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CALIBRATION OF THE COSSOR CR 353 WEATHER SURVEILLANCE RADAR

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Abstract

The CR 353 meteorological radar at Ohakea was calibrated by measuring the attenuation required to reduce the observed signal from a spherical metal target of known reflectivity to a fixed reference level. When account is taken of the differences in the radar equation for distributed and point targets the results enable similar attenuation measurements on precipitation echoes to be used to find precipitation reflectivity.

A method of standardising radar performance to maintain the fixed reference level is described.

1. Introduction

For quantitative measurements of rainfall rate, the radar must be calibrated for received power against display amplitude. A complete, absolute calibration of this type requires expensive equipment, and has rarely been done. For practical work a less rigorous method must be used. The quantitative weather radar, type WSR57, which is used in the U.S.A. is calibrated by inserting into the waveguide a signal of known power from a microwave signal generator. Display amplitude is then adjusted to a fixed level by attenuation. Although this method is convenient in use, the generator must be very stable and theoretical figures must be used for waveguide and aerial coupling losses, and antenna gain.

An alternative method (Atlas and Mossop, 1960) uses a metal sphere as a reference target. Signals are attenuated to a fixed level at the A-scope. By comparing the equations for distributed and point targets, similar attenuation readings on weather echoes may be used to

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compare the reflectivities of the weather echo and reference target. Aerial coupling and waveguide losses apply equally to measurements taken on the sphere and to weather echoes, and they need not be considered.

This paper describes an application of Atlas and Mossop's method to the calibration of the CR 353 weather radar at Ohakea.

2. Comparison of power received from point targets and distributed targets

For a point target on the beam axis

$$P_p = \frac{P_t G^2 \lambda^2 \sigma}{64 \pi^3 r^4} \qquad \text{.............(1)}$$

where P_p is received power; P_t, transmitted power; G, axial gain of aerial system; λ, wavelength; r, range; σ back-scattering cross-section of target. Atmospheric attenuation is not included in the equation as for 10.7 cm wavelength it is negligible (W.M.O., 1966).

The reference target used in this study was a spun aluminium sphere of 1 foot diameter having a geometrical cross-section of 730 cm^2. Barclay and Unthank (1966) show that the Mie back-scattering cross-section for such a sphere is 616 cm^2 for 10.7 cm wavelength radiation. The Mie cross-section as a function of diameter shows a turning point near a diameter of one foot, and small deviations of the sphere from its nominal radius have little effect on its reflectivity.

Probert-Jones (1962) has derived an equation for uniformly distributed targets filling the beam which takes account of the non-uniformity of the beam. For the case of a circular paraboloid reflector the mean received power $\overline{P_r}$ is given by

$$\overline{P_r} = \frac{P_t G^2 \lambda^2 h \theta^2}{1024 \pi^2 \ln 2} \cdot \frac{\eta}{r^2} \qquad \text{.............(2)}$$

where h is the pulse length; θ the beam width between half-power points and η the sum of back-scattering cross-sections of particles in unit volume. Combining equations (1) and (2) we obtain

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$$\overline{P_r} = \frac{\pi r^2 h \theta^2}{16 \ln 2} \frac{\eta}{\sigma} P_p \quad \ldots\ldots\ldots\ldots(3)$$

The signal from the sphere is coherent, while that from precipitation is incoherent. Amplitude at the A-scope is proportional to $\overline{P_r^{\frac{1}{2}}}$. Austin and Williams (1951) show that for randomly distributed scatterers $\left(\overline{P_r^{\frac{1}{2}}}\right)^2 = 0.79\,\overline{P_r}$ If $\overline{P_r}$ and P_p are attenuated to the same level at the display,

$$\eta = \frac{16\,\sigma \ln 2}{0.79\,\pi r^2 h \theta^2} \quad \ldots\ldots\ldots\ldots(4)$$

To relate η to the drop size distribution we note that at a wavelength of 10.7 cm, Rayleigh scattering can be assumed for all precipitation in liquid form. If the radar reflectivity Z of precipitation particles is defined by the relation $Z = \Sigma D^6$ where D is particle diameter, and the summation is over one cubic meter, then

$$\eta = 10^{-12} \frac{\pi^5}{\lambda^4} \left|\frac{\epsilon - 1}{\epsilon + 2}\right|^2 Z$$

where ϵ is the dielectric constant. If Z is expressed in mm^6/m^3, then for water, at 10.7 cm wavelength,

$$\eta = 2.168 \times 10^{-14} Z$$

3. Calibration Procedure

The target sphere was suspended from a tethered balloon. The target rig was first flown without the sphere, however, to establish that no measurable signal was being received from the rig. It was then flown with target as high as possible, to minimise ground returns. The beam width between half power points is 2.8°, with a steep cut-off outside this cone, while the

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target was flown at elevations between 3° and 4°. In the direction of the calibration area, the highest elevation of the intervening ground is just over 1°, except for one isolated point in the area. Hence the effect of ground returns was very small.

Transmitter output power was monitored. The monitoring system ensures that $P_t h$ remains constant. Receiver gain was monitored at the i.f. detector. It is set by aligning the aerial in a no-signal direction, and adjusting the i.f. gain to give a fixed reading at the output meter. Automatic gain control was not used.

By conical scanning in wind-finding mode, the target was accurately centred in the beam. Display amplitude of the received signal was reduced to a fixed level by an attenuator situated between the head and i.f. amplifiers. After attenuation readings were taken, the sphere was again centred to ensure that it had not drifted off the axis. This procedure was repeated at several ranges.

The attenuation readings gave the locus of P_p with range for the spherical target relative to the reference level selected. From (4), after substituting appropriate values for the CR 353 radar and for the spherical target, we find that

$$Z = 2{\cdot}57 \times \frac{10^4}{r^2}$$

along this locus, where r is here expressed in nautical miles. Use of a linear scale for attenuation (db), and a logarithmic scale for range allowed the locus to be checked for agreement with the inverse fourth power law with range. Values of Z were selected along the locus, and lines of constant Z with range were drawn to conform with the relation Zr^2 = a constant. These are shown in Fig. 1.

4. Choice of Reference Level, and Secondary Calibration Procedure

Receiver noise could not be used as a reference level. In the CR 353 it is not possible to locate the attenuator on the input side of the head amplifier. Most of the receiver noise is generated in the mixer, and this would have been attenuated together with the signal. In any case, a higher reference level permits better accuracy in attenuation readings (at the cost of some loss in sensitivity) since equal increments of attenuation give decreasing decrements in amplitude at the display.

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For these reasons an arbitrary level of display amplitude on the A-scope was selected as the reference level. Radar performance was standardised with respect to this reference level by a secondary calibration procedure. At 50 n.m., the minimum detectable rate of rainfall at the reference level selected, is about 0.5 mm/hr. Any loss in sensitivity due to this choice of reference level is therefore not important, especially since beam-filling is a more important factor in rainfall estimation at Ohakea with ranges in excess of 50 n.m.

For the secondary calibration a nearby small isolated permanent echo was selected. At a fixed elevation, the azimuth for maximum returned power was determined. On this azimuth, the signal was attenuated until the display amplitude reached reference level. The A-scope and video gain controls were preset. The attenuation gave a check on changes in radar performance since the last calibration, providing that reference target reflectivity had not changed. Video gain is not monitored in this radar and it was assumed that the A-scope is stable enough to be used as a reference.

The P.P.I. was aligned with the A-scope, in conjunction with the secondary calibration as follows. After the previous steps, the aerial was set in auto-rotation. The brightness control was then adjusted until the permanent echo was just visible at the P.P.I.

5. Discussion

The four calibrations made at Ohakea are shown in Fig. 1. Little change in calibration took place, either during the short periods separating the first three, or the longer period after the third. During the latter period extensive servicing was carried out, and although the small change in calibration may be coincidental, it is encouraging.

Errors in rainfall estimation due to calibration factors may arise through changes in secondary calibration target reflectivity and through instability in A-scope gain. The latter could be checked with a signal generator. Observed fluctuations in secondary calibration are about $\pm$ 2 db. It is not known whether these are due to changes in radar performance or in secondary target reflectivity.

Providing receiver noise does not vary greatly, and no major changes are made in the equipment, it would appear that complete recalibration should not be frequently needed. The secondary calibration could be done more often as this takes only about two minutes.

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Use of attenuation to measure received power assumes that a given change in received power (db) always corresponds to the same change in attenuation throughout the entire range of received power. Whilst this is certainly not true if the receiver becomes saturated, the stepped attenuation method used in rainfall estimations ensures that saturation never occurs. However, the assumption is still not strictly valid, because if appreciable noise is fed into the attenuator together with the signal, the received power is overestimated. In the actual case, at i.f. frequency, the noise and signal voltages are not additive, but for an approximate calculation of the error due to this effect an upper limit may be obtained by treating them as such. Allowing for the known noise characteristics of the CR 353 it is found that for a range of 50 n.m., a rainfall rate of 1 mm/hr is overestimated by up to 15%. For rates over 2 mm/hr the error is negligible.

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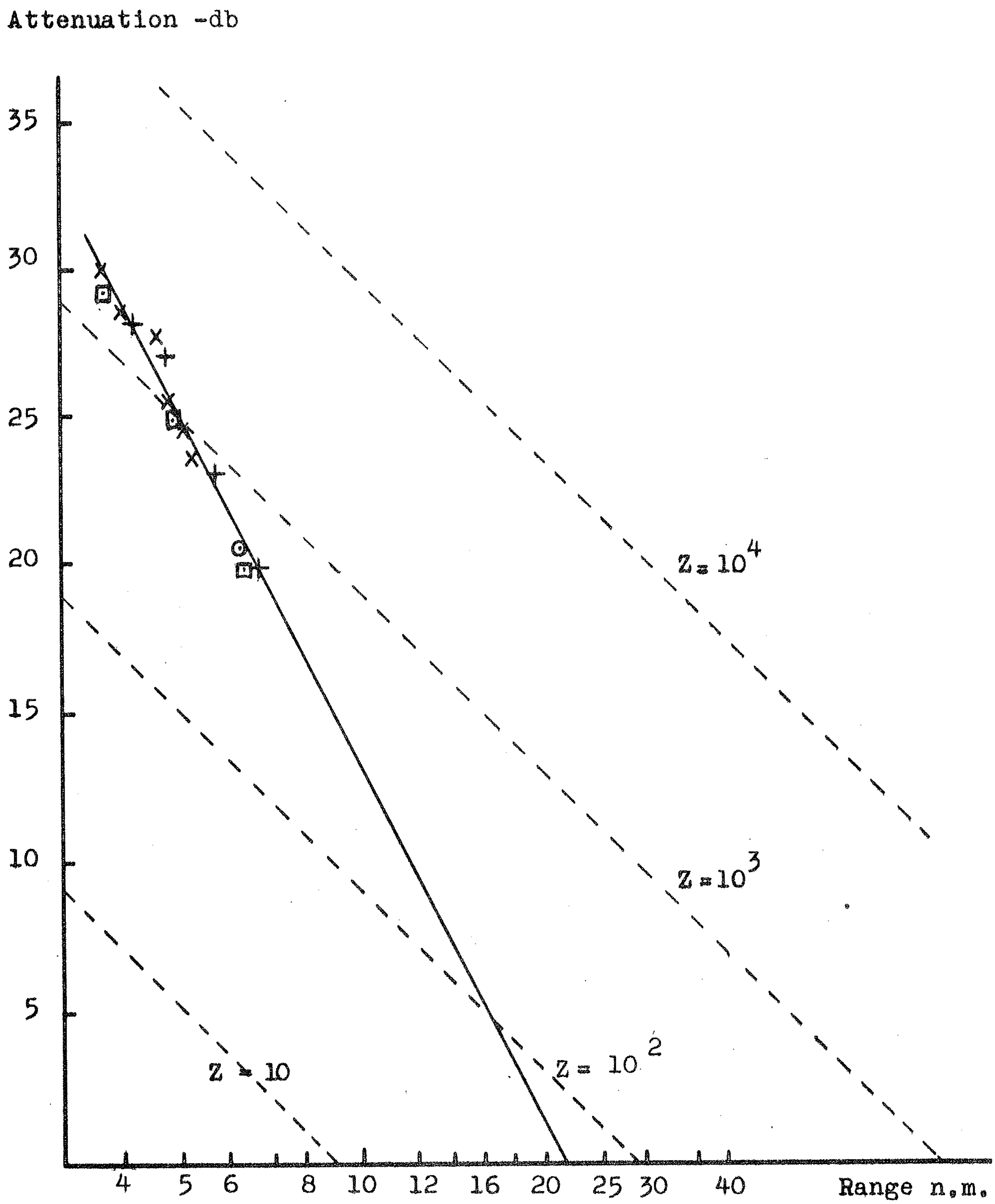

Fig. 1. Results of calibrations.

+ 19/6/66

⊙ 20/6/66 (one point only)

x 28/8/66

⊡ 23/4/67

<u>Note</u>. (a) The points near 4.6 n.m. may have been influenced by reflections from high ground.

(b) Dashed lines are derived from the relation $Z = 2.67 \times 10^4 / r^2$ which applies on experimentally determined (solid) curve.