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Full Length Research Paper

A New Way to Implement Fully Autonomous and Automatic Large-Scale Anti-Hail Protection

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This article describes a new method for implementing a fully autonomous and automatically operating global network of an anti-hail protection including hail detection and alerting, hail prevention, hail suppression and hail trapping.

Keywords: Hail; Hail Detection and Alerting; Anti-Hail Protection; Hail Prevention, Hail Suppression; Hail Trapping; Sonic Cannon; Sonic Generator; Sky Brightness Temperature; Microwave Radiometer

INTRODUCTION

The protection of rural and urban areas from hail remains an actual problem for many countries, since every year, hail causes great and severe damage to agriculture, rural and urban vegetation and properties, both, civil and state, namely, roofs and windows of buildings and houses, cars, trains, planes and their traffics, TV and communication, etc. To prevent hail or to suppress hail power and reduce damage from hail in agriculture and in the economy it is necessary to use anti-hail protection methods and stations of hail prevention and suppression that will be more effective and inexpensive in application and in exploitation.

At present the anti-hail protection is implemented by the following three methods: hail prevention method, which hinders in advance hail formation or interrupts the further growth of small ice particles in clouds, hail suppression method, which hinders the growth of already formed small and moderate hailstones into large ones, and plants overlapping method, which complete hinders or reduces the physical-mechanical impact of hail on the plant.

Two techniques for hail prevention and suppression is widely employed in the world: seeding of clouds with silver iodide or other substances, which induce freezing to occur at warmer temperatures than otherwise, and the use of sonic cannons or other kinds of explosive devices,

There are two ways in which seeding is postulated to reduce hail severity. Seeding is intended to cause a vast increase in hail embryos, none of which grows to large hail because of competition for the available liquid water. Another approach, premature rainout, involves seeding of cloud elements at an early stage, so that particles which might otherwise become hail embryos fall out of the cloud as rain from lower levels rather than ascend to the higher levels where hail formation takes place. Seeding of clouds, which is implemented by shells or rockets, is an expensive and ecologically harmful one, and as mentioned in (Steiner 1988), carefully designed scientific experiments have not demonstrated any reduction of hail resulting from cloud seeding, however there is evidence that many hail suppression operations in various parts of the world appear to have reduced hail damage.

The use of supersonic cannons (generators), which are cheap and ecologically harmless in application, involves supersonic and significant shock waves generation by sequential detonating an explosive mixture of combustible gas (fuel) and air in a combustion chamber of the sonic generator and their direction upwardly to the sky. It is believed that the succession of shock waves transports positive ions from ground level to cloud level which disrupt formation of hail nuclei. It is assumed as well that due to the shockwaves which emanate from the hail generators, the super cooling water situated on the external layer of hailstone is transformed from liquid state to solid state. Therefore the hail nuclei do not melt anymore and remain at small sizes which thus prevent them from inflicting damage when they hit the ground. By selecting material and quantity of the combustible fuel, number and duration of detonations it is possible to provide significant shock waves and to effect on the hail clouds up to 10km of altitude, changing hail cloud structure, preventing further development of hail and transforming hail into rain or wet snow or small ice drops.

Both described techniques are not efficient against already formed hailstones, so the most important requirement in their application remains their timely startup. Shells or rockets must be fired or launched at least in cumulonimbus before large hailstones forming. The hail preventing sonic generator's operation must be approximately initiated 15-20 minutes before hail storm formation or storm arrival. The efficiency of both techniques decreases in proportion to startup delay. If the anti-hail device is activated when the storm is directly above, its efficiency will be very low. Therefore, for both techniques of protection it is strongly recommended to use them in conjunction with hail detectors.

Despite the fact that in some countries anti-hail launchers are manually controlled and their positioning along both azimuth and elevation directions are regulated on the basis of commands coming from human operators, in most countries for hail detection and clouds accurate and timely seeding usually powerful Weather Doppler radar is used, operating at short centimeter or millimeter band of waves. Although these radar cost several hundred thousand (Weather Radar, www.meteo-radar.com) or millions (Antigrad, www.hsrc-antigrad.com) USD, in dependence of the power and service facilities, however, they have serious disadvantages and cannot solve the problem totally. The Weather radar can detect and classify with high probability already formed hail clouds, but cannot classify hail bearing (hail generative) cloud which may be transformed in hailstorm. In addition, the meteorological radar consumes relatively high power and requires certain installation and operating conditions.

Usually an anti-hail protection network, consisting plurality of spatially distributed acoustic generators, also controlled by the radar. However, in many places the control of separately operating cannon or a small group of cannons is carried out manually or remotely by means of cellular or radio communications, according to the visual observations of the staff (human) operator, which is not acceptable for effective prevention or suppression of the hail, since include human factor.

The overlapping method of plants by the anti-hail net of course is an efficient technique for protection. However, this technique is widely employed to protect some important farms only, since the expenses of the anti-hail net's installation and handling are high enough and in a case of large-area farms the overlapping will cost very expensive. Really, the cost is about 5,000€ per hectare for installation and is about 1,200€/hectare/year for both mandatory required handling operations (unroll nets in springtime and roll up in winter). Besides, its period of use is limited and after several years the net should be entirely renovated and repaired.

Unfortunately, in spite of its high cost the anti hail net is not efficient in the event of severe hail storms. Consequences are potentially even worse than for a completely unprotected farm, because if the net's structure collapses on the crops the grower will often be forced to replant the entire afflicted areas. Therefore, it is more reasonable to protect such areas as well additionally by cheaper cost methods and means of hail suppression and to prevent severe hail using a sonic generator, for instance, which may operate autonomous and automatically.

So, regardless of the applied anti-hail protection methods and technology a reason is appeared to use for hail timely prevention and suppression new kind of detector-classifier which will cost cheap and will have additional advantages in hail and hail generative clouds detection and hail prediction.

As shown in (Arakelyan et al., 2010; Grigoryan et al., 2010; Arakelyan et al., 2011; Arakelyan et al., 2012a; Arakelyan et al., 2012b; Hambaryan et al., 2014; Hambaryan et al., 2016), microwave radiometers with usual sensitivities may be successfully used for hail detection, clouds classification and for early alerting on impending hail danger. By an application of radiometric detector-alerter it is possible to implement an autonomous and automatically functioning anti-hail protection of a local area of a limited size, as well as to implement a fully autonomous and automatically functioning network of spatially distributed hail traps (Arakelyan 2017). As shown in (Arakelyan et al., 2016c), by the application of microwave radiometers, as a detector-classifier for hail generative clouds timely detection and hail prediction, it is possible to implement fully autonomous and automatically operating global network of the anti-hail protection including hail detection and alerting.

In this article particular solutions for implementation of fully autonomous and automatically operating wide-ranging anti-hail protection network which can be

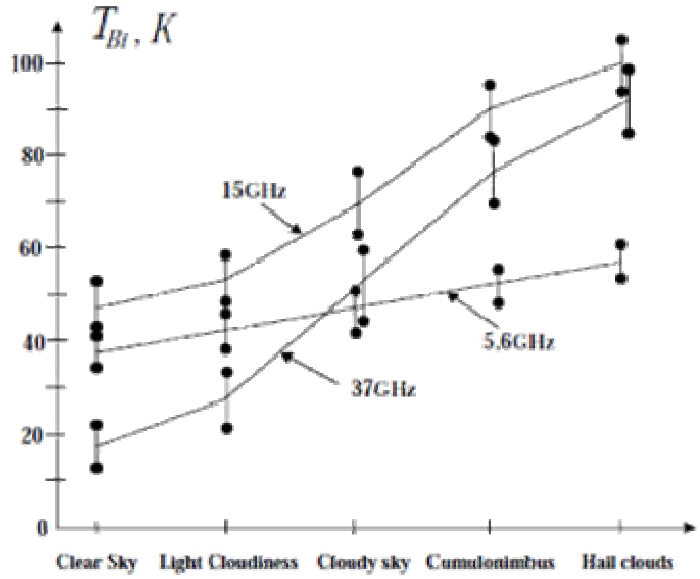

Figure 1 Clear sky and clouds brightness temperatures

applicable for highly efficient prevention, suppression or trapping of the hail without spatial and relief (lie of the ground) restrictions.

Simple and Cheap Way for Hail Early Detection and Prediction

As mentioned above by simple microwave radiometers with usual sensitivities it is possible to predict and detect hail and classify hail generative clouds with high probability and with high certainty for early alerting on impending hail danger. This statement is based on the experimental results obtained during experimental researches carried out in Armenia under frameworks of the International Science and Technology Center's (ISTC) Projects A-871 and A-1524 (Arakelyan et al., 2010; Grigoryan et al., 2010; Arakelyan et al., 2011; Arakelyan et al., 2012a; Arakelyan et al., 2012b). The physical basis of the above mentioned idea is the following. Cloud's brightness temperature is a function of many parameters, in which air and particles temperatures, fraction type (water or ice) and particles size are the principal variables. The changes of cloud's brightness temperature, related with the changes of dielectric properties of particles (water or ice) and air temperature, depend on the frequency of sensing. Therefore, microwave radiometers which measure intrinsic emission of observed media in radio frequencies can be used for precise and high probable detection and classification of hail and hail generative clouds. Radiometric observation may not miss the stage of transformation of water vapor and drops of water to hail as well, because water and ice dielectric constants are very differ and such formations' brightness temperatures (powers of their intrinsic microwave emissions) will sufficiently vary one from other.

Really, in **Figure 1** the results of radiometric measurements of clear air and clouds (including cumulonimbus) brightness temperatures (more exactly apparent temperatures) are presented measured at various microwave frequencies and polarizations (Arakelyan et al., 2010; Grigoryan et al., 2010; Arakelyan et al., 2011; Arakelyan et al., 2012a; Arakelyan et al., 2012b). These measurements were carried out in the experimental site of ECOSERV Remote Observation Centre Company (ECOSEVR ROC), from the measuring complex constructed under the framework of ISTC Projects A-872 and A-1524. The measurements were carried out under various elevation angles of sensing, at vertical and horizontal polarizations of sensing by radiometric channels of C (5.6GHz), Ku (15GHz), and Ka (37GHz) band combined scatterometric-radiometric systems (ArtAr-5.6, ArtAr-15, and ArtAr-37) developed and built by ECOSERV ROC under the framework of the above mentioned ISTC Projects (Arakelyan et al., 2005; Arakelyan et al., 2007; Arakelyan et al., 2007). The results of **Figure 1** corresponding to hail clouds are not measured results. They are approximately estimated values obtained from existed theories.

Measured and estimated results of observed sky (clear and cloudy) apparent temperatures presented in Figure 1 have
shown that radiometric contrasts due to occasional appearance of a hail cloud on the clear sky may reach up to 20-80K or more in dependence of the frequency band. This means that microwave radiometers with usual sensitivities ~0.2K (C-band), ~0.5K (Ku-band) and ~1.0K (Ka- band) at 1s integration time may be successfully used for hail prediction, for hail early detection and hail generative clouds classification. Besides, in mass production, such radiometers will cost incomparably cheap than radar, about 1,000-2,000USD in dependence of their operation frequencies and can solve hail early detection and prediction problems better than radar.

Method and Network for Creating Wide-Ranging Anti-Hail Protection of a Vast Area

The idea to use microwave radiometers for early detection and classification of hail and hail generative clouds which is significant for hail prevention and suppression by timely start-up of sonic generators has been initially patented in Armenia as an invention (Arakelyan 2013). After that the invention was patented in China (Arakelyan 2016a), in the USA (Arakelyan 2016b), in Canada (Arakelyan 2017a), in the EU (Arakelyan 2017b), and in Russian Federation (Arakelyan 2017c). On the basis of the obtained European Patent the invention is patenting in France, in Germany, in Spain, in Italy, in Switzerland, in the UK and in Turkey. The invention is patenting also in India (Arakelyan 2014).

As shown in (Arakelyan 2017), by one or two radiometers it is possible to implement fully autonomous and automatically functioning of the anti-hail device, like a sonic cannon, for instance, and to provide anti-hail protection of the area (circle space) of 50-70 hectare of a size. Consequently, by application hundreds, thousands radiometers it will be possible to perform a global anti-hail protection of a vast area.

Then a reasonable question may arise. If the cost of hundreds or thousands of radiometers can reach the cost of the meteorological radar, then, where is it the advantageous to use radiometers? The benefit is obvious from the following. Let us assume that the meteorological radar and thousands of radiometers protect the area of the same size. Then, in the event of an accidental failure of the radar, the whole protected area remains unprotected for a long time, since, it is not always possible to repair the failed radar on site, and its replacement will require large financial and labor costs and the time which is the main decisive factor for successful implementation of the protected area's anti-hail protection.

And in a case of radiometers, at the simultaneous failure of even half of the number of radiometers, which is almost unbelievable, only half or lesser part of the protected area will remain unprotected. Moreover, replacing or repairing faulty radiometers is easier, cheaper and faster than in the case of the radar. In addition, radiometers has low power consumption, can be supplied by a power from a small solar panel, they do not require certain installation or operating conditions, and as mentioned above, radiometric observations cannot miss the stage of transformation of water vapor and drops of water to hail, and can detect and classify hail and hail generative clouds better than radar.

In Figure 2 an option is presented for implementation of a fully autonomous and automatically functioning large-scale (wide-ranging) network of anti-hail protection to protect a large area (1) of M>>1 spatially distributed protected sites (2) 50-70 hectares each. Each protected site (2) is equipped with an anti-hail protection system (3) comprising a sonic generator (4) and a detector-alerter (5) for early detection of impending hail or hail generative clouds, by measuring apparent temperature of the corresponding part of the sky just over the protected site, and for timely starting up the corresponding site's sonic generator. In Figure 3 detailed block diagrams of the corresponding site's detector-alerter (5) and sonic generator (4) are presented.

The large-scale network of anti-hail protection of the protected area (1) of any size, which is a particular case of a general solution fully described in (Arakelyan 2013; Arakelyan 2016a; Arakelyan 2016b; Arakelyan 2017a; Arakelyan 2017b; Arakelyan 2017c; Arakelyan 2014), is implemented by the following way. After initial running of the wide-ranging anti-hail protection network, that is after initial starting of any of M anti-hail protection systems, that is after opening corresponding mechanical valve (23) of the fuel supplier (21) of each ant-hail protection system and switching on corresponding power supply (17) which begins feed corresponding control means (18), corresponding ignition means (19) and corresponding detector-alerter (5), each anti-hail protection system of the network and the whole anti-hail protection network continue their operation autonomous and automatically. The control means of any ant-hail protection system opens corresponding solenoid valve (24) and sets corresponding hail preventing sonic generator in a "waiting mode" of operation. Flow of the combustible gas through open corresponding solenoid valve and corresponding pressure regulator (pressure reducer) (25) comes from the fuel reservoir (20) to the input of closed fuel injector (26) of corresponding sonic generator. Up-directed antenna (6) of corresponding anti-hail protection system (3) observes the sky, receives continually signals

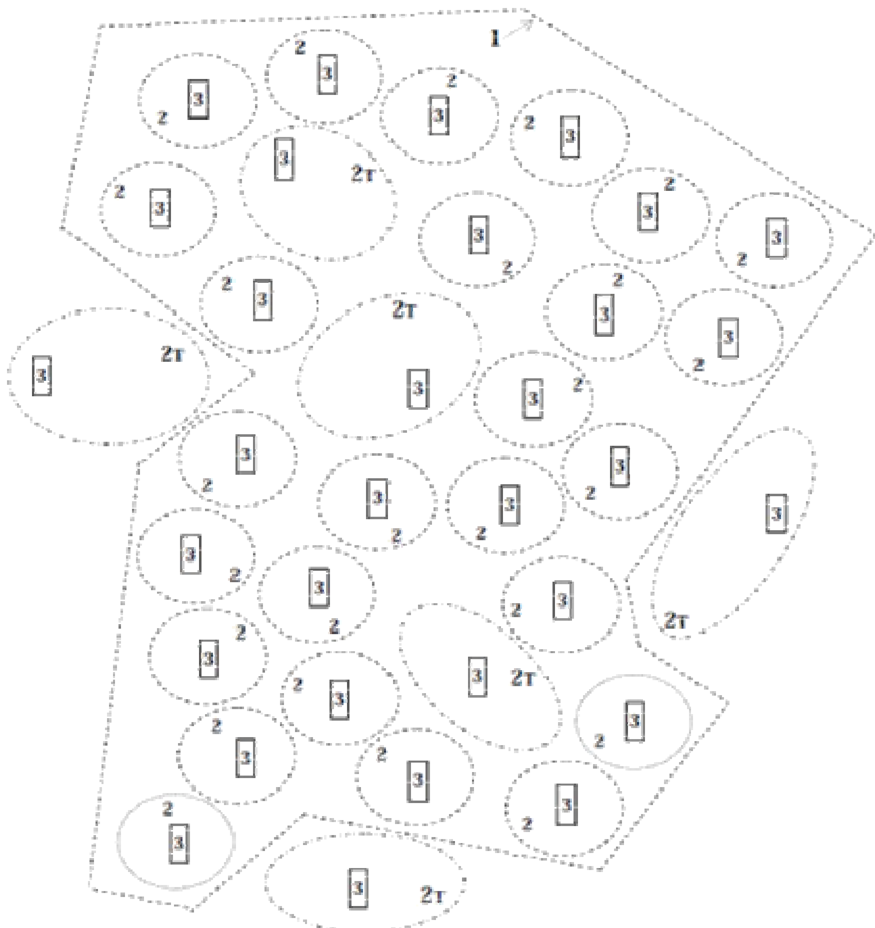

Figure 2 An outline of a version of wide-ranging anti-hail protection network 1 – a protected area, 2 – a protected site, 2T – a trapping area, 3 – an anti-hail protection system

of sky intrinsic microwave emission in radiofrequencies and transfers them to the input of corresponding radiometric receiver (7). The radiometric receiver processes received signals and outputs to the input of corresponding controlled compensation device (8) a signal corresponding to a sum of powers of signals of external emissions (from sky, surrounding and external interference) and internal noises. Controlled compensation device compensates a part of the incoming signals corresponding to clear air condition of sky observation and outputs remainder of the signals to the input of corresponding controlled multi-channel thresholder

(9). In controlled multi-channel thresholder the remainder of the signals is compared with N various threshold levels in N single level thresholders. Each single level thresholder outputs "1" signal to the corresponding input of corresponding warning device (10) if its input signal exceeds the respective threshold, and a "0" signal otherwise. Warning device processes jointly received "1" and "0" signals as a binary number in a binary code, creates a binary number code-signal corresponding to the recorded binary number, generates a warning code-signal in accordance with the binary number code-signal and outputs generated warning code-signal to the input of the corresponding transmitter (11) and to the input of the corresponding control means (18). The control means sets the operation mode of the corresponding sonic generator in accordance with the received warning code-signal, such as a "switching-on mode", a "waiting mode", an "operating mode" and a "turning-off mode", and sets operation parameters, such as power (the combustible fuel quantity) and duration of detonations, number (frequency) of detonations and a detonation window. The control means keeps corresponding sonic generator in a “waiting mode” of operation if received warning code-signal has the value “0”. When the control means receives a warning code-signal with the value “1” (corresponding to the “minimum” threshold level) or more it sets the “operating mode” of operation of corresponding sonic generator, sets operation parameters of the sonic generator in accordance with the value of the received warning code-signal, generates control signals and runs corresponding sonic generator.

When hail preventing sonic generator is operated, corresponding control means causes combustible fuel to be released through corresponding fuel injector (26) into corresponding combustion chamber (27) until sufficient combustible gas for a full explosion resulting in a significant shock wave is present in corresponding combustion chamber. Mixing of the combustible fuel (combustible gas) with air in combustion chamber is automatic and rapid. A short time after solenoid valve of the fuel injector is closed corresponding control means triggers spark gap coil of corresponding ignition means (19) to create a high voltage pulse resulting in a spark across the electrodes of corresponding igniter (20). As the gas in combustion chamber rapidly combusts, a shock wave results which is directed by corresponding conical barrel (30) having a large diameter upper end (32) and a small diameter lower end (31). The momentum of the combustion gases is directed upwardly, and once the combustion gases have fully expanded, the upward momentum of the gases causes a negative pressure to be created in combustion chamber which results in corresponding flaps of corresponding air inlet ports (33) being drawn open so that fresh air may be drawn from ambient through air inlet ports to fill corresponding combustion chamber. It is important to select a fuel and ignition system which can operate even when rain water (ice, snow) passes through conical barrel into corresponding combustion chamber. It is important to select the parameters of combustible fuel, combustion chamber volume to corresponding upper orifice (29) size of the neck (28) as well as corresponding conical barrel dimensions (including its length) in order that a good shock wave is generated and sufficient aspiration through corresponding air inlet ports takes place in order to bring in sufficient fresh air for the next combustion.

Simultaneously with setting the “operating mode” of operation corresponding transmitter (11) generates and transmits on the air an alert code-signal.

When control means receives the warning code-signal corresponding to the upper-range (maximum) value of the binary number $P=\sum_{k=1}^{N}2^{k-1}$ results when “1” signal is transferred to any of $k=1\div N$ inputs of the corresponding warning device the control means sets the “turning-off mode” of operation of the corresponding anti-hail protection system (3), turns off corresponding sonic generator and interrupts detonations that is stops fuel injection and ignition. The control means switches on corresponding sonic generator and resets the “waiting mode” of operation when it receives from corresponding warning device next (next in turn) signal with the value “0” only.

The number N is defined on the basis of technical capabilities and performance to change operation parameters of corresponding sonic generator, such as power and number of detonations, repetition frequency of detonations or a detonation window.

After initial starting of any of M anti-hail protection systems (3) of the wide-ranging anti-hail protection network and simultaneously with setting the “waiting mode” of operation of any of M sonic generators of the network corresponding receiver (12) begins listening watch (ether) for reception alert code-signals transmitted by transmitters (11) on the air from other sites of the anti-hail protected area of M sites. Controlled code comparator (13) of the corresponding receiver compares outputs of the corresponding receiver with L proper code-signals of the corresponding site and generates an alert signal if received alert code-signal coincides with any of L proper code-signals of the corresponding site, and a “0” signal otherwise. Output signals of the controlled code comparator come to the controlled terminal (input) of corresponding first controlled switcher (14) which connects together input/output terminals of the corresponding first controlled switcher if an alert signal comes to the controlled terminal of corresponding first controlled switcher, and keeps disconnected input/output terminals of corresponding first controlled switcher otherwise. The first controlled switcher with joined input/output terminals connects an output of corresponding controlled compensation device (8) with an input of corresponding controlled single-channel thresholder (15). The single-channel thresholder compares accumulated signals of the corresponding site with an “alert” threshold and an alerting code-signal is generated and is outputted to the corresponding output of single-channel thresholder if accumulated signal exceeds the “alert” threshold, and a “0” signal otherwise. The alerting code-signal passes through second controlled switcher (16) with connected input/output terminals and

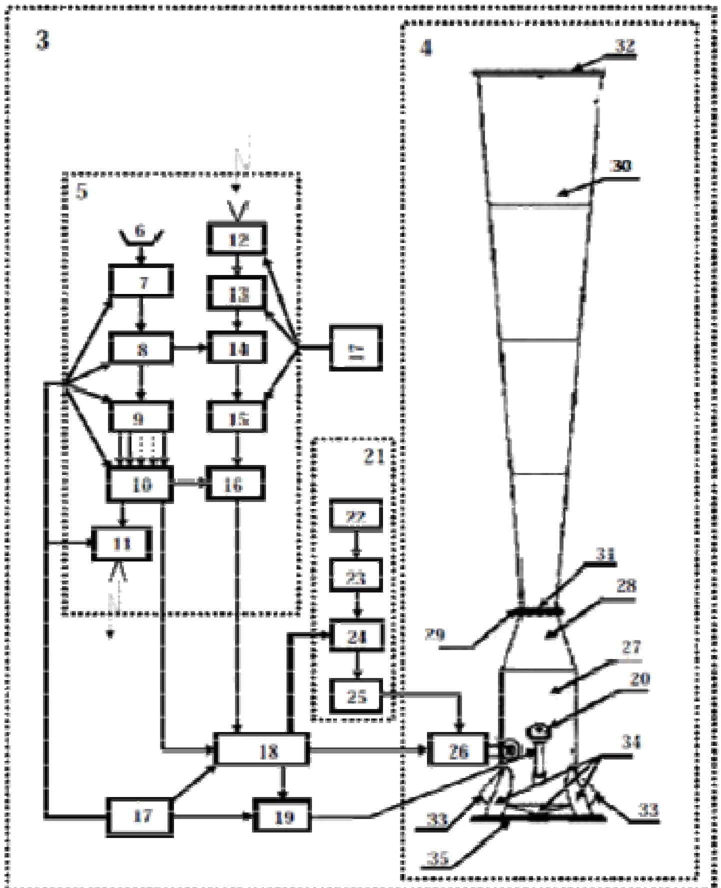

Figure 3 A block diagram of an anti-hail protection system

3 – an anti-hail protection system, 4 - a sonic generator, 5 - a detector-alerter, 6 – an antenna, 7 – a radiometric receiver, 8 – a compensation device, 9 – a multi-channel thresholder, 10 – a warning device, 11 – a transmitter, 12 – a receiver, 13 – a code comparator, 14 - the first controlled switcher, 15 – a single-channel thresholder, 16 – the second controlled switcher, 17 – a power supply, 18 – a controller, 19 – an ignition means, 20 – an igniter, 21 – a fuel supplier, 22 – a fuel reservoir, 23 – a mechanical valve, 24 – a solenoid valve, 25 – a pressure regulator, 26 – a fuel injector, 27 – a cylindrical combustion chamber, 28 – a neck, 29 – an upper orifice, 30 – a conical barrel, 31 – a small diameter lower end, 32 – a large diameter upper end, 33 – air inlet ports, 34 – feet, 35 – a concrete pad

from the output terminal of the second controlled switcher is transferred to the corresponding input of the corresponding control means which generates an alert control signal and starts up the corresponding sonic generator in accordance with the generated alert control signal at specified operational conditions of an "alert mode" of operation. The "alert mode" of operation of any sonic generator of any site of the protected area of M sites is turned-off simultaneously with interrupting the alert code-signal corresponding to that site, that is when a "0" signal comes from the output of corresponding controlled code comparator (13) to the controlled terminal of corresponding first controlled switcher (14), when the corresponding first controlled switcher disconnects its input/output terminals and by that way disconnects the output of corresponding controlled compensation device (8) from the input of the corresponding controlled single-channel thresholder (15). The "alert mode" of operation of any sonic generator is turned-off as well simultaneously with setting the "operating mode" or the "turning-off mode" of operation of corresponding sonic generator, when corresponding warning device of that site generates a warning code signal with a value "1" and more, up to upper-range value of P , when corresponding second controlled switcher disconnects its input/output terminals due to non-zero code-signals at its controlled terminal (input) and by that way disconnects the output of corresponding controlled single-channel thresholder from

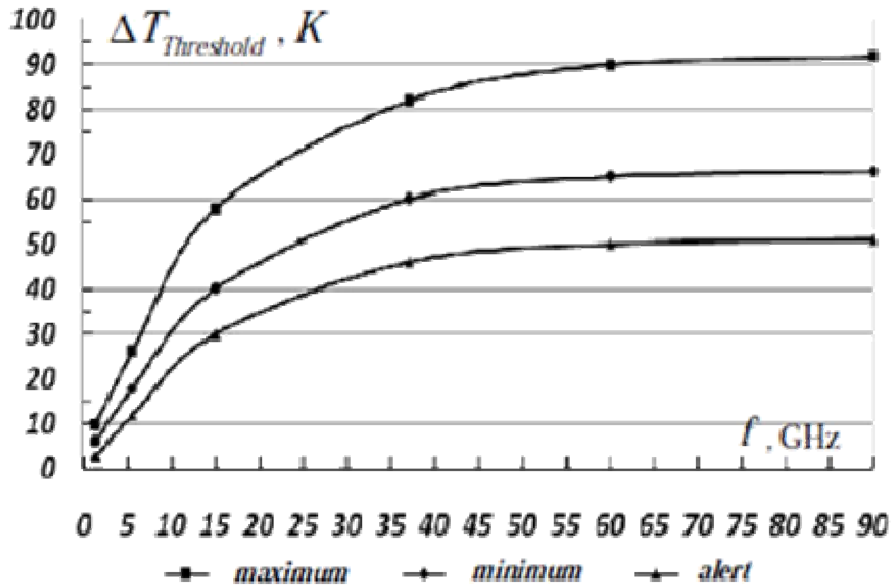

Figure 4 The curves of "maximum", "minimum" and "alert" thresholds frequency dependences

the corresponding input of corresponding control means. This is a way to enhance operation efficiency of the wide-ranging anti-hail protection network and to automate its exploitation in the autonomous mode.

Threshold levels of the controlled multi-channel thresholder (9) depend on an operation frequency (a frequency band) of the radiometric receiver (7). In **Figure 4** frequency dependences of "maximum", "minimum" and "alert" threshold levels are presented, where the curve of "minimum" threshold level corresponds to radiometric contrasts frequency dependence of cumulonimbus caused a rainfall with rare hail stones. "Minimum" values of radiometric contrasts of **Figure 4** were estimated and approximated from the results of multi-frequency and dual polarization (vertical and horizontal) radiometric measurements carried out under elevation angles 20^0 and 30^0 of sensing (Arakelyan et al., 2010; Grigoryan et al., 2010; Arakelyan et al., 2011; Arakelyan et al., 2012a; Arakelyan et al., 2012b), and from the known theory of passive microwave (radiometric) remote sensing. Theoretical approximations show that these curves are acceptable for elevation angles from the interval 0-300 as well.

"Maximum" threshold level's frequency dependence of **Figure 4** was estimated and approximated from the results of theoretical and experimental researches and corresponds to radiometric contrasts frequency dependence of cumulonimbus causing a hard hail storm which is impossible to prevent by existed technical means.

The "alert" threshold level of controlled single-channel thresholder (15) depends as well on operation frequency of corresponding radiometric receiver and in dependence on frequency band of operation it is about 3-15K smaller than corresponding "minimum threshold level. "Alert" threshold level's frequency dependence of **Figure 4** was estimated and approximated from the results of theoretical and experimental researches (Arakelyan et al., 2010; Grigoryan et al., 2010; Arakelyan et al., 2011; Arakelyan et al., 2012a; Arakelyan et al., 2012b).

Radiometric contrasts of **Figure 4** are given in Kelvin. Corresponding thresholds values in volts depend on structure and technical parameters of utilized radiometric receiver and may be defined from the results of theoretical estimations or from the results of experimental measurements and calibration. A preferable solution is to carry out preliminary calibration of radiometric receivers (7) in laboratory conditions or to carry out calibration of detector-alerters (5) in field conditions.

A threshold interval between "maximum" and "minimum" thresholds levels of Figure 4 can be divided in N-1 parts, where the dividing by 2 or 4 or 8 or 16, etc. parts that is when N=3 or 5 or 9 or 17 etc. is preferable. In dependence on application conditions of the present method and the network of wide-ranging anti-hail protection the values of "maximum, "minimum" and "alert" thresholds levels can be changed. When the values of "minimum" and "alert" thresholds levels are decreased then hail detection and false alarm probabilities are increased simultaneously. Taking into account low exploitation expenditures (low price of the combustible fuel) of the sonic generator it is possible to agree with high false alarm probability and to decrease minimal and alert thresholds levels of **Figure 4** by 2-10K in dependence on operation frequency of the corresponding radiometric receiver (7).

It is possible to save material resources and decrease exploitation expenditures of the sonic generator by decreasing the values of “maximum” threshold levels which will cause increasing of a target (hail storm) drop-out probability.

“Maximum”, “minimum” and “alert” thresholds levels can be corrected and can be changed individually during the exploitation of corresponding anti-hail protection system (3) by the corresponding controlled multi-channel and single-channel thresholders.

Since, the sonic generator’s impact area is limited in a size (500-600m in radius) the sonic generator usually is mounted near protected agricultural fields and lands. As for the detector-alerter (5), it can be mounted at any distance away from the corresponding sonic generator, but in that case it should be equipped with a separate power supply.

Method and Wide-Ranging Anti-Hail Protection Network at Advance Detection of Hail or Hail Generative Clouds

The above described network is an effective one when marginal sites (2) of the protected area (1) can be used as hail traps and as an alerter which will provide required time for in time running of the internal sites sonic generators that is 15-20 minutes before the hail storm arrival. However, such a situation with marginal sites is not common. Usually, the marginal sites are agricultural land too and for their highly effective protection it is necessary to get advance information about the impending hail storm. This problem can be solved by the following way.

The protected area (1) is additionally equipped with a remote sensing complex of K far-detection (far-ranging) systems (36) spatially distributed along the edges of the protected area, as shown in **Figure 5**. The remote sensing complex which serves the whole protected are of M sites is used for far-ranging detection of hail or hail generative clouds over an adjacent lands all around the protected area (1) at a horizontal distance 3-6km far from the edge (boundary) of the protected area (1) and at the altitude 3-5km, as well as for alerting the anti-hail protected systems of the protected sites of the protected area by transmitting on the air the alert code-signal on impending hail danger from a certain adjacent land of the protected area of M sites. The number K depends on the kind of spatial distribution of M sites and it can have a value from the interval [1 |M], e.g. if M sites are spatially distributed around a common center, a possible embodiment of which is separately presented in **Figure 5a**, then it will be possible to use only one (K=1) far detection system. If all M sites are located far apart (as shown in **Figure 5b**) then for entire serving the protected area of M sites it will be necessary to use K=M far detection systems. Depending on the terrain relief, any of the far detection systems can be installed individually, near or at a distance from the corresponding detector-alerter, inside or outside the corresponding protected area, etc.

In Figure 6 a detailed block diagram of the far detection system is presented. Any of K far detection systems comprises a far-ranging antenna (37) for receiving signals of intrinsic microwave emission of the sky corresponding the adjacent land, a far-ranging radiometric receiver (38) for measuring a power of the received signals and for estimating apparent temperature of the corresponding part of the sky, a far-ranging controlled compensation device (39), a far-ranging controlled single-channel thresholder (40) for far-ranging hail or hail generative clouds detection, a far-ranging warning device (41) for creation an alert code-signal on impending hail danger from the adjacent land, a far-ranging transmitter (42) for transmitting on the air the alert code-signal on impending hail danger from the adjacent land, a far-ranging power supply (43), and a scanner (44) for the far detection system’s revolving, rocking or setting the far detection system to the fixed direction of observation. The threshold level of the far-ranging controlled single-channel thresholder corresponds to the “minimum” threshold level of **Figure 4**. However, it can be fixed and changed individually during the exploitation of the far detection system.

Independence on the spatial distribution of M protected sites the far-ranging antenna under fixed elevation angle of observation can periodically revolving in azimuth plane to monitor currently the adjacent land sky all around the protection area of M sites, can periodically rocking within a specified azimuth sector to monitor currently the sky of the adjacent land’s selected sector, or can uninterrupted observe a specified part (point) of the sky of the adjacent land at fixed azimuth angle of observation. Spatial disposition of far detection systems and the elevation angle of observation of the far-ranging antenna are defined from the assumption that the footprint of the far-ranging antenna beam at the altitude of 3-5km should be located above the adjacent land located 3-6km far from the corresponding edge of the protected area (1).

Any of K far detection systems is set in its “working mode” of operation after clarification of the value of a

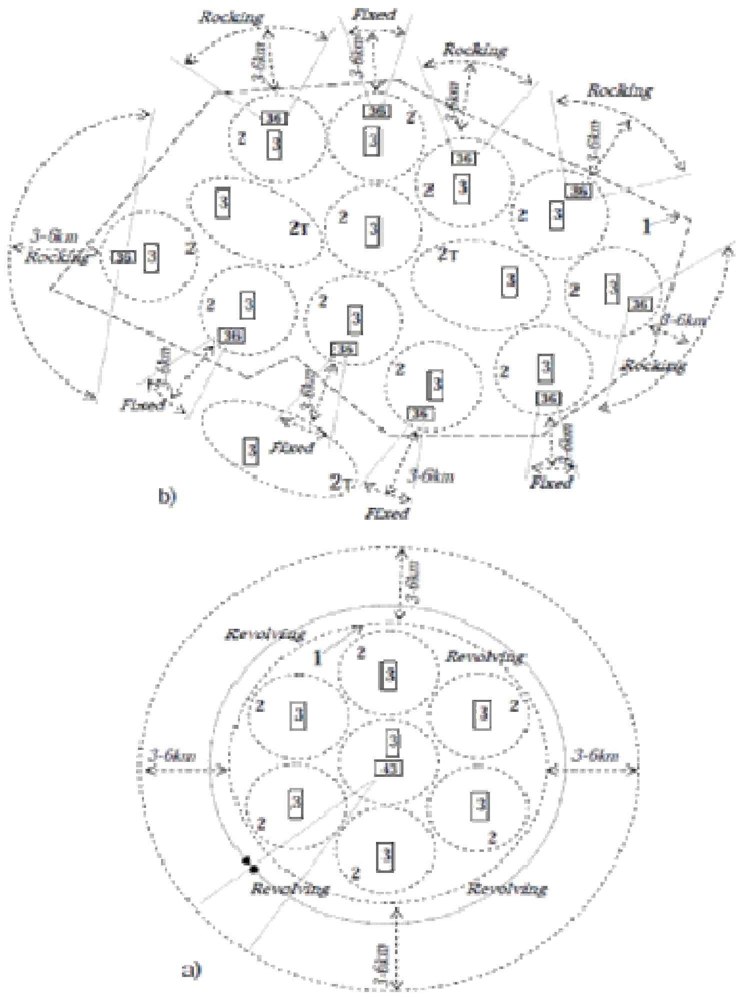

Figure 5 An outline of a version of wide-ranging anti-hail protection network with far-detection systems 1 – a protected area, 2 – a protected site, 2T – a trapping area, 3 – an anti-hail protection system, 36 – a far-range detector-alerter

compensation signal of the corresponding far-ranging controlled compensation device. K far detection systems is running simultaneously with the anti-hail protection systems of M sites of the protected area, and when any of K far detection systems detects hail or hail generative cloud at a certain azimuth angle of observation it creates and transmits on the air the alert code-signal on impending hail danger from the adjacent land of that azimuth direction which is received by receivers of the detector-alerters of nearby located protected sites. Received by any receiver the alert code-signal on impending hail danger from the adjacent land is compared in the corresponding controlled code comparator (13) with L proper code-signals of the corresponding site, one of which is coincided with the alert code-signal on gathering hail danger from the corresponding adjacent land are located under that azimuth direction, and if received alert code-signal on impending hail danger from the adjacent land coincides with one of L proper code-signals of the corresponding site then the "alert mode" of operation is set for the corresponding sonic generator and the whole network continued its autonomous and automatic operation by the way described in the section 3. In dependence on the far detection complex's spatial distribution the number L may reach up to 7-9.

Wide-Ranging Anti-Hail Protection at Hail Trapping Possibility

Sometimes an already formed hail cloud with an apparent temperature of the level "maximum" and higher

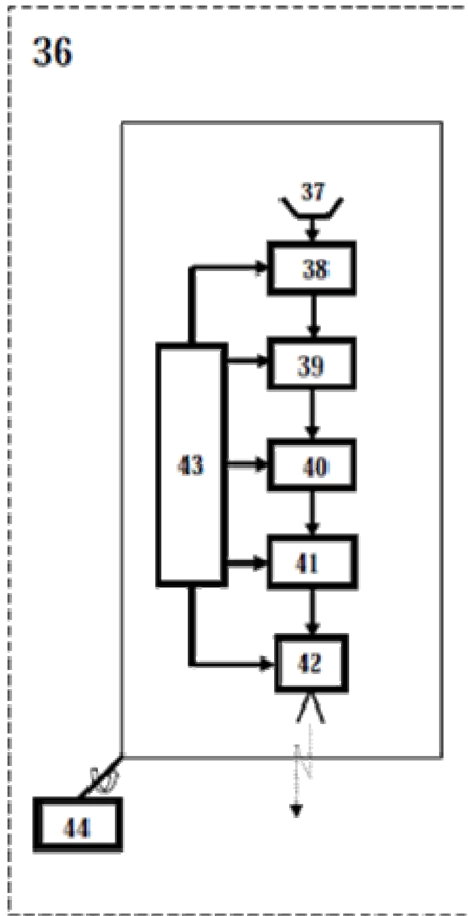

Figure 6 A block diagram of a far-range detector-alerter 36 – a far-range detector-alerter, 37 – a far–range antenna, 38 – a far-range radiometric receiver, 39 – a far-range compensation device, 40 – a single-channel thresholder, 41 – a far-range warning device, 42- a far-range transmitter, 43 – a far-range power supply, 44 – a scanner

approaches the edge of the protected area. At that case, when it is impossible to prevent hail by any existed technical means of prevention and suppression, the detector-alerters of the protected sites of that direction turn-off corresponding sonic generators and wait still the storm passes across the protected sites and the protected area, if it is lucky, of course. In such cases, it is better not to interfere (meddle) and allow the storm continue its movement. Passing across some protected sites, and maybe the entire protected area, the hail can fall out on such place where the damage can be much less. Since, if to effect on such a cloud then the hail even if and does not fall out on the functioning site, it will necessarily fall out on the neighboring sites located further along the direction of its movement.

In some regions in the surrounding or inside of the protected area one can find places where hail is allowed. These facts can be used to capture hail, to force hail to fall out on a territory where its damage can be relatively small. The method of early detection of hail clouds described above makes it possible to implement a completely autonomous and automatically functioning network of hail traps. Such a network can be completely implemented separately or in combination with the realized network of wide-ranging anti-hail protection, if there are places inside, near or far from the edge of the protected area where hail can fall out.

Outlines of versions of realization of autonomous and automatically functioning anti-hail protection network presented in **Figure 2 and Figure 5** include as well networks of trapping areas (2T) (hail traps) for hail capture.

When the far-range detector-alerter of any azimuth direction detects hail cloud or cumulonimbus coming from certain azimuth direction it warns detector-alerters of nearby located protected sites. Simultaneously it warns as well detector-alerters of the relevant trapping areas (2T) by transmitting on the air warning cods-signals about impending hail danger from the certain direction. In a case if the far-range detector-alerter detects a cloud of severe hail the detector-alerters of nearby located protected sites turn-off their sonic generators to skip impending hail cloud. In opposite, the detector-alerters of the relevant trapping areas set the "alert mode" of operation for their sonic generators and start up their sonic generators when the signals of sky brightness temperature (apparent temperatures) exceeds the "alert" threshold level. Detector-alerters of the involved trapping areas turn-off their sonic generators when the corresponding far-range detector-alerters interrupt transmitting warning code signals on impending hail danger and when the levels of the signals of sky intrinsic microwave emission measured by their detector-alerters fall below the "alert" thresholds levels.

So, by this way it is possible to implement fully autonomous and automatic trapping of hail and to enhance protection possibilities of the above described networks of wide-ranging anti-hail protection. This is also a particular case of a solution fully described in (Arakelyan 2013; Arakelyan 2016a; Arakelyan 2016b; Arakelyan 2017a; Arakelyan 2017b; Arakelyan 2017c; Arakelyan 2014).

CONCLUSION

Thus, microwave radiometers with usual sensitivities may be successfully used for hail detection, clouds classification and for early alerting on impending hail danger. By application of radiometric detector-alerters it is possible to create autonomous and automatically functioning networks for implementation of anti-hail protection of a wide area, as well as to prevent and to suppress hail by capturing hail by fully autonomous and automatically functioning network of spatially distributed hail traps.

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