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APPARATUS FOR THE REAL-TIME DISPLAY OF CORRELATION AND RELATIVE PHASE ANGLE DATA FROM THE ALBERTA HAIL STUDIES RADAR

BY

- A. HENDRY AND L. E. ALLAN -

OTTAWA

JANUARY 1973

ABSTRACT

The Alberta Hail Studies S-band radar, which has a polarization diversity antenna and a dual-channel receiving system, provides outputs from which the relative phase angle and the degree of correlation between the signals received on two orthogonal polarizations may be calculated. This report describes apparatus which accepts these radar outputs and generates from them quantized grey-scale levels for presentation of either the correlation or the relative phase information on a PPI-type display in real time. Circuit details and PPI photographs taken during a hailstorm are included.

APPARATUS FOR THE REAL-TIME DISPLAY OF CORRELATION AND RELATIVE PHASE ANGLE DATA FROM THE ALBERTA HAIL STUDIES RADAR

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INTRODUCTION

The S-band Hail Studies radar situated at Penhold, Alberta, includes a polarization diversity system comprising a dual-polarization antenna[1], and a dual-channel receiving system. One receiver channel responds to radar echoes having the same polarization as that transmitted, while the other responds to the orthogonal polarization. With such a system, if for example, vertical linearly polarized signals are transmitted, the orthogonal channel responds to horizontally polarized waves. If, however, the transmitted polarization is circular, say of right-hand sense, the orthogonal polarization is also circular but of the opposite sense, i. e. , left-hand.

For the study of radar back-scattering from precipitation, circular polarization is extremely useful. Normally, the Alberta Hail Studies radar is operated with circular polarization. When precipitation particles which tend to have nearly circular symmetry about line-of-sight are illuminated with circularly polarized waves of a given sense, the reflected energy is mainly circularly polarized in the opposite sense, with a smaller component of the same sense. The magnitude of the same-sense component depends upon the asymmetry of the scattering particles, and also, for the shorter wavelengths, upon the propagation conditions along the path between the radar and the observation cell. In addition, imperfections in the antenna and receiving apparatus can give rise to a same-sense component. Ideally, for perfectly spherical targets, the same-sense component will be zero in the absence of propagation effects.

Much may be learned about the properties of precipitation by measurement of the ratio of the received power in the same-sense component to that in the orthogonal component. This ratio, called the cancellation ratio, is a measure of the mean shape of the particles, provided that propagation effects are negligible and the particles are small compared to the wavelength.

In addition to the cancellation ratio, a circularly-polarized radar having a dual-channel receiving system provides the possibility of measuring two other physical quantities; namely, the degree of correlation between the signals in the two receivers, and (if a significant degree of correlation exists) their relative phase angle. From these two quantities, considerable information about the scattering medium may be obtained [2,3,4]. Furthermore, by examining the ways in which these quantities vary throughout a storm, propagation effects can be deduced.

The degree of correlation between the received signals is a measure of the extent to which the non-symmetric scattering particles have a preferred alignment, e. g. , have their axes of symmetry at a common angle α with respect to the vertical. Assemblies of particles having perfect alignment would produce completely correlated radar returns in the two receivers, while for randomly oriented assemblies, the returns are uncorrelated.

The relative phase angle of the two returns is, in the absence of propagation effects, determined by the mean orientation angle of the scattering particles and by any differential phase shift occurring upon reflection at the particle. The latter effect is believed to be small at S-band for raindrops. Under circumstances where the relative phase and correlation are determined by the scattering properties of the precipitation particles, different forms of precipitation, e. g. , rain, snow, hail, etc. , may be distinguishable on the basis of these parameters. In order to test this hypothesis, the apparatus described herein was constructed and installed at the Alberta Hail Studies site. Although these parameters have been available for the past four years from four-track chart recorder outputs, these data are severely limited in scope. They pertain only to a single observation cell which may be positioned by the operator at any chosen location in the storm area. Moreover, the chart recorder system does not provide a real-time output of correlation and relative phase; consequently, these results are not usually available until after the end of the storm.

The apparatus described in this report provides for the real-time display of either correlation or relative phase angle throughout the area covered by the radar.

A system using a standard PPI-type display was chosen as the most appropriate way of presenting the data. Direct comparison of such a display with the normal PPI may easily be made. Furthermore, photography of the display may be incorporated into the observational program, so that post-observation comparisons of the photographs with hail reports from area farmers are possible.

Description of Apparatus

The apparatus was designed in such a way that the polarization diversity receiver outputs, which normally drive a four-track chart recorder system with range and azimuth gating, could alternatively be used as signal sources for the phase and correlation display. Figure 1 shows, in simplified form, the receiving system of the radar.

As indicated, there are outputs from four phase detectors, each of which is supplied with a reference signal of constant amplitude (+6 dBm). Phase detectors 1 and 2 are also driven by linear amplifiers 1 and 2, respectively, with signals proportional to the radar returns available from Ports 1 and 2 of the antenna. Thus, phase detectors 1 and 2 operate as linear detectors, and provide video outputs. As described earlier, when circular polarization is used, Port 2 supplies a larger signal than does Port 1, and is designated the "main channel", while Port 1 is the orthogonal channel or "cancellation channel".

Phase detectors A and B provide the two outputs which contain the phase and correlation information. As shown in Figure 1, not only the reference inputs to these detectors are limited, but also the "signal" inputs (obtained from receiver No. 1 at a lower level (-2 dBm). Furthermore, it will be noted that an electrical phase shift $\pi/2$ is added to one of the inputs to phase detector A. As a result, the outputs designated V_A and V_B in Figure 1 are quadrature components of a

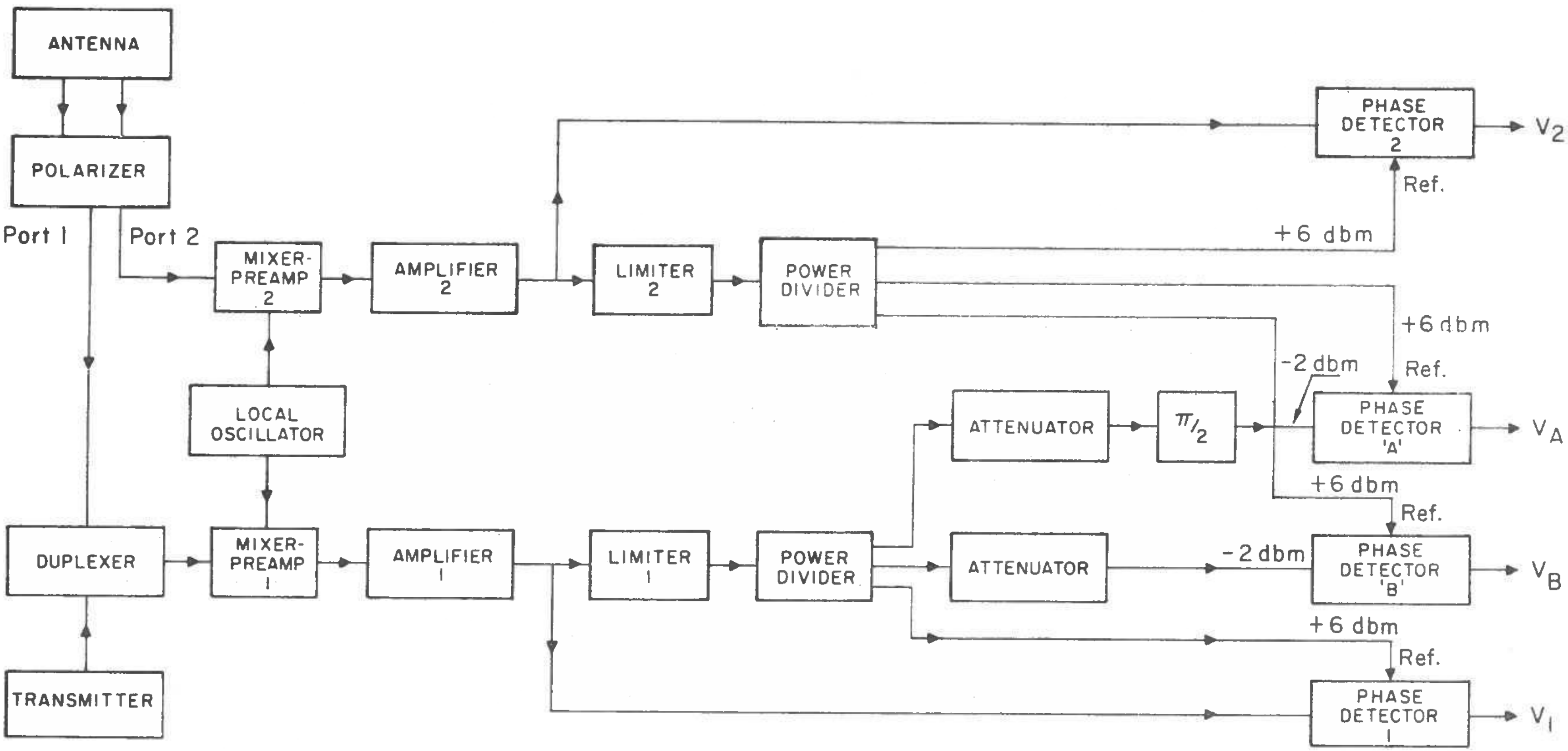


Fig. 1

Simplified block diagram of dual-channel receiving system of Alberta Hail Studies radar phasor of fixed amplitude (because the phase detector inputs are limited) whose phase angle is related directly to the phase difference between the signals delivered at Ports 1 and 2 of the antenna. For completely uncorrelated signals, V_A and V_B will be noise-like, with average value zero, and the phase angle will be random. As the degree of correlation increases, V_A and V_B will tend to steady values, becoming noise-free when correlation is complete. Plate I shows the nature of signals V_A and V_B for various conditions.

For partially correlated signals, the physically significant quantities are the time averages of V_A and V_B, designated $\bar{V}_A$ and $\bar{V}_B$. As noted earlier, for uncorrelated signals, $\bar{V}_A$ and $\bar{V}_B$ are zero, while for partially correlated signals, the uncorrelated component averages to zero, leaving the correlated component to contribute to $\bar{V}_A$ and $\bar{V}_B$. Hence, the display problem is to provide for presentation of the voltage $\sqrt{\bar{V}_A^2 + \bar{V}_B^2}$ and

$\theta = \arctan\frac{\bar{V}_B}{\bar{V}_A}$, where $\bar{V}_A$ and $\bar{V}_B$ are time-varying quantities, the variation being at video rates.

For quantitative analysis, the main return and the cancellation signals obtained with the Alberta Hail Studies radar are quantized before presentation on their respective PPI displays. This is accomplished by generating discrete voltage levels which produce corresponding brightness levels (grey-scale levels) on the PPI's. Quantization in a similar manner was chosen for the display of correlation and phase information produced by the apparatus described in this report. Five active grey-scale levels are used. From past experience it has been found that five is the maximum number of levels easily distinguishable on pictures taken from the tube of the display. A sixth or off level, which does not result in illumination of the tube, is used whenever the correlation drops below a pre-set threshold. On the basis of preliminary results obtained with the chart recorder system, it was decided that the display of a total range of 180° in phase angle would be sufficient at any one time, however, provision should be made for changing the limits of the displayed range. With five active levels, the phase angle is thus quantized into 36° sectors. (Actually, ten sectors are possible and the display can be set for 0° - 180°, 36° - 215°, 72° - 252°, etc., as appropriate for the storm conditions prevailing at the time of observation.) To further simplify the system, it was decided that either phase or correlation information would be displayed, but not both simultaneously. This was done principally to limit the display requirement to one additional PPI.

A calibration grey-scale is used to give reference levels for the operator and on the photographs taken from the display. The range and azimuth of the grey-scale are adjustable so they do not block out part of the storm of interest, but may be positioned sufficiently close so as to make comparison with the storm data easy.

Figure 2 shows the correlation/phase angle circuitry which has been devised. (The circuitry for quantization and grey-scale generation is described later.) The operation of this circuitry may be described as follows: signals V_A and V_B are supplied by the existing phase detectors A and B which form part of the dual-channel receiving system. Averaging or smoothing of these two signals takes place at video frequency by shunt capacitors. These capacitors, in parallel with the line impedance,

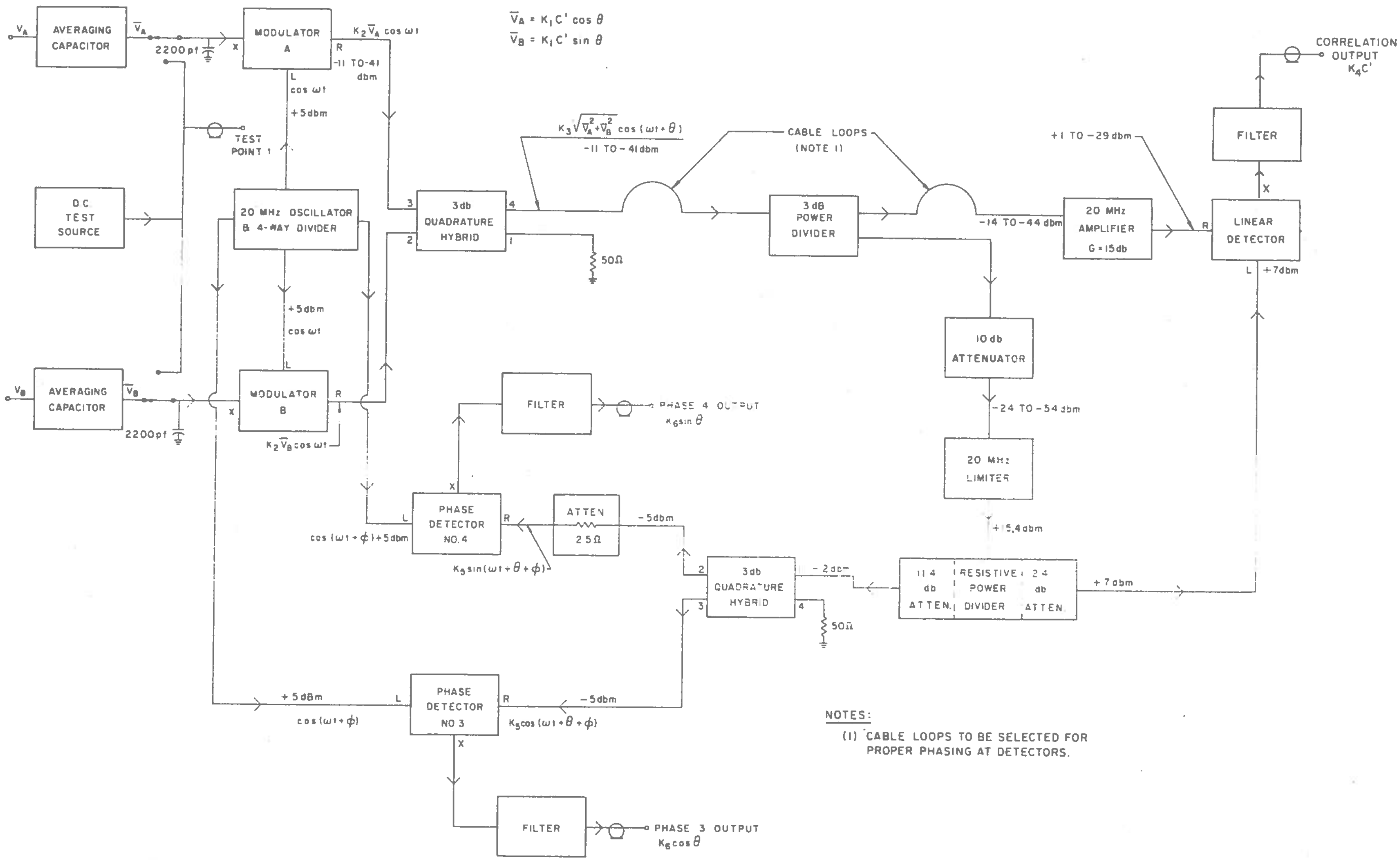


Fig. 2.

Block diagram of correlation/phase circuitry for Alberta Hail Studies radar provide a time constant which is normally 6 μ seconds. A selector switch enables the operator to select either 2.5 or 13 μ seconds, if a shorter or longer time constant is desired. The normal time constant is approximately 3.5 times the radar pulse length of 1.75 μseconds

After averaging has taken place, the voltages $\bar{V}_A$ and $\bar{V}_B$ are re-modulated onto a 20 MHz carrier. The smoothed voltages may be written as follows:

$$\bar{V}_A = K_1 C' \cos\theta \qquad (1)$$

$$\bar{V}_B = K_1 C' \sin\theta \qquad (2)$$

In (1) and (2), K_1 is a gain constant, introduced for convenience, with the assumption made that the two phase detectors are made identical by appropriate settings of gain controls, etc. C' is related to the correlation, and varies from zero to unity. θ is the relative phase angle of the L and R inputs to phase detector A. Both C' and θ may vary rapidly, i.e., at video frequency rates.

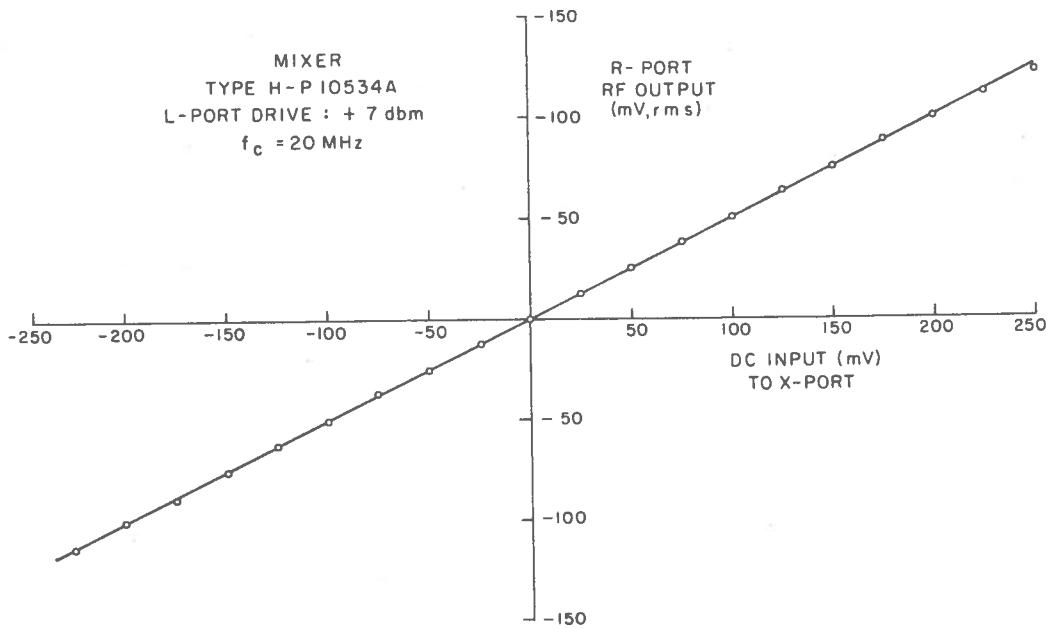


Fig. 3.

Modulation characteristic of double-balanced mixer at 20 MHz

Modulators A and B are double-balanced mixers operated with carrier inputs of +5 dBm. The modulation characteristics of these devices exhibit good linearity over a 30 dB dynamic range (see Fig. 3). The outputs of modulators A and B are combined in a 3 dB quadrature hybrid to produce the composite signal

$$K_3\sqrt{\bar{V}_A^2 + \bar{V}_B^2}\ \cos(\omega t + \theta) = K_3K_1C'\ \cos(\omega t + \theta)$$

which is fed to a 3 dB power divider. One output of this divider is then amplified, and applied to a double-balanced mixer used as a linear detector. A filter following the detector is used to provide proper termination at the sum frequency (40 MHz) while simultaneously preventing any of the sum frequency components from appearing at the output.

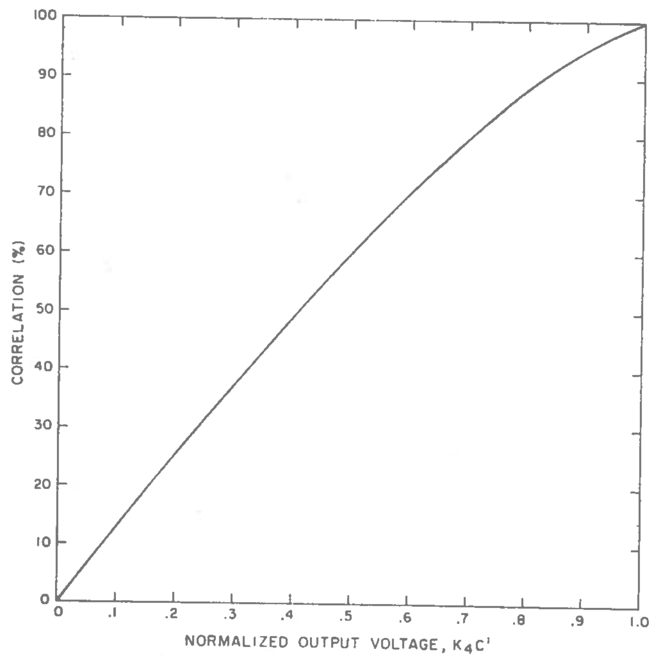


Fig. 4.

Relationship of correlation to normalized output voltage, K_4C' (noise-free case)

The relationship of correlation to C' for the Alberta Hail Studies radar is shown in Fig. 4. (This relationship becomes invalid for weak signals close to receiver noise level). In the figure, correlation varying from zero (uncorrelated) to unity is plotted vs the normalized value of K_4C'. Since only quantized levels of correlation are needed for the display, the non-linearity is unimportant. Electronic circuitry, to be described below, automatically selects the appropriate quantization level depending upon the voltage K_4C'.

The second output of the power divider provides a signal from which angle information may be obtained. In the absence of sufficiently fast four-quadrant analog divider circuitry, the scheme chosen is that illustrated. It is first necessary to remove amplitude fluctuations; this is accomplished by passing the signal through a constant-phase limiter. The electrical performance of this limiter is indicated in Fig. 5, which shows the phase variation of the limiter output as a function of input amplitude. The limiter output is used not only for phase angle determination, but also, as indicated, as the reference signal for the linear detector. In order to obtain proper phasing at the detector, a cable loop is used between the 3 dB power divider and the 20 MHz amplifier.

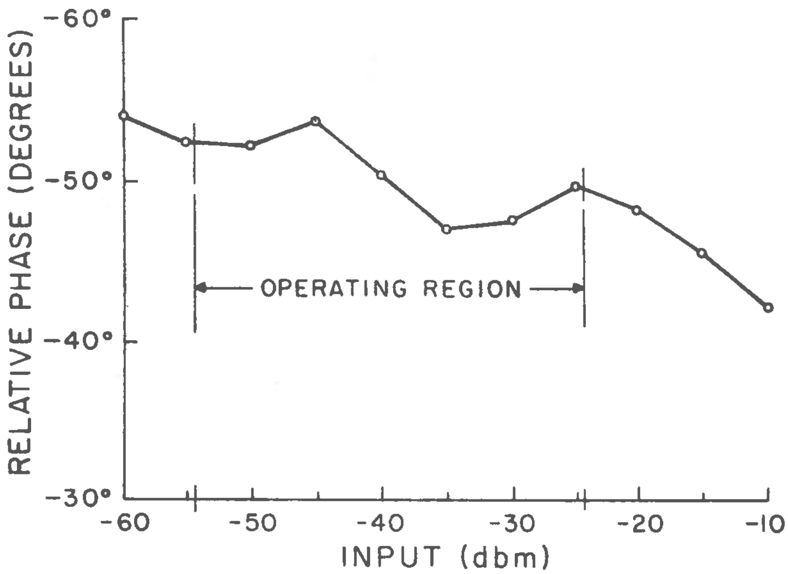


Fig. 5
Phase characteristic of 20 MHz limiter.
Variation over the operating range is $\pm$ 3.5°.

After attenuation, the limiter output, which now contains only phase information, is fed to another 3 dB quadrature hybrid, whose outputs in turn are applied to phase detectors 3 and 4. The reference inputs to the latter devices are obtained from the original 20 MHz oscillator output. Finally, after filtering, outputs $K_6 \cos \theta$ and $K_6 \sin \theta$ are obtained. The net result of the re-modulation and limiting, thus, is to provide for separation of the phase and correlation information.

The transfer characteristic of the correlation portion is shown in Fig. 6.

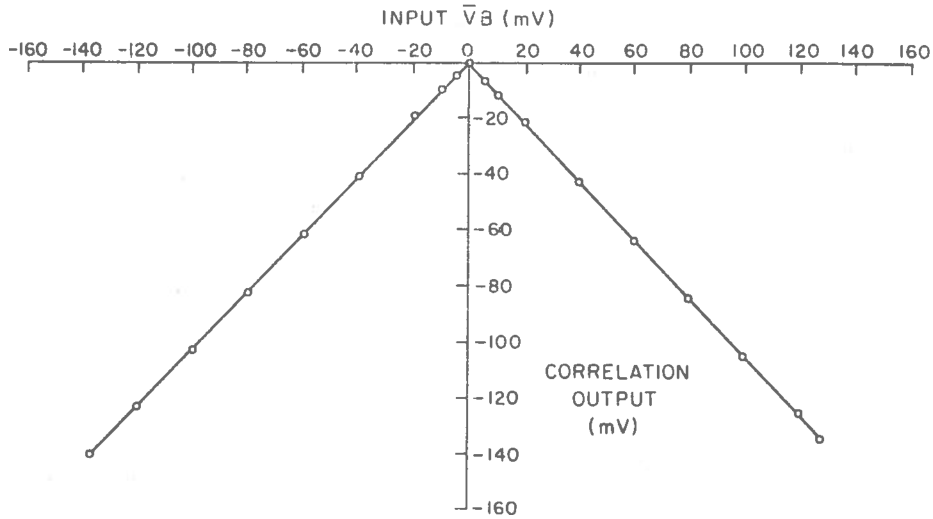


Fig. 6.

Transfer characteristic of circuitry. Bipolar dc input produces unipolar (negative) dc output with good linearity and symmetry

Phase Quantization

The phase information voltage, $K_6 \sin\theta$, is first amplified by 20 dB in amplifier A_1 (Fig. 7). The signal is then fed into five differential voltage comparators, $B_{1,2,3,4,5}$. If a sine wave of fixed amplitude is fed into the circuit the bias on the comparators is set so that they switch in 36° steps as shown in Fig. 8. The outputs of the comparators are then fed into logic circuit inverters $C_{1,2,3,4,5}$ and gates $D_{1,2,3,4}$ (Fig. 7). C_5 has an output when the voltage is too low to switch any of the comparators on. As the input voltage increases from -V, comparator B_1 switches on, turning C_5 off and D_1 on. As the input voltage increases further, comparator B_2 will also switch on. This will give an output from D_2 but will turn off D_1 with the signal from B_2 through the inverter C_3 so that only D_2 provides an output. As the input voltage increases further, B_3 switches, turning D_3 on and turning D_2 off. This process continues as the input voltage increases until only C_4 has an output signal.

The outputs from gates $D_{1,2,3,4}$ switch twice during each cycle of an input sine wave resulting in an ambiguity. To separate these switching points, the second phase voltage ($K_6 \cos\theta$) is used. This signal is first amplified by 20 dB (A_2 of Fig. 7),

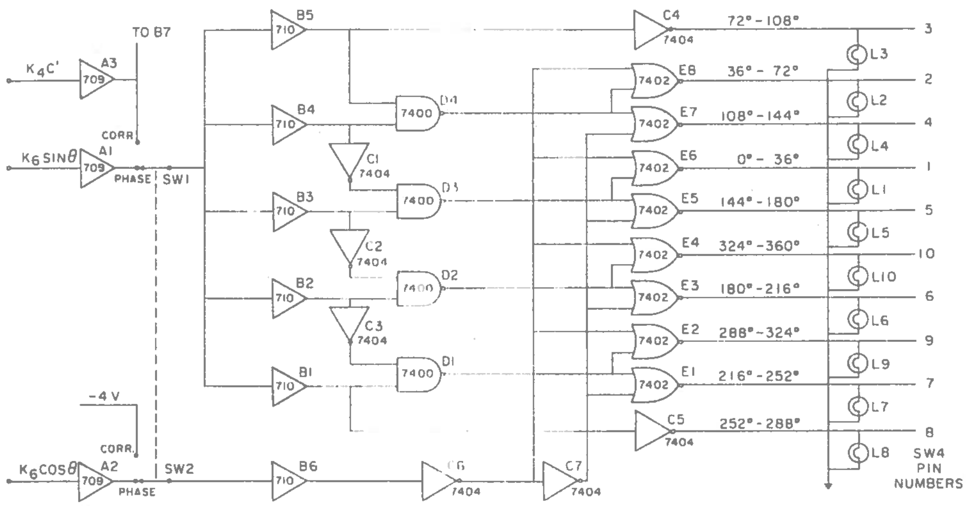


Fig. 7
Phase and correlation data converter

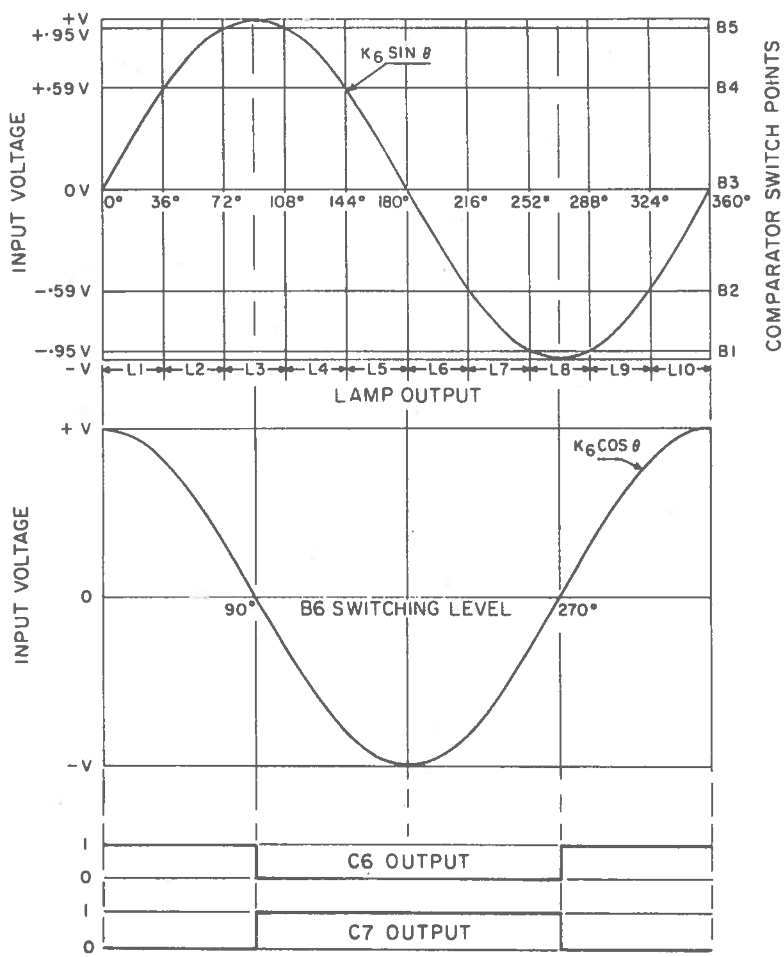


Fig. 8
Voltage switching points for phase display

then fed to a voltage comparator (B_6) which switches states at the zero voltage crossover. The signal is then fed to two inverters, $C_{6,7}$ which provide reference signals to gates $E_{1,2,3,4,5,6,7,8}$. The output from $C_{4,5}$ and $E_{1,2,3,4,5,6,7,8}$ will each produce one signal every 360° of the sine wave. These signals control ten lamps which are used to calibrate the system. The bias voltages on the comparators are adjusted to switch the lamps at 36° intervals.

The ten outputs from $E_{1,2,3,4,5,6,7,8}$ and $C_{6,7}$ are also fed to a five-wafer, ten-position switch (SW4, Fig. 9). This switch is wired to give any five sequential outputs depending on the operator's choice (see Table 1).

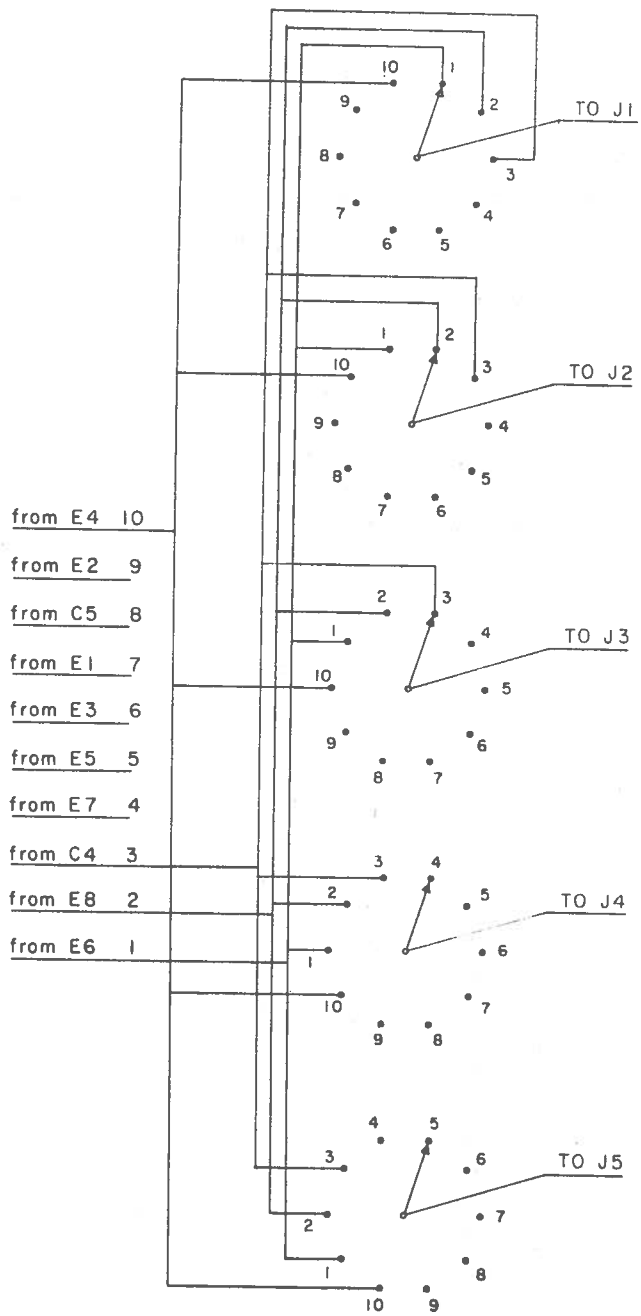


Fig. 9

Circuit schematic of phase angle selector switch, SW4.

Table 1.

Phase readout of SW4, degrees

Switch Position	Grey-Scale Level 1	2	3	4	5
1	0 - 36	36 - 72	72 - 108	108 - 144	144 - 180
2	36 - 72	72 - 108	108 - 144	144 - 180	180 - 216
3	72 - 108	108 - 144	144 - 180	180 - 216	216 - 252
4	108 - 144	144 - 180	180 - 216	216 - 252	252 - 288
5	144 - 180	180 - 216	216 - 252	252 - 288	288 - 324
6	180 - 216	216 - 252	252 - 288	288 - 324	324 - 0
7	216 - 252	252 - 288	288 - 324	324 - 0	0 - 36
8	252 - 288	288 - 324	324 - 0	0 - 36	36 - 72
9	288 - 324	324 - 0	0 - 36	36 - 72	72 - 108
10	324 - 0	0 - 36	36 - 72	72 - 108	108 - 144

Correlation Quantization

To display the correlation, selector switch SW1 (see Fig. 7) is turned to the correlation position, thus applying the correlation signal to comparators $B_{1,2,3,4,5}$ through B_6 and at the same time changing the set of bias voltages on the comparators. The correlation voltage is amplified by 15 dB in amplifier A_8 before being fed to the five voltage comparators, $B_{1,2,3,4,5}$. These comparators are biased to switch at pre-determined voltages between zero and one hundred percent correlation as shown in Fig. 10. The logic circuits $C_{1,2,3}$ and $D_{1,2,3,4}$ work the same as for the phase data. The gates $E_{1,2,3,4,5,6,7,8}$ are also controlled by the negative voltage applied to the input of comparator B_6. Consequently, outputs are only possible from $E_{1,3,5,7}$ and C_4 when correlation is being displayed. The five-wafer, ten-position switch (SW4, Fig. 9) is turned to position three to give the outputs in the right sequence. The remainder of the circuit works the same as in the phase display.

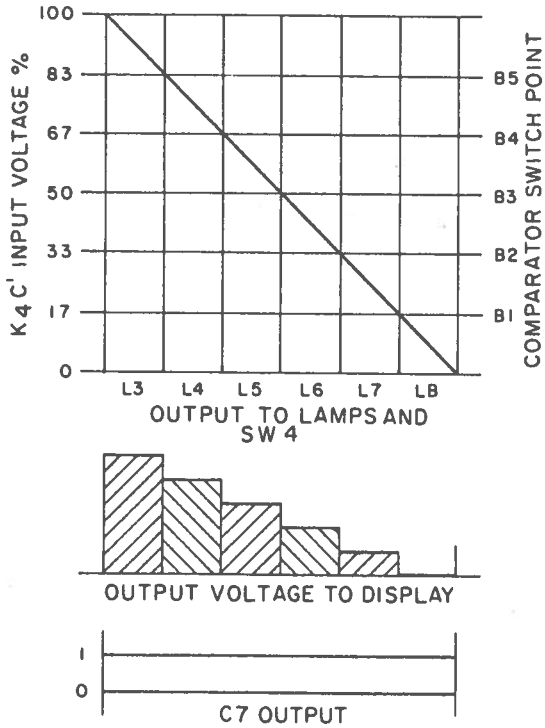


Fig. 10

Voltage switching points for correlation display

Grey-scale Calibration Generator

The grey-scale calibration generator is made up of eight monostable multivibrators $F_{1,2,3,4,5,6,7,8}$ each of which has a time delay as indicated in Fig. 11. Each time the antenna rotates past a pre-selected azimuth, a relay completes a circuit for a short time generating a Heading Marker (see Fig. 12). When this relay opens, multivibrator F_1 is triggered. A pulse, with adjustable delay of up to eight seconds is generated by F_1. This pulse triggers the chain of five series multivibrators $F_{2,3,4,5,6}$, each of which gives an output for 130 Milliseconds then triggers the next one in the series. These five outputs are fed to the five positive nand gates $G_{1,2,3,4,5}$. Each of the five grey-scale levels is on for 130 milliseconds, the delay provided by F_1 permitting the start of the grey-scale to be positioned at any chosen azimuth.

It is desirable to have the grey-scale calibration on for only a short range interval so that not too much storm data will be blocked out. The grey-scale calibration is therefore gated in range as follows: at the beginning of each range scan a positive trigger voltage actuates multivibrator F_7. Depending on the range at which the grey-scale is desired, F_7 triggers F_8 after 640 to 1000 μseconds F_8 gives an output for 100 μseconds each range scan. This output is fed to gates $G_{1,2,3,4,5}$. When gates $G_{1,2,3,4,5}$ receive a logical one from the azimuth and range delays, they put out a logical zero. This zero is fed to the output driver nand gates $K_{1,2,3,4,5}$. Each driver gate gives a logical one output. A fraction of the voltage chosen to suit the grey level desired is tapped off by a potentiometer and fed through a diode to the output. The diodes (shown in Fig. 11) keep the circuits from loading each other and provide higher output resistance.

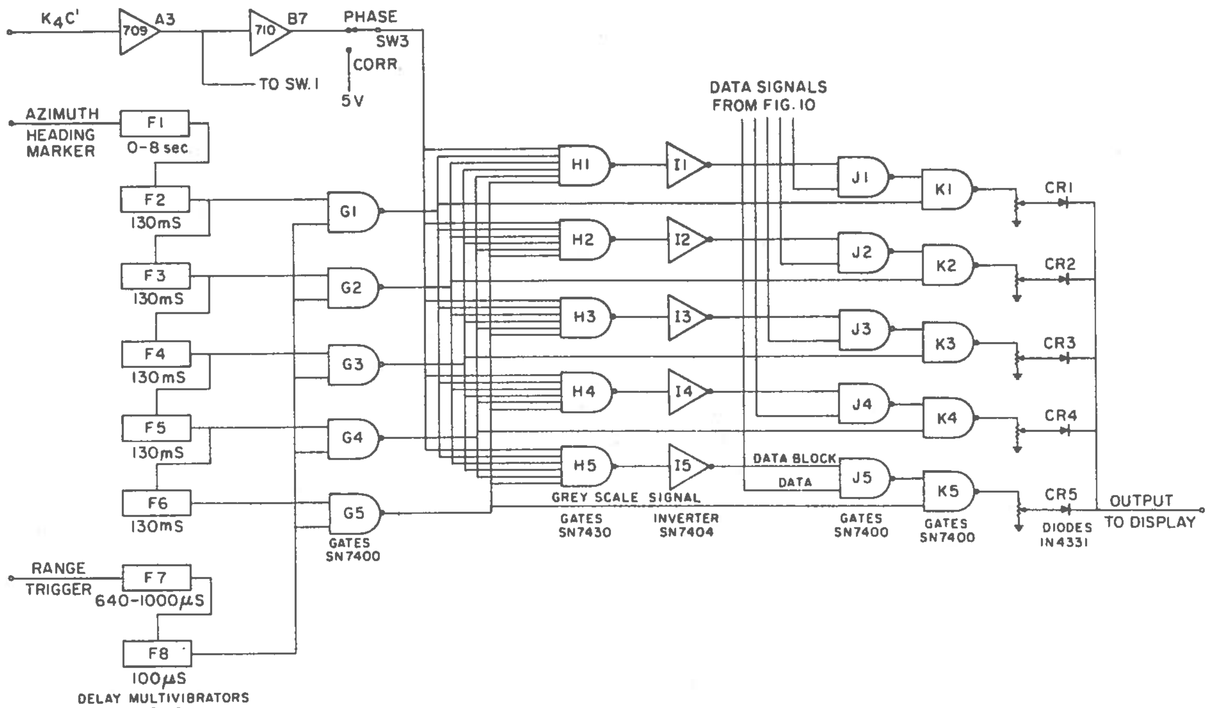


Fig. 11

Grey-scale generator and output circuits

Data Display

Under two conditions the data signals must be blocked off from the display. First, the grey-scale calibration must be free from data signals to be usable. Second, during the phase mode of operation, if the signals approach noise level, the phase information becomes random and the display would show all phases. To block the signals during these two conditions, a zero level signal is fed into the inputs of gates $H_{1,2,3,4,5}$, Fig. 11. For the grey-scale calibration period the zero comes from the output of gates $G_{1,2,3,4,5}$. For the low signal level case, the voltage K_4C' is amplified by 15 dB (A_3 of Fig. 11), and fed to a threshold limiter B_7. The limiter is set to give a zero out when the correlation voltage K_4C' is below a pre-determined level. This zero is fed to the inputs of gates $H_{1,2,3,4,5}$ which give one-level outputs. These one levels are inverted to zeros by inverters $I_{1,2,3,4,5}$ and in turn cause one levels at the outputs of $J_{1,2,3,4,5}$ whether the signal level is a one or zero.

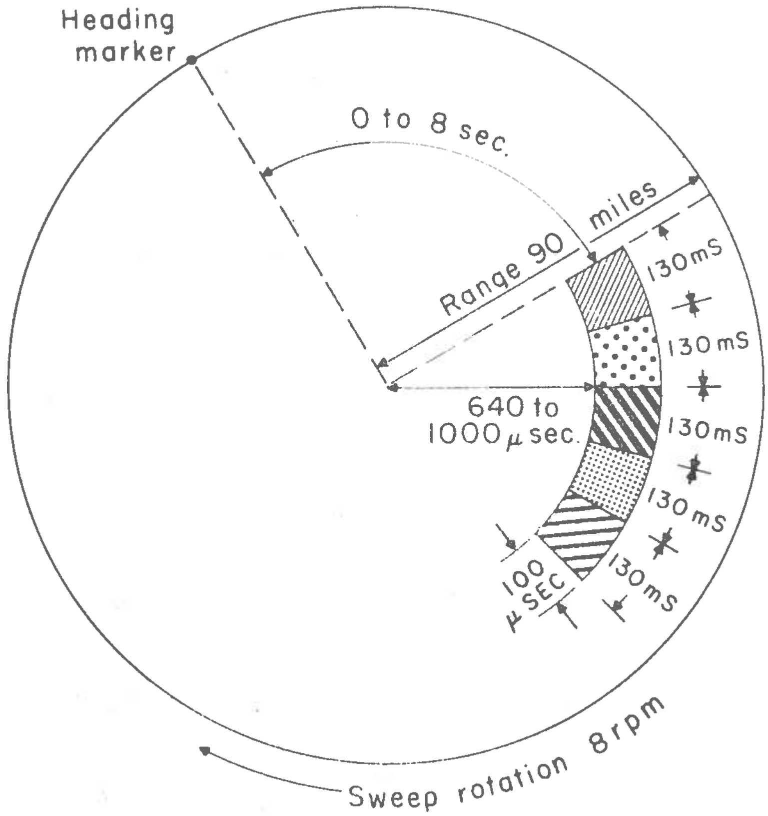


Fig. 12

Grey-scale on PPI display

During signal display time the outputs of inverters $I_{1,2,3,4,5}$ are at a one level. This one level into gates $J_{1,2,3,4,5}$ will allow the data input from SW4 to have control of the J-gates. Finally, these outputs of $J_{1,2,3,4,5}$ are fed into output gates $K_{1,2,3,4,5}$ and have control of the output when the grey-scale is not displayed. The grey-scale input of $K_{1,2,3,4}$ is held at a one level during signal display time.

Plate II shows the apparatus. The upper chassis contains the circuitry shown in Fig. 2, while the lower chassis contains the correlation and angle quantization circuitry, and the grey-scale generator.

RESULTS

The apparatus was installed at Penhold, Alberta, early in 1972 and was operated throughout the summer. Numerous PPI photographs of the phase and correlation displays were taken during hailstorms by Mr. R. Humphries of McGill University, who has made copies of his photographs available to us. Plate III shows the correlation display taken at approximately 0145 MDT on 27 July, 1972. Range rings, starting at 20 miles are spaced at 10-mile intervals. A large storm area extending from approximately 26 to 85 miles range is visible on this display. On the grey-scale, the darkest shade corresponds to correlations from 17 to 33%, while the brightest corresponds to 83 to 100%. About three shades of grey are discernible in the storm, the brightest of which corresponds to correlations of 67 to 83%. Some ground clutter is visible near the centre of the display.

Plate IV, taken at approximately the same time, shows the phase angle for the same storm. In this case, the darkest shade of grey corresponds to 0-36° phase angle, and the brightest, 144 to 180°. Three shades are visible indicating that the phase varies by more than 36° within this storm. Evidence of a propagation effect is indicated by the increase in phase angle with range. (Note the progression to brighter shades of grey with increasing range.)

These photographs are included in this report to illustrate the capability of the apparatus. Analysis of them will be carried out at McGill University.

ACKNOWLEDGMENT

The authors are indebted to Messrs. G. Gibson and P. R. Cook who constructed and tested the apparatus described in this report; to Dr. G. C. McCormick for helpful discussions and for the material of Fig. 4; and to Mr. R. Humphries of McGill University for permission to use Plates III and IV.

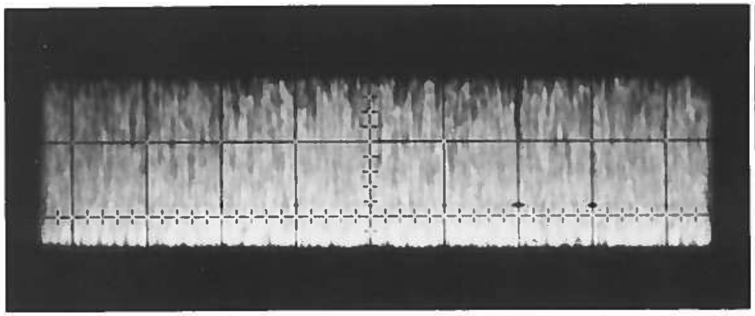
REFERENCES

1. L. E. Allan, R. C. Markell, and G. C. McCormick, "A Variable-Polarization Antenna", NRC/REED, Report ERB-768, 1967.

2. G. C. McCormick, "An antenna for obtaining polarization-related data with the Alberta Hail Radar", Proceedings, Thirteenth Radar Meteorology Conference, Montreal, 20-23 August, 1968. pp. 340-347.

3. G. C. McCormick and A. Hendry, "The study of precipitation backscatter at 1.8 cm with a polarization diversity radar", Preprints, Fourteenth Radar Meteorology Conference, Tucson, 17-20 November, 1970. pp. 225-230.

4. A. Hendry and G. C. McCormick, "Polarization properties of precipitation scattering". Quarterly Bulletin of Radio & Electrical Engineering Division, National Research Council of Canada, Vol. 21, (3): 9-20; 1971.



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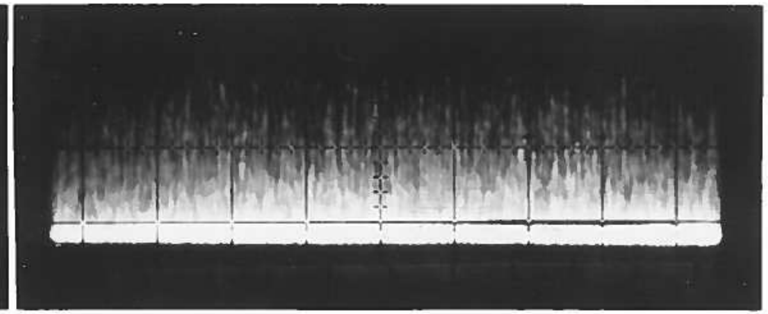

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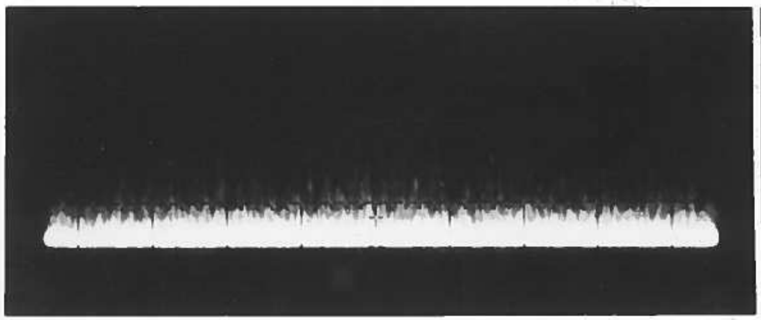
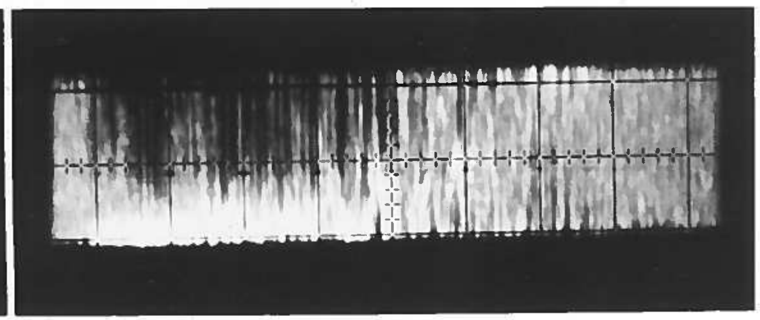


1(c)



1(d)

Plate I. Typical A-scope traces of voltage V_A, obtained with Ottawa-based radar of similar receiver design.

1(a) Noise plus small amount of CW signal.

1(b) Noise plus moderate amount of CW signal.

1(c) Noise plus strong CW signal.

1(d) Range trace through shower activity, 25 August 1972.

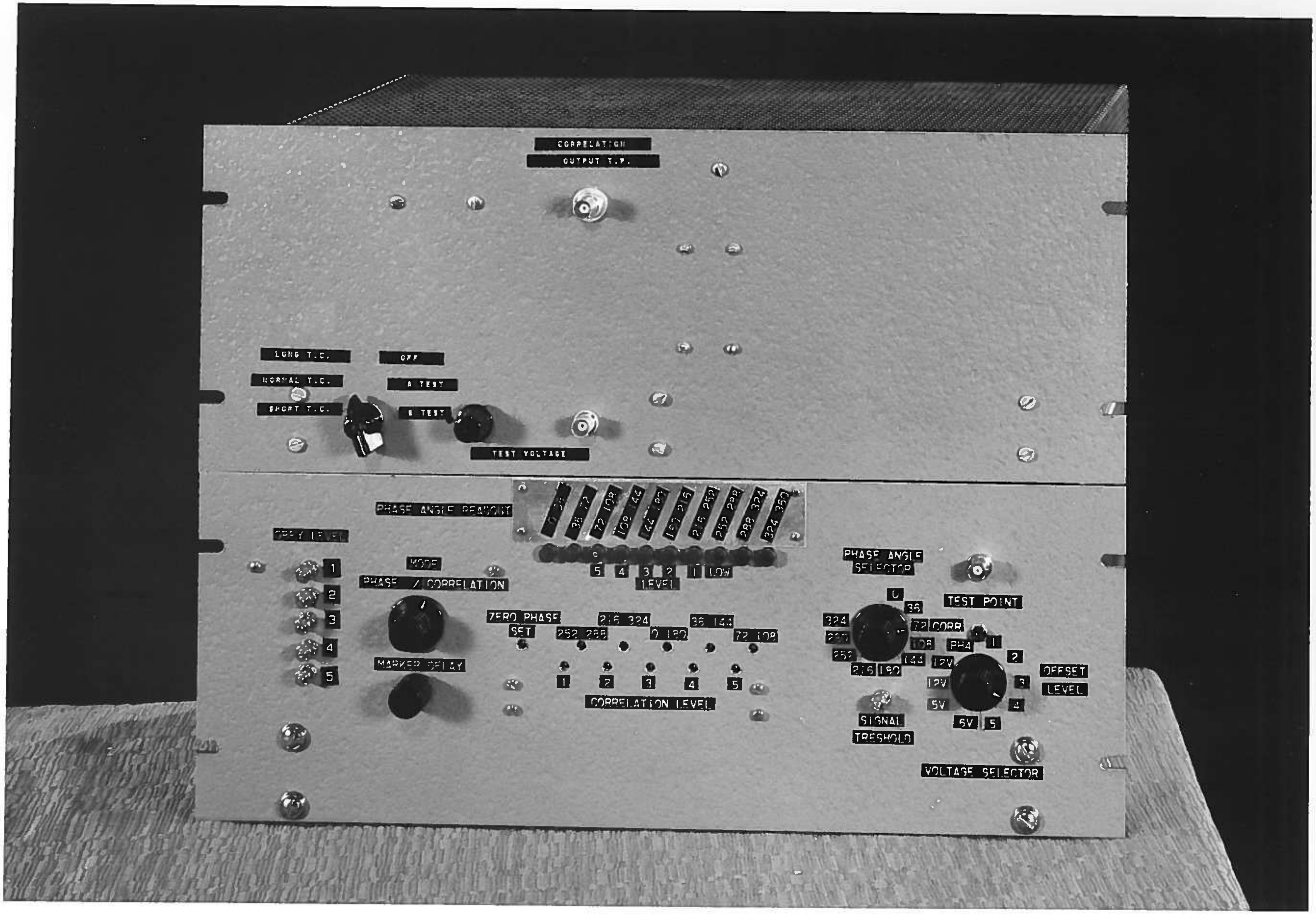


Plate II. Apparatus for correlation/phase angle data display; above - correlator circuit; below - quantization circuit and grey-scale generator.

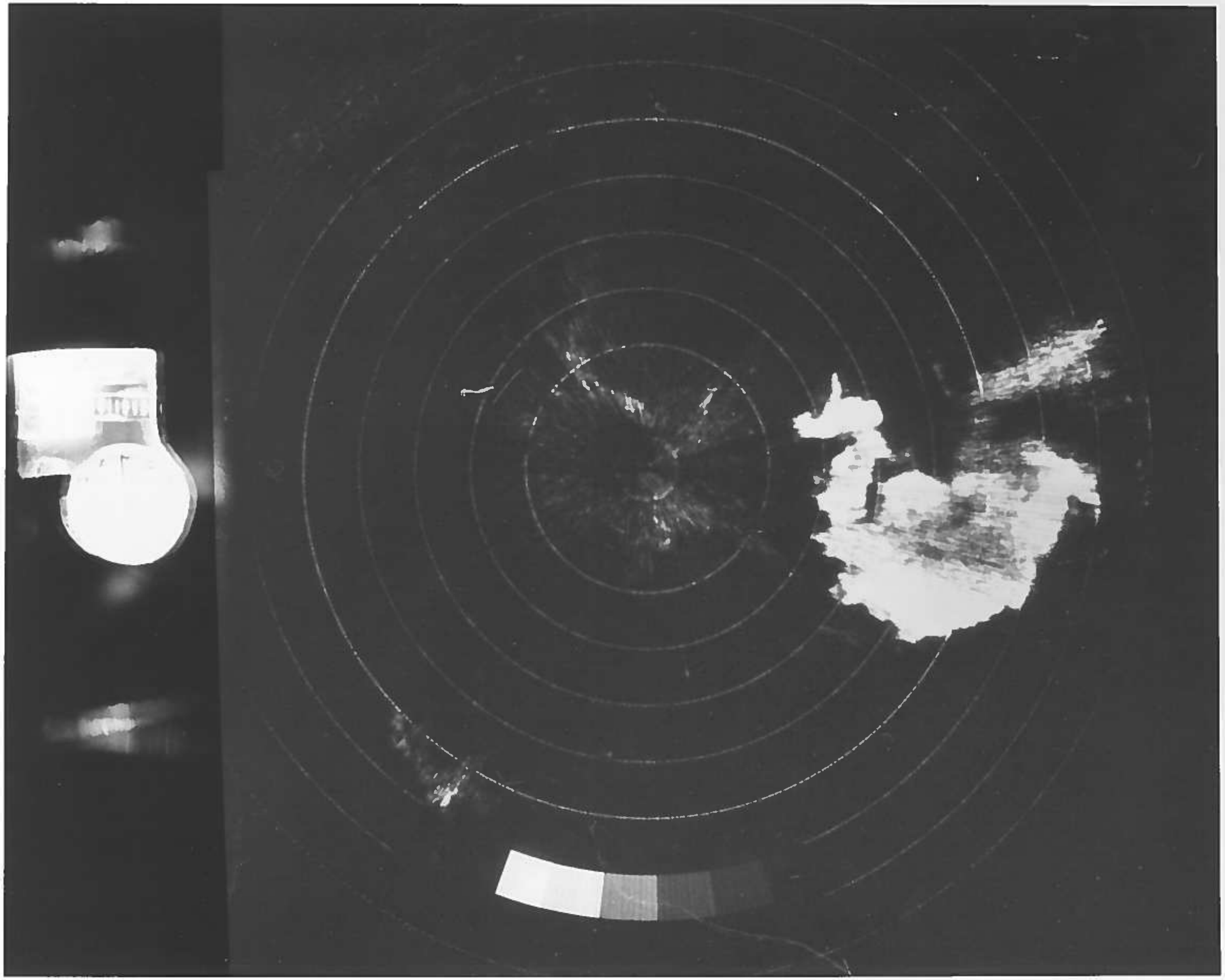


Plate III. PPI photograph showing correlation output. Radar elevation angle 0-1°, range displayed 0-90 statute miles. Data taken 0145 MDT, July 27, 1972.

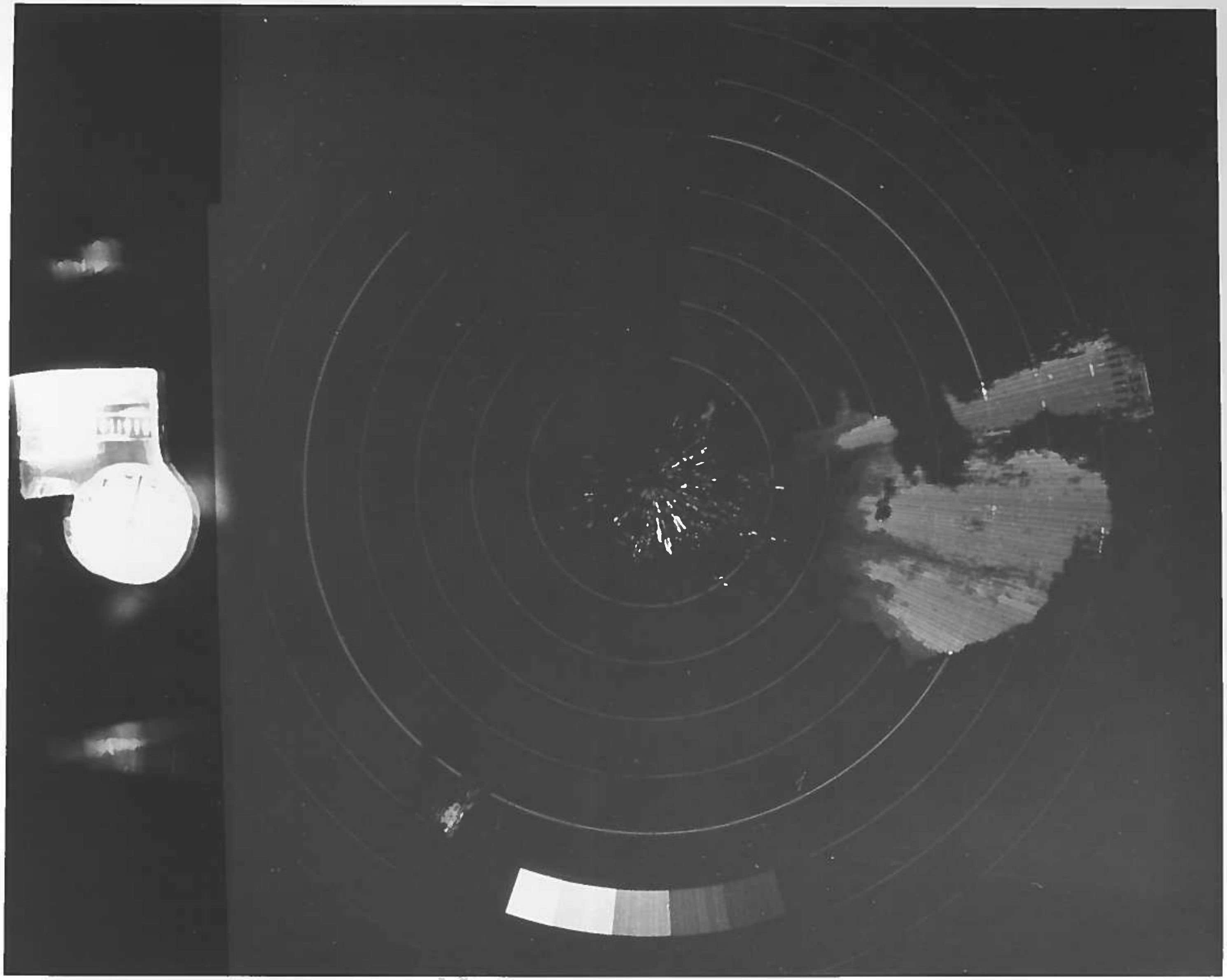


Plate IV. PPI photograph showing phase angle data. Radar elevation angle $0-1^o$, range displayed 0-90 statute miles. Data taken 0145 MDT, July 27, 1972.