The Low Cost Radio Frequency Rain Meter

A.Koldaev*, A. Kutarov*, D.Konovalov**, A.Mironov*

*Central Aerological Observatory, State Hydro Meteorological Service of Russian Federation.

** Main Hydrological Institute, State Hydro Meteorological Service of Russian Federation.

Abstract

The low cost radio frequency rain meter was developed and constructed. The principle for operation is in measurements of Doppler spectra of raindrops in the vicinity of the sensor. The low cost of the sensor is achieved by employment of serially produced microwave unit (generator + detector), which is ordinary used for home security systems. The microwave unit is accomplished with amplifier and microprocessor board. The microprocessor board pre-programmed for: executing of FFP, integration of the retrieved spectra within 10min, transforming of average Furies spectra into Drop Size Distribution (DSD), and translating of this data via RS232 port. The main advantage of the sensor is in its small size dimensions (10sm x 10sm x 20sm) and small weight (less then 1kg), so the sensor can be easy added to the current meteorological musts. Power consumption can be provided by accumulator battery and data transmission can be made via GSM modem. With these two options, the sensor is ideal for unmanned meteorological stations. The comparisons of the radio rain meter with the standard rain gage were carried out within summer 2004 at the Valday State Hydro Meteorological Experimental Site, Russia.

1. Introduction

The measurement of atmospheric precipitation is a routine job for any meteorological observations worldwide. The most common applications of the data are: floating warning, agriculture, draying warning, global climate change. Most recent applications are in Weather Radar validation/calibration procedure as well as in validation experiments for Satellite Meteorology. The Tretyakov precipitation bucket O-1 was accepted as the first common device on the whole territory of former USSR. The principle is very simple: just collection of precipitation and measuring of the accumulated amount within definite period of time. The problems are basic: wind, evaporation, and losses on damping. The disadvantage cannot be overlapped: any autoimmunization is impossible. The next step: self recorded rain gage P-2: the accumulating amount of precipitation pushes the pen, which record the current level on the tape of mechanical recorder. The disadvantage stills the same as for O-1.

Most recent developments are based on Doppler type micro radars, which allow retrieving Drop Size Distribution (DSD) in the vicinity of the installation of the system. There are a lot of companies, who produce Doppler radio technical gages now. But the first one (POSS) was developed in Canada in the beginning of 90th and is widely used in Canada up to current days.

The presented development LCR-11 (Low Cost Rainsensor, operating at frequency 11GHz) was focused on accumulation of all advantages provided by Doppler radar gages, but the main goal was in reduction the price up to bottom level for such type of sensors. The original algorithm for Doppler spectra processing was proposed and tested to decrease impact of wind into the errors of rain intensity measurements. The comparisons prove that the accuracy of the new radio rain meter corresponds to the Russian State Standard for rain precipitation measurements. The results of the comparisons, including the rains with different nature and intensity are discussed in the paper.

2. Theoretical Background

The basic physical principle is that the drops of rain have sustainable (constant for each size of drops) velocity of sedimentation, and thus the Doppler spectra is "one-to-one" corresponded to the DSD. It is well know [1] that back scattering cross-section of the falling rain drop with time correlation is:

$$s_B(r, l, t) = s_B(r, l)\, c(\bar{k}, t) \exp(i, \bar{k}, \bar{U}, t)$$

$\bar{k}$ - wave vector; $s_B(r, l)$ - stationary back scattering cross-section; $c(\bar{k}, t)$ - drop velocity fluctuation function; $\exp(i, \bar{k}, \bar{U}, t)$ - wave phase factor which is changed by the drop velocity U.

The spectrum of that back scattering cross-section can be written as:

$$W_{sB}(w) = \int_{-\infty}^{\infty} s_B(t) \exp(iwt)\, dt \qquad \textit{where} \qquad W_{sB}(w) = W_{sB}(w, r)$$

If to take into account that rain contains the assemble of particles with DSD described as n(r), the Doppler power spectrum can be written as:

$$W_{sB}(w) \rightarrow \boldsymbol{A} \quad \text{where}$$

$$P(w) = \int_{r_{\min}}^{r_{\max}} n(r) W_{wB}(w, r)\, dr \qquad P_i = P(w_i) \text{®}\ \bar{P} \qquad A_{ij} = W_{sB}(w_i, r_j)$$

$$n_j = n(r_j)\, dr_j \rightarrow \bar{n}$$

$$\bar{P} = A\bar{n} \qquad (1)$$

If to suppose that the drop with the radius r is moving with the constant speed U, the power $P(w_j)$ *in the Doppler spectra will correspond to* $w_j = 2kU(r_j)$. Thus:

$$P(w_j)\Delta w_j = s_B(r_j)\, n(r_j)\, \Delta r_j \qquad \Delta w_j = -2k \left. \frac{\partial U(r)}{\partial r} \right|_{r=r_j}$$

$$P(w_j) = s_B(r_j) n(r_j) \left(-2k \frac{\partial U}{\partial r}\bigg|_{r=r_j} \right)^{-1}$$

From where we can retrieve the matrix for the task (1) in the strait form as:

$$A_{i,j} = -\frac{s_B(r_j)}{2r \frac{\partial U}{\partial r}\bigg|_{r=r_j}}; A_{i,j} = 0 \quad i \neq j$$

As far the n(d0 is determined from (1), we can determine the intensity of precipitation as:

$$p = t * \frac{4}{3} p \int_0^{\infty} U(r) n(r) r^3 dr$$

Where: p- rain intensity, t- time of measurements.

3. Principle of operation and block diagram

The principle of operation is based on measurements of vertical velocities of rain drops by means of micro power Doppler radar working in continuous mode of radiation at frequency 11GHz.

The system is consist with:

- Microwave receiver/transmitter working through the same horn antenna (Microwave Module)
- Low Frequency Amplifier (LFA)
- The Digital Processor, which performs FFT algorithm and all digital exchange functions.

The block diagram is presented on the fig.1.

Micro power Microwave transceiver works according to the principle of homodyne continuous-wave radar. Major portion of the energy of non-modulated microwave oscillations, produced by the open wave-guide section with build in Gun diode, is emitted into the space by horn antenna. The part of the energy, due to the uncontrolled connection, passes directly into the wave-guide mixing section and is used as the signal of heterodyne.

It is known that the uniform velocities of the raindrops are within the range 1 to 10 m/s. Thus, at the frequency of transmitter of approximately 11 GHz value Fd will be found within the range 60 to 700 Hz. Further, the signal, detected on mixer diode, is amplified by Low Frequency Amplifier and transferred to digital processing board. The digital processing board converts the analog signal by means of low frequency ADC and, using the algorithm of digital Fourier Processing transforms it into the spectrum. Then, the spectral data are accumulated in the working storage during the assigned period of time. The averaged spectra is used for retrieving of DSD and thus for further calculation of the current precipitation intensity.

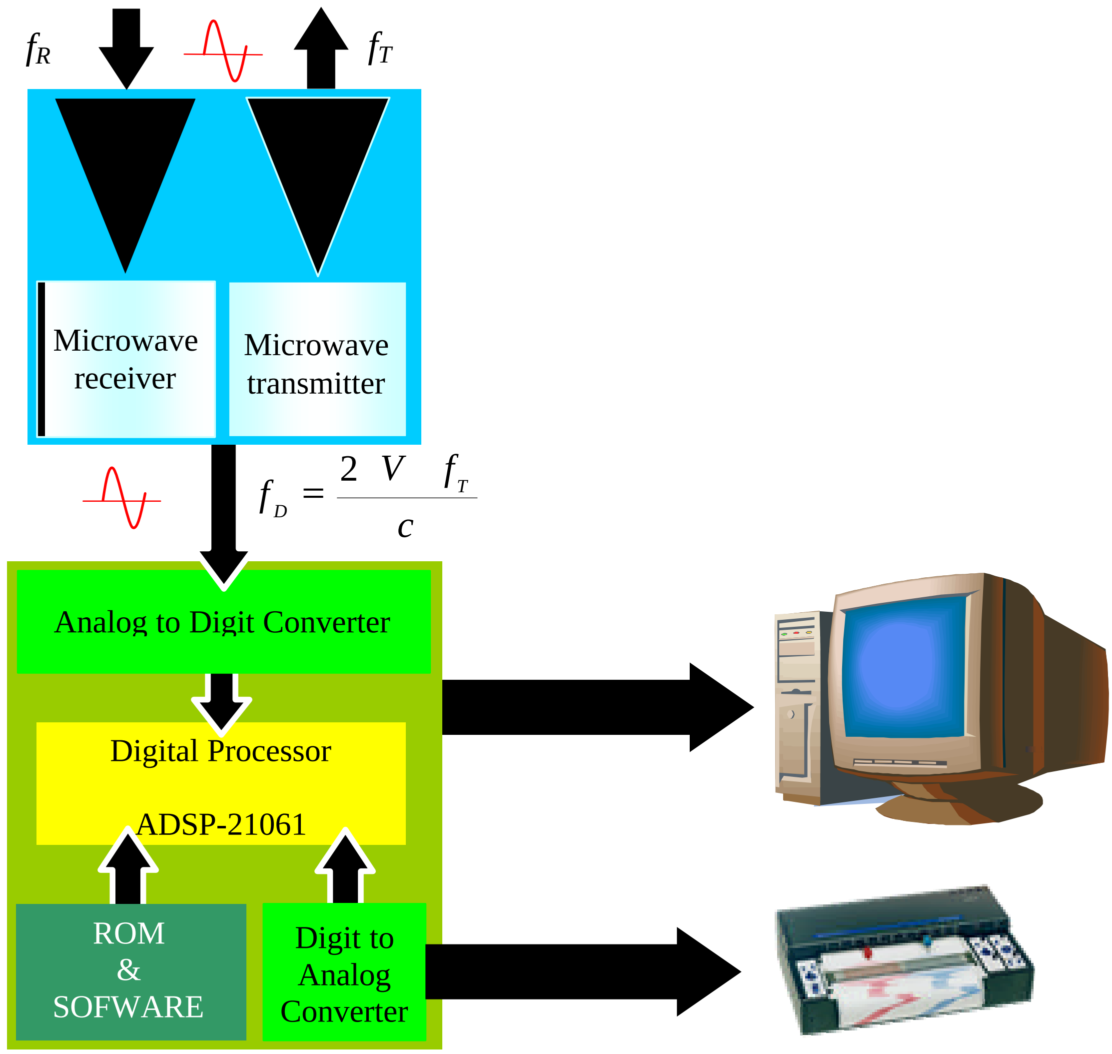

Figure 1.

The main advantage of proposed and realized in LCR-11 technical solution is that the Microwave Module (MM) is the same as MM industrially produced in large series for microwave alarm systems for common life. Thus the price of this part of the system is extremely cheap. It is executed as a solid part composed with two wave-guide sections: mixing and generator, and common horn antenna. Horn antenna is equipped with the shielding radio-transparent cap of conical shape, made from glass-fiber-reinforced plastic and intended for the protection from the meteorological effects and the pollution. The conical shape of cap is caused by the need for avoiding the accumulation of precipitation layer on its surface and preventing destruction of the instrument by birds.

Horn antenna is connected to the output of wave-guide section and has various forms of antenna pattern for the transmitting and receiving section. In this case the acting radiation pattern is determined by the intersection of the diagrams of receiver and transmitter. This feature makes it possible (without using large-dimension antenna) to create narrow “effective” antenna beam.

The specialized signal processor of firm Analog Devices Inc ADSP of 21061 "Sharc" is used in the system. This processor has the built-in working storage and the arithmetic-logical device, intended for the work with 32- bits discharge words with the floating point. The architecture of this processor is adapted for its effective application in the devices, which use different algorithms of digital processing of signals, in particular the translation algorithms of Fourier. Moreover, the application of arithmetic with the floating point makes it possible to qualitatively increase the accuracy of processing signals. The presence of the built-in the processor device of direct access to the memory (Direct Memory Access - DMA) makes it possible to organize the continuous processing of signals. It means that, the processes of the accumulation of the data from ADC and processing of the previously accumulated data are performed in parallel mode. The transmitting of data to the external terminals does not interrupt the calculations also. Great possibilities for the subsequent modernization and the expansion are placed in the computational part of the instrument. There is a possibility of the performance of instrument for the work in the autonomous regime with the transmission of information along the existing contemporary communication systems.

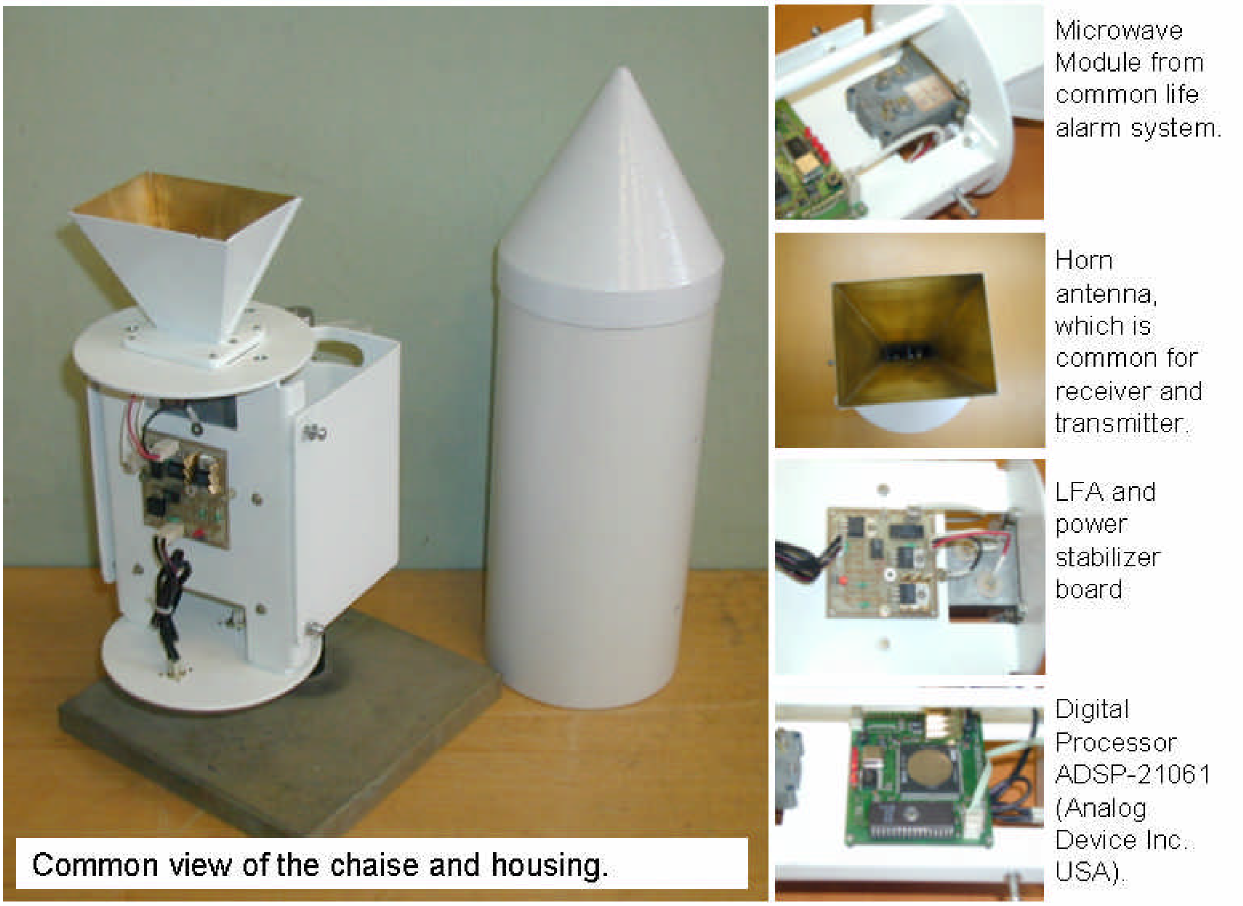

Figure 2.

The housing of instrument is made from weather proof plastic and is intended for the protection of instrument from the mechanical and meteorological actions. The aluminum chassis, which ensures the hardness of construction and fastening all knots and instrument units, is located inside the housing. For fastening of instrument on the vertical supports is provided the aluminum bracket rigidly connected with the chassis. The common view of the LCR-11device and their parts is presented on the Fig.2

4.Laboratory and field tests

The laboratory tests were conducted in the Central Aerological Observatory, Dolgoprudny, Moscow Reg. The tests included the measurements with LCR-11, weight type precipitation gage and 3D wind measurements. The comparisons were performed within fall 2003 –spring 2004 period. The results of this comparisons were very promising, that allow us to schedule and conduct field comparisons on the territory of State Hydrological Experimental site in Valday , Novgorod Region. The main feature of the State Hydrological Experimental side is that it is equipped with Russian Federation State Standard of Rain Precipitation. This standard is just a composition of three (3) Tretykov type precipitation gages, which located in special environment.

Figure 3. *Comparisons of LSR –11 with the Russian Federation State Standard of Rain Precipitation on the experimental site of State Hydrological Institute. Valday, Novgorod Reg. May-September 2004.*

The State Hydrological Experimental site is a unique place not only because of State Rain Standard. On the territory of the Experimental site there are more then 20 rain gages of different type. In accomplishment to the rain gages, the Experimental site is equipped with a set of evaporation pools, meteorological stations and special wind sensors. The wind sensors were actively used in our work, because the influence of a side wind as well as a vertical wind is one of the main source of errors for the Doppler type precipitation gages. We have used three mechanical wind sensors installed on three different standard heights and one ultrasonic wind sensor , which was installed immediately in vicinity of LCR-11. The field tests were conducted within May-September 2004. The picture with common view of the installation is presented on the Fig.3.

5. Results of comparisons

It was recorded about 60-e rain events of different nature, intensity and duration. The results were presented in three grope of plots: The first grope is the plots for “case study” which describes the time series of accumulated precipitation for each individual rain. The example of such direct comparisons of LCR-11 with the Rain recorder P-2. is presented on the Fig. 4. The graphs presented the precipitation accumulation within about 7 hours. (Valday, 28 August 2004).

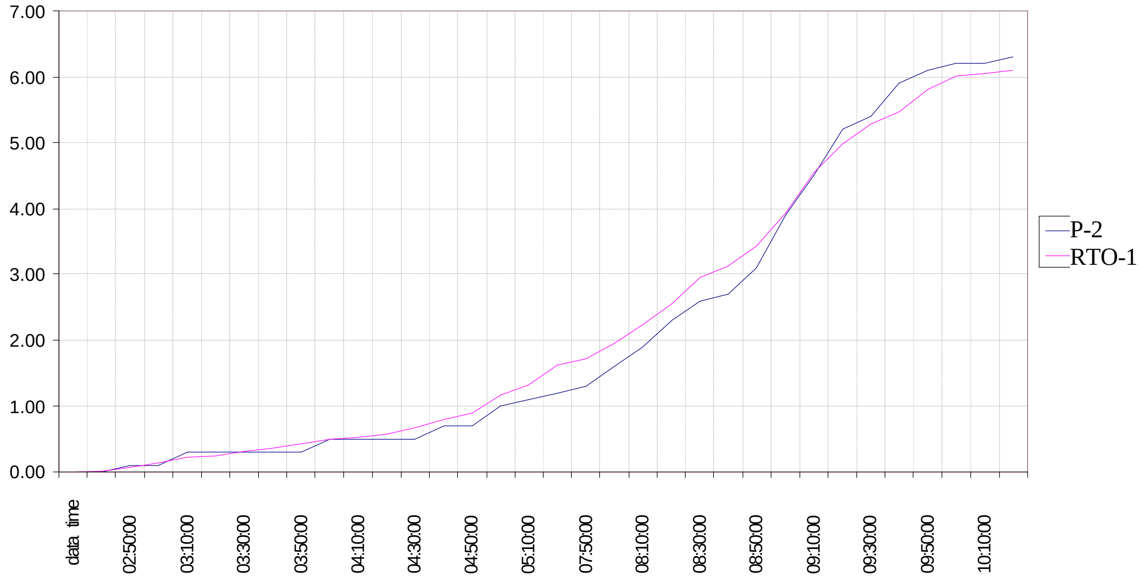

Figure 4. *The results of direct comparisons of LCR-11 with the Rain recorder P-2. The graphs of precipitation accumulation within about 7 hours. Valday, 28 August 2004.*

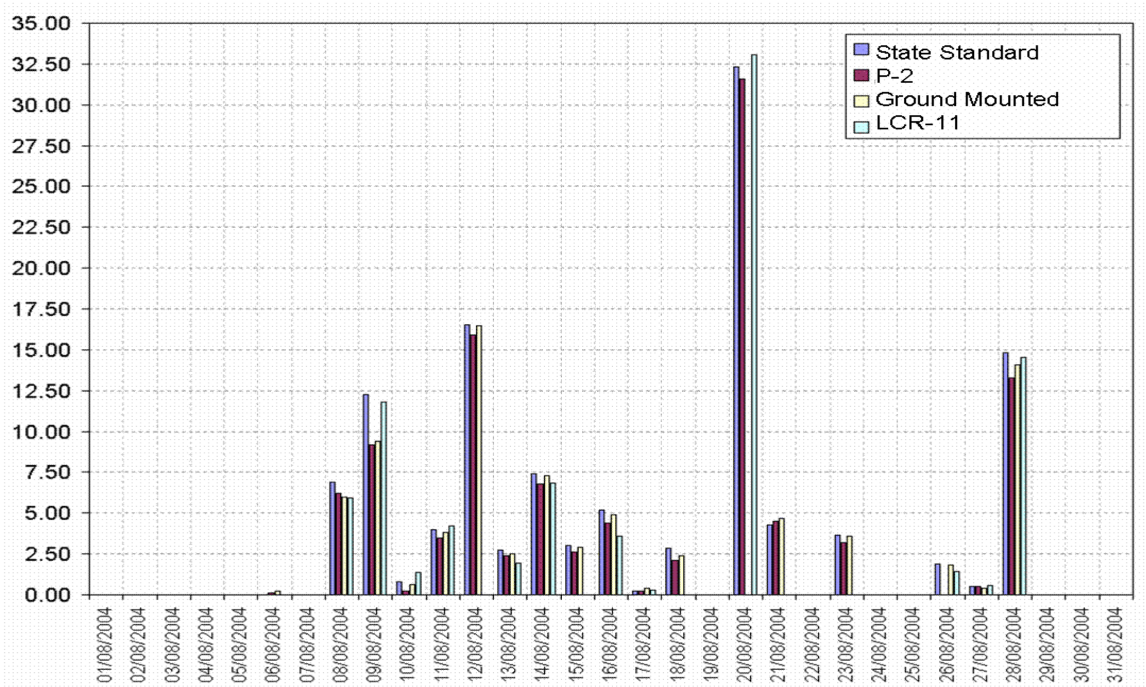

Figure 5. *The results of comparisons with State Standard and Ground Mounted Standard within a whole month. (Valday, 1-31 August 2004). On the plot the 24 hours accumulated values are presented. P-2 data are presented also for reference only*

The second grope is the plots with histogram presentation of accumulated precipitation within 24 hours by different type of precipitation gages. The example of such histogram obtained within August 2004 is presented on the Fig. 5.

And the third type of the plots is the scatter plot of LCR-11 versus State Standard in Log scale with division of the results for the different range of precipitation accumulation within 24 hours. The example of that plot for August 2004 is presented on the Fig.6.

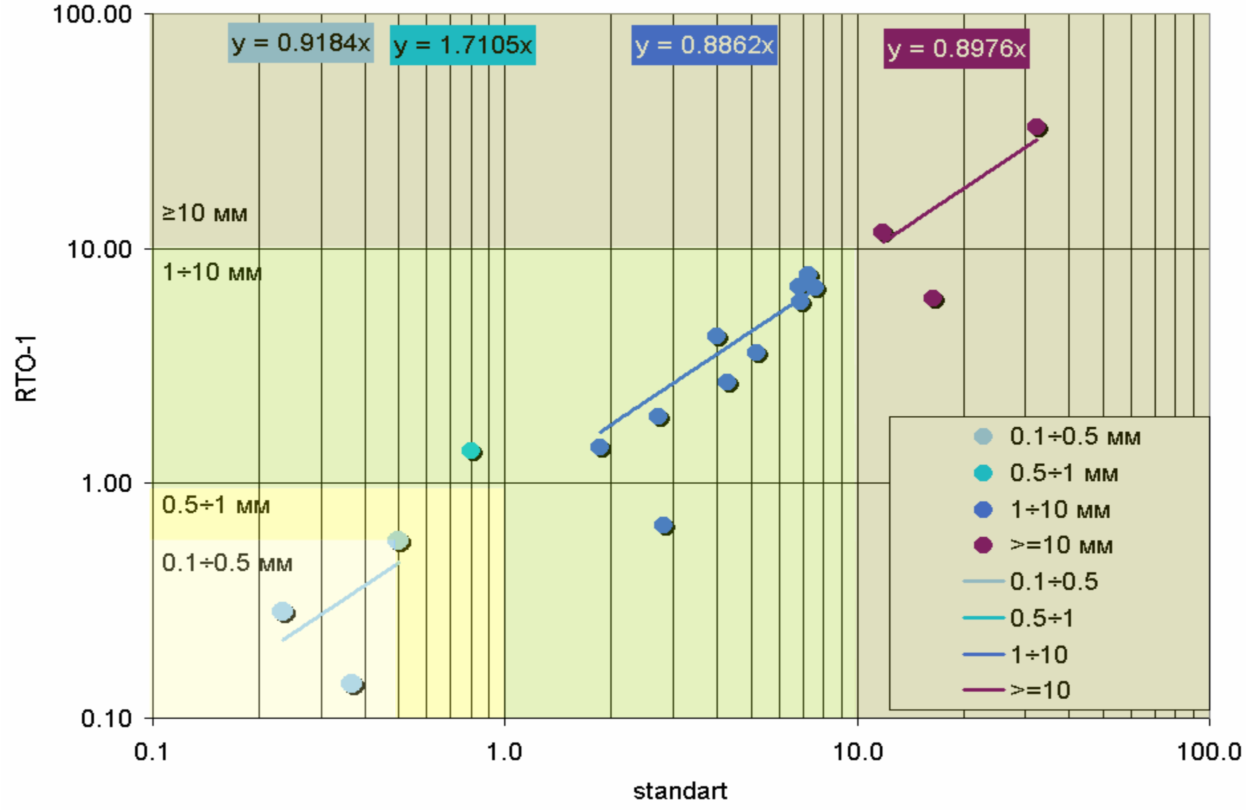

Figure 6. *Scatter plot of comparisons with State Standard in Log scale with division of the results for the different range of precipitation accumulation within 24 hours*

As a result of field tests the big volume of experimental data was obtained. This information allows to improve the parts and whole construction of the device and to start the production of signal series of LCR-11 The influence of wind was investigated also, and it was experimentally proven that wind not decrease the accuracy, which is found in good agreement with the accuracy of State Standard.

Conclusions

1. As the result of field tests all disadvantages of the LCR-11 “alpha” sample were reviled. This allows improving the construction and starting serial production of the devices.

2. The performed comparisons prove the accuracy of measurements of 24 hours accumulated rain within the range of accuracy of Russian Federation State Standard. The influence of horizontal wind is found negligible small.

3. The improvements of the devices made on the basis of field tests have not increased its price, but sufficiently increase its reliability and Customer oriented properties.