are not disturbed by the wind.

The difference between LCR-11 and Etalon was calculated as:

$$\Delta_i = A_{LCR-11} - A_e, mm$$

A_{LCR-11}- 12 hours accumulation by LCR-11

A_e – 12 hours accumulation by State etalon

Systematic error was calculated as:

$$\Delta c = \frac{1}{n} \sum_{i=1}^{n} \Delta i, mm$$

Random error was calculated as:

$$\overset{0}{S}(\Delta) = \pm \sqrt{\frac{\sum_{i-1}^{n} (\Delta_i - \Delta_c)^2}{n-1}}, mm$$

Total error was calculated as:

$$\Delta_\Sigma = \Delta_c \pm 2\overset{0}{S}(\Delta), mm$$

Relative error was calculated as:

$$\boldsymbol{s}_i = \frac{\Delta_\Sigma}{A_i}100\%$$

Absolute error was calculated as:

$$\boldsymbol{s}_{LCR-11} = \sqrt{\boldsymbol{s}_e^2 + \boldsymbol{s}_1^2}$$

The same procedure was preformed for the data obtained from Tretyakov double fence rain gage and the data of the absolute errors are presented at the Tab.2 together with LCR-11 absolute accuracy.

Range of accumulating [mm]	Absolute accuracy LCR-11 [%]	Absolute accuracy Tretiakov double fence [%]
0.1-1.0	63	79
1.0-10.0	27	26
10.0-200.0	3	8

Tab.2 Absolute accuracy of LCR-11 and Tretyakov rain gage in real conditions for four rain accumulation ranges with respect to State Etalon.

Conclusion

The Russian State certificate was obtained in May 2006 and the device is included in Russian State Register of tools for measurements with the N 31690-06.

Fig.4 State Certificate for LCR-11

State Hydro Meteorological Service of Russian Federation ordered 8 (eight) LCR-11 for experimental implementation at the territory of central European Russia. All the sensors were installed during summer 2006 and the experience of first season net operations is studied.

Acknowledgments

Reference:

A.Koldaev, A.Kutarov, D.Konovalov, A.Mironov. 2005 The Low Cost Radio Frequency Rain Meter. WMO/TD-No. 1265 Proc. Of TECO-2005, Bucharest.