A Radar Rainfall Contouring Device

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Abstract

This paper describes a device that indicates rainfall contour lines on radar scopes. For this purpose a range correcting signal r , a signal K_1r correcting atmospheric gases attenuation, a signal $K_2R^{\alpha}dr$ correcting for attenuation by intervening rain and predetermined B , β signals which show the raindrop characteristics, are compensated for the input signal Pr which is reflected from the rainfall. After the resultant signals are selected by a predetermined level which corresponds to a certain rainfall, the selected signals are presented on the PPI or the RHI scope as rainfall contours.

It is convenient to use Pr , r and B in the logarithmic unit for the circuit construction and the rainfall measurements will range over 60 dB.

A mechanism which carries out level selections is added to this device. As the mechanism is constructed so as to synchronize with the radar antenna rotation, the iso patterns are automatically photographed by a 35 mm camera. It is also possible to skip certain levels freely for effective photographing.

Comparisons between rain gages and this device show pretty good agreement, by correcting for the attenuation by intervening rain. But the attenuation will be one of the very important causes of the errors in case we use a 3.2 cm wavelength radar.

1. Introduction

There are two principal processes in the meteorological researches by radar, the qualitative study of shapes, movements and variations of rainfall echoes, and the quantitative study which concerns the radar reflectivity factor Z . Though these two types of study were seemed quite separate, they are now developing toward the unification of the two.

The rainfall contour presentation on PPI or RHI scope is one of the most effective methods for such measurements. Up to now two kinds of devices have been developed for this purpose. One is KODAIRA's method in which range correction and atmospheric gases attenuation correction are made for input signals, using a 10 cm wavelength radar, and a preselected level of the resultant signal is represented as a rainfall contour. The other is LHERMITTE's method in which no correction is made and a preselected level of the input signal is represented as an iso-echo contour.

Fig. 1. Front view of the radar rainfall contouring unit.

In the present device, as five corrections have been adopted for compensating input signal, it is possible to represent directly the preselected rainfall rates on the scope. Consequently, the errors due to the subjective observation by means of receiver gain change or the narrow dynamic range of the cathode ray tube will be overcome by such a contouring system.

The levels of the iso patterns presented on the scope are changed by synchronization with the antenna rotation, and the contours are photographed by an automatic 35 mm camera. After the films are developed, one sequence of the contour patterns is superposed on tracing paper for analysis.

Fig. 1 shows the front view of a Radar Rainfall Contouring Device.

It shows, starting from the lowest part :

(1) Power source	(2) Power regulator
(3) Log R calculator	(4) Level operator
(5) Level selector	

All the units have good power regulation and efficient negative feed back in the vacuum tube circuits so as to maintain high accuracy in quantitative measurement. So that few fluctuations are expected due to the power source change and the tube degenerations.

2. Log R calculator

The power Pr received by the radar from rainfall R at range r is given by

$$(1) \quad P_r = \frac{C \cdot B R^\beta}{r^2} \cdot 10^{-0.2K_1 r - 0.2K_2 \int_{r_0}^r R^\alpha dr},$$

where

- C : radar constant (4.04×10^{-8})
 B, β : meteorological statistical constants ($Z = BR^\beta$)
 K_1 : gases attenuation constant
 K_2, α : rain attenuation constants.

Equation (1) is rewritten logarithmically,

$$(2) \quad \log R = \frac{1}{\beta} \left\{ \log Pr + 2 \log r - \log B - \log C + 0.2K_1 r + 0.2K_2 \int_{r_0}^r R^\alpha dr \right\}.$$

The calculation of this equation is carried out by the Rainfall Contouring Device as shown in the block diagram of Fig. 2.

log r term

The range correction and the atmospheric gases attenuation correction are made from 2 km of normalized range r_0 to 100 km. Having an amplitude of $0.5V/dB$, the former amounts to 0 volt at 2 km and 17 volts at 100 km, and the value of the latter at 100 km is 1.35 volts, for K_1 equal to $0.014dB/km$.

log B term

The term log B is negative which corresponds to a constant amplitude in calculation, and as $\log \frac{B_0}{B}$ has to be always positive, it is necessary to satisfy the following relations;

$$(5) \quad \left\{ \begin{array}{ll} \log \frac{Pr_0 \cdot r_0^2}{CR_0^\beta} \cdot 10^{0.2K_1 r_0} - \log B > 0 \\ \text{(i)} \quad R_0 < 1 & \frac{Pr_0 \cdot r_0^2}{CR_0^{\beta_{\min}}} \cdot 10^{0.2K_1 r_0} > B_{\max} \\ \text{(ii)} \quad R_0 = 1 & \frac{Pr_0 \cdot r_0^2}{C} \cdot 10^{0.2K_1 r_0} > B_{\max} \\ \text{(iii)} \quad R_0 > 1 & \frac{Pr_0 \cdot r_0^2}{CR_0^{\beta_{\max}}} \cdot 10^{0.2K_1 r_0} > B_{\max} \end{array} \right.$$

From the raindrop observations, the available range of B is found to be from 70 to 700. The maximum value of B_0 in this unit is designed to be 700 which will satisfy the above condition (i), and when $B=70$, the actual voltage corresponding to B is 5 volts.

attenuation term

The attenuation constant for various wavelengths is shown in Table 1. The effect of attenuation on 3.2 cm wavelength radar could never be neglected for accurate measurements. So it is certainly necessary to adopt a compensation circuit, and this circuit needs an anti-log characteristic, as it is evident from equation (2).

	3.2 cm	5.7 cm	10 cm
K_2	0.007	0.0013	0.0003
α	1.3	1.1	1.0

The present device is equipped with a correcting circuit to compensate the attenuation for the rainfall from 0.3 mm/hr to 60 mm/hr, because the exponential characteristic ranges over 60 dB.

Log R signals to the level slicer are separately fed to the attenuation correcting circuit, in which, after they are converted into quantities proportional to $R^{1.3}$, they are integrated over the range r (2 km~100 km). The signals are again fed back to the adder input circuit.

This circuit needs a gate signal which is formed by the echo signal and range gating signal for calculation. If the signal from the rainfall area is attenuated to zero or in the neighbourhood of the threshold, negative errors at the time of observation will be unavoidable. Negative errors are also expected for rain over 60 mm/hr.

log R term

All the signals are set in proper values, they are superposed through the adder circuit, and the resultant signal is adjusted by the gain of the amplifier which corresponds to β . β is found to be ranged from 1.3 to 1.8 from observations, and so it is settled between 1 and 2 in this device.

The signal which has the equivalent value to the rainfall is amplified to 3 V per twice rainfall change at the following level slice circuit to keep good accuracy of a preselected rainfall. This value was decided on by both the expected range of rainfall and the linearity range of the vacuum tube amplifier.

Finally equation (4) is rewritten as follows, where $\log C = -7.39$, and the attenuation term is neglected for convenience' sake, supposing there is no attenuation in Pr or perfect compensation for the attenuation is carried out.

$$(6) \quad V_I = 10 \left\{ \log R - \frac{1}{\beta} (\log \frac{Pr_0 \cdot r_0^2}{CB_0} + 0.2K_1 r_0) \right\} = 10 \log R + \frac{39.5}{\beta}$$

3. Level operator

The rainfall signal from log R calculator which is shown in equation (6) is fed to the level slice circuit through a cathode follower. There are two level slicing methods: one is to use the cut-off characteristic of a diode, another is to use a multielectrode tube. It is found from the results of the experiments that even at cut-off condition, a part of the input signal, the high frequency components will be transported to the output circuit through the capacity between plate and cathode of the diode. So a pentode which has a very small $P-G_1$ capacity and a large transconductance G_m has been selected as the slicing tube.

The mechanism for the level slicing is shown in Fig. 3. At first, with no input signal, the plate current of the slicing tube is made zero by 'zero adjust' resistance, setting 'level select' switch on 'slice level.' Next, rainfall signals which are adjusted by the operational amplifier gain depending upon β of equation (2) are fed in the level slicing circuit. As the D.C. level of the signals will change with β of the second term of equation (6), the compensation for this has to be done by ' β ' adjust resistance in the switching mechanism.

In this mechanism, the voltage division will be as follows:

$$(7) \quad V = (10 \log R + 6) + \left(\frac{39.5}{\beta} - 6 \right).$$

The first term is checked by 'check R ' terminal, and the second term is by 'check β ' terminal. The level selection is carried out by changing the terminal of No. 1 stepping switch.

A pentode cut-off characteristic is used for the level slicing and the change of the characteristic from cut-off to conduction must be as steep as possible. The magnitude of the slope would easily cause errors of measurements though the following amplifier has enough gain to saturate the smallest signal coming from the slicing tube. In this device, a difference between the threshold and the perfect iso-lines tested by a signal generator on a radar scope, is not more than 1 dB, and it corresponds to 15% of the rainfall intensity which is selected for $\beta = 1.6$.

Fig. 3. Level slicing circuit and level selecting mechanism.

When a small rainfall selection is required on a scope and the level reaches to the threshold level of the input signal at greater distance, the pattern on the scope will suffer unseen. So gate signals are supplied to the grid circuit of the pentode through a gating tube, which makes it possible to avoid the smudge on the scope. But the analysis of a feasible rainfall area should be careful, because it seems that there is a weaker rainfall area by a stronger rainfall signal at greater distances.

The outputs of the level slicing tube, having amplified (40 *dB*) enough to be rectangular wave forms, are differentiated by an *R—C* circuit and are shaped the wave forms, and fed finally to the radar scope. The differentiated signals that show iso-contour lines have two different widths, because the sweep velocity on the scope will change by the radar range.

A wide line width ranges from 1.5microsec to 3microsec and a narrow line width ranges from 0.3microsec to 1.5microsec. These are both adjusted to the most suitable values on the scope. The narrow pulse is suitable for observations at the range of 20 km or smaller.

A part of the log R signal to the slicing tube is branched for displaying directly on the scope. This presentation is carried out by the zero gate signal method and is only for qualitative indication.

4. Level selector

Level selection is performed by the 12-point stepping switch, as shown in Fig. 3. The main functions are operated by three stepping switches.

- In No. 1. The selected levels are in turn from terminal 1, the input signal $\log Pr$ (video), the rainfall signal $\log R$, 0.3, 0.5, 1, 2, 4, 8, 16, 32, 64 and 128 mm/hr (iso). The selection is operated by manual or auto: the former is by a push button method and the latter synchronizes with the radar antenna.
- In No. 2. As terminals from 2 to 12 are each attached switches, it is possible to skip a certain level, which need not be indicated, by pushing the switch, except terminal 1 'video.' A relay RL 2 is necessary to prevent the breakdown of the terminal contacts caused by large current of the stepping switch relay RL 1.
- In No. 3. At terminal 1, -48 V information is transmitted to the radar stepping switch mechanism in case of setting 'level change' switch on 'auto.' By this method, it is possible to take one series of 35 mm photographs with any time interval (2 minutes in this case). That is, after finishing the photographing of one series within 2 minutes, the switching mechanism until 2 minutes elapses from the start of the series would be interrupted the photographing, and 2 minutes later, the operation is repeated again. In this terminal the video signal is not through this device.

At terminals 2~12, it is the mechanism for pattern change between iso and $\log R$. A 'diode' is in conduction from terminal 3~12 to terminal 2, so the change relay in the radar set is prepared always for displaying iso or $\log R$ patterns on the scope.

Next, a continuously variable rainfall selection part is added to measure any rainfall at a particular point.

Fig. 4. Calibration curve.

5. Overall characteristics

Many check terminals are prepared for calibration and the overall characteristics are calibrated on PPI scope by a signal generator. Fig. 4. shows an example of

Fig. 5. PPI photographs of a thunderstorm on 22 August 1958. 1700 JST, range markers are 10 km apart.

the calibration, where the solid lines are theoretical ($B=200$, $\beta=1.6$) and the points are measured. The hatched area is a calculated region. As the signal generator cannot operate over 60 km range, there will be extrapolated from nearer than 60 km.

Errors from theoretical curves are due to the poor *i.f.* logarithmic characteristic, because this *i.f.* amplifier has dual characteristics, log and linear. However, this logarithmic characteristic will be improved to the extent of 60 dB by minor techniques in near future.

6. Observations

Fig. 5 shows the iso patterns of a thunderstorm. Each level is at an interval of about 5 dB. The reflected power from the rainfall is always accompanied by fluctuations. If the rainfall signal is very weak or at a high level to show only the top portion of the echo signal, the fluctuating signals will go through the *R-C* differential circuit just as it is. Therefore the patterns are not strict iso contours, but only the outer side represent a true rainfall level.

In order to represent the fluctuating signals as an iso contour, these signals should be superimposed about 20 times to make a mean value of the fluctuated signals, and then the arranged signals will show a perfect iso contours on the scope. A device for this averaging has not yet been installed, but will be in near future.

Fig. 6. Comparisons between terrestrial rainfall (Points) and radar rainfall (Solid line). Rainfall in mm/hr. on 26 August 1958. T=Tokyo U=Urawa O=Omiya KO=Koshigaya I=Iwatsuki A=Ageo K=Kawadaya SH=Shiraoka SU=Sugito SA=Satte HI=Higashimatsuyama KA=Kazo KUM=Kumagaya G=Gyoda H=Hanyū KI=Kitakawabe KU=Kuzuwada.

Fig. 6 shows an example of comparisons made on 26 August 1958 between the observations of the rainfall gages and the contour device. An area enclosed by dotted lines is a raingage network, selected in a part of the eastern plains of Saitama Prefecture. There are settled 16 raingages and they can indicate only the point rainfall scattered in the radar iso patterns because the number of these gages is so small.

B , β is selected 200 and 1.6 respectively by reason of continuous rain, and the attenuation is not yet corrected in this observation.

In this case, however, we can not draw a definite conclusion for want of data on rain drop distributions. The contour lines and rain gage measurements are in respectable agreement in the short ranges, but in the greater distance, the returned signals are suffered from the attenuation of the intervening rain. By correcting the measured values from the values in Table 1, it will approach to the true values.

7. Conclusion

This device is suitable for calculating rainfalls over wide ranges by using the logarithmic characteristic element, and it is reliable for us by reason of its high accuracy and good stability.

As the normalized range is selected at 2 km, the measured rainfalls correspond to input powers on the range.

Though the attenuation correcting circuit is set in for the 3.2 cm wavelength radar, it will cause the measurement errors by spreading of the attenuation value due to the type of drop-size distribution and also by the reasons described in section 2. For these reasons, 5.7 cm and 10 cm wavelength radars will be more suitable for quantitative measurement. However, even with 3.2 cm attenuating wavelength radar, the combined use with this device will bring considerable developments in scope meteorology.

Usually rain contours have a tendency to become fuzzy and broad by echo fluctuations which are caused by the vector addition of the energy reflected from many rain particles. However, these phenomena would also be useful for some other studies, because the meteorological informations about turbulence are involved in these signals. Generally, averaging the fluctuating signals is very useful for the observations of iso contour patterns. An averaging device using magnetic drum is being produced.

In this study one sequence of iso patterns is photographed and they are superposed later. However, successively, if one sequence of iso patterns is taken on a single film, it will be more convenient because it will simplify the process of analysis. The color film method is now being planned.

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レーダー等雨量線指示装置

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この論文では PPI 又は RHI scope に等雨量線を描かせるための装置について述べる。この目的のために雨域からのレーダー反射波信号に距離の補正・大気減衰の補正・途中の降雨により受ける減衰の補正及び降雨の種類によつて反射波の影響を及ぼす2つの factor B , β の補正が同時に行われる。この補正された雨量信号は、装置であらかじめ選定された1つの雨量 level だけを scope に表示する。

雨量信号は対数特性であらわされているので雨量 level は2倍(約5 dB)ごとに選ぶのが適切であり、その level は 0.3, 0.5, 1, 2, 4, 8, 16, 32, 64 及び 128 mm/hr の10段階である。且つその対数特性の直線範囲は 60 dB に及ぶことが出来るので広い範囲の雨量測定が可能であり、電源の安定化、真空管回路の負選選に特に留意したので信頼すべき雨量の測定精度が得られる。

level の選定はレーダーアンテナと同期しているので自動的に一連の雨量 level の pattern が順次に 35 mm カメラに撮影される。しかし効果的な撮影を行うために不必要な雨量 level の飛越走査も可能である。

この装置を 3.2 cm 波レーダーに併用して雨量の観測を行つた。雨域からの反射波はその性質上非常に変動しているので、その iso pattern は必ずしも等雨量線でなく幅をもつたものであるがその外側は常に定められた雨量をしめしている。この等雨量線のもつ幅又は等雨量線間隔の大小は多くの気象的情報をあたえ得るだろう。しかし量的測定について考えればその変動をなくするために20回程度の信号の平均化が必要でありその装置は近い将来とりつけられる筈である。

地雨性降雨についての地上雨量との比較例が示めされるが良い対応性を示めしている。減衰の補正がほどこされているとは云えこの項の及ぼす測定誤差はもつとも大きいものの1つである。このため 5.7 cm 又は 10 cm 波レーダーは量的測定にもつと有用であるが 3.2 cm 波レーダーと云えどもこの装置の付加によつて scope meteorology に一層の貢献を及ぼすだろう。