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Radar Rings from the Abbotsford Radar

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INTRODUCTION

Last year the SCEPTRE-radar, i.e., System for Constant Elevation Precipitation Transmission and Recording, became operational at Abbotsford. SCEPTRE is a radar ancillary system designed to provide quantitative precipitation information for a given set of constant altitudes.

The information is transmitted to the Pacific Weather Centre and displayed in hard-copy chart form. The display is known by the acronym CAPPI, Constant Altitude Plan Position Indicator.

Figure 1 portrays the background map of the CAPPI display on which the precipitation rates, in four shades of gray, are superimposed.

Several months ago, as well as during the subsequent months, sets of sausage-like radar echoes were recorded on the display. The phenomena generally persisted for an hour. In our example, figure 2, several rings are evident.

Clearly, Mother Nature never intended these precipitation patterns and the explanation for them must rest with the display composing technique.

The formation of the "radar-rings" will be explained, albeit roughly, in this note. Furthermore, the explanation will enhance our understanding of the CAPPI technique.

SYNOPTIC STATE

Last October 24, 2000Z, a deep cyclone was located about 300 miles off the Oregon coast. The associated frontal wave positioned just offshore, figure 3. The wave, tracking northeast, had spread rain along the coast already.

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In general, the area of concern was under the influence of an approaching warm front. The airmass ahead was nearly saturated to the 4 km level as confirmed by the Quillayute tephigram, see figure 4.

THE PHENOMENA

The "radar-rings", figure 2, persisted approximately an hour with some deformation. For example, the series of smaller rings dissipated and gave way to one major sharp-edged return echo across southern Vancouver Island and Washington, figure 6. For comparison, figure 5, gives the precipitation returns at the lower 1.5 elevation. No ring-like precipitation bands are evident at this altitude.

Note the sharp rear-edges of the precipitation bands which if extended would form a series of unevenly spaced concentric rings.

THE RADAR

The Abbotsford radar is a pulsed radar, i.e., electromagnetic waves at a fixed frequency are transmitted in a series of short rapid pulses. Each pulse is of duration 2μs. Now each pulse samples an almost cylindrical volume in space. The volume width being 300 m and the mean diameter a function of the radar beam width and the distance (range) from the antenna. Figure 7 illustrates the main features of the radar beam. Since the power which arrives back at the radar at the same instant in time is involved in a two-way path, the pulse width is only one-half the pulse volume width (d/2). Also notice how the resolution deteriorates with range as the beam diameter grows from 1 km near the radar to 4 km at the edge of the CAPPI display.

The distance of the pulse volume from the antenna is determined by the time required for the pulse to travel to the target and back again to the antenna. Figure 8 gives the simplified ray geometry and the relationships between the range and the height of a pulse. The Earth's curvature and beam refraction are accounted for as well .

CAPPI COMPOSING TECHNIQUE

Here, we will only outline the process by which the display is generated. A comprehensive discussion is beyond the scope of this note.

Basically the antenna is rotated at constant speed and elevation angle while the pulses are transmitted. Monitoring the range of the return pulses one may select only those returns originating from a volume in space centred about the desired elevation. This volume swept out by those signals near the height in question is referred to as the range-gated volume, see figure 9.

As the antenna rotates, an annular ring is swept out centred at the selected elevation. Raising the antenna will generate an adjacent annular ring centred at the same height as the previous one. Continuing this process will result in a complete set of rings covering the entire area of the display.

The return pulses from within the range-gated volume are processed in turn. The group of signals obtained from the volume are averaged both in time and range. The processed signals are then recorded on the horizontal CAPPI map, see bottom part of figure 9. As the beam rotates the range internal ring is slowly filled. The adjacent ring is filled when the antenna is raised to the next elevation.

DISCUSSION

Having acquired a basic overview, we may now proceed to examine the cause of the "radar-rings".

Consider a crossection along line AB in figure 2. From the original CAPPI display chart, the approximate location of each sharp rear-edge was determined. In addition, it was noted that the precipitation rate at or near each rear boundary was relatively heavy and gradually decreased (faded) toward the outer edge of each precipitation band.

These observations are schematically shown in figure 10, bottom part. Each precipitation band is illustrated by a shaded area. Each area is somewhat exponentially curved to indicate the initial heavier precipitation rate and then decreasing away from the sharp rear-edge. Further each area begins at the approximate location determined from the original display.

The top diagram in figure 10 represents the range-gated volumes, the data from which the display was produced. These gated volumes were drawn roughly to scale. Knowing the elevation angles and the range intervals, together with the beam width, one may compute the diameter and elevation of each volume. The appropriate equations are given in figure 8.

Consider the semi-shaded range-gated volume in figure 10. Let us also assume that the precipitation commences near the 4 km level. This assumption is reasonable in that the Quillayute tephigram shows saturation to 4 km and the warm frontal airmass will slope positively toward the area under radar surveillance. In figure 10, we let the shaded area in the range-gated volume ABCD represent rain and the area immediately above has no rain.

Initially a pulse of diameter AB will trigger a return echo as rain is encountered. Note that most of the pulse volume will be filled and consequently a fairly strong echo will be returned. As the subsequent return pulses are analyzed, each successive return will be weaker as the amount of precipitation droplets encountered steadily decreases.

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Near the end of the range-gated volume, the pulse has a diameter CD and will be sensing almost above the 4 km height. From the picture it is clear that now little or none precipitation will be sensed.

Therefore, in the display the precipitation rate goes from relatively heavy, sensing just below the 4 km level, to quite light or none, sensing almost above the 4 km level.

For the adjacent range-gated volumes an identical argument applies.

The reason for the sharp cut-off at the rear adges is that no averaging takes place between adjacent range-gated volumes, i.e., the returns from each annular ring are processed independently. If some averaging did take place one would expect a series of smooth ridges instead.

CONCLUSIONS

Tentatively, we may note the following wherever some "radar-rings" are observed.

(1) The airmass is fairly stable and, of course, moist;

(2) The airmass is likely to be associated with a warm front;

(3) The precipitation is fairly uniform and commences near the height selected by the CAPPI display.

ACKNOWLEDGEMENTS

The author would like to thank P. Carlson and L. Torok for their helpful comments and information.

The support from the Pacific Weather Centre's ODIT Unit is gratefully acknowledged.

REFERENCES

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(2) Sychra, J., 1971: Coefficient of Beam Filling in a Standard Atmosphere, Canadian Meteorological Research Report CMRR 3/71, 22 pp.

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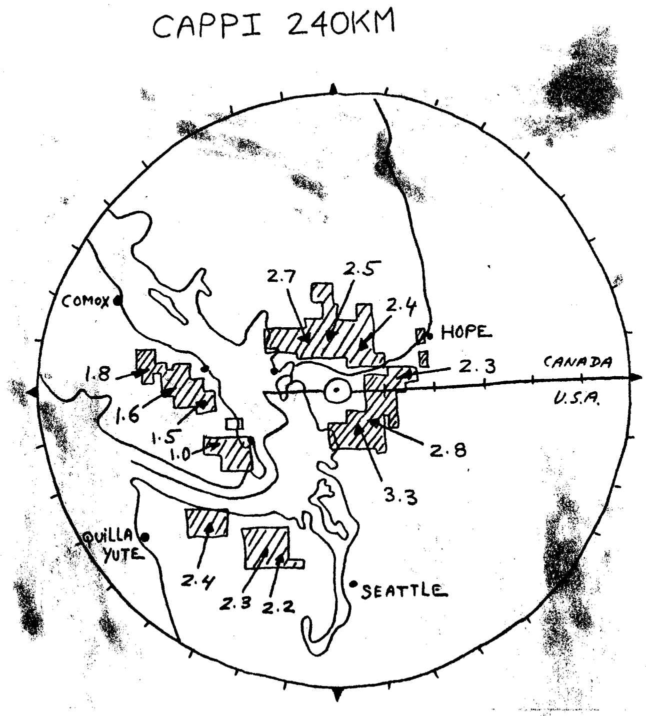


Fig. 1. The geographical area encompassed by the SCEPTRE radar system located at Abbotsford. The constant altitude plan position indicator (CAPPI) display has a radius of 240km with the centre at Abbotsford. The hatched areas are generated automatically by the radar program when the scanning altitude is set for 1.5km. At this elevation the mountain ranges present constant return echoes and to avoid confusion those areas are "blocked-out". The arrows with the attached numbers give roughly the location and elevation (km) of the more significant mountain peaks.

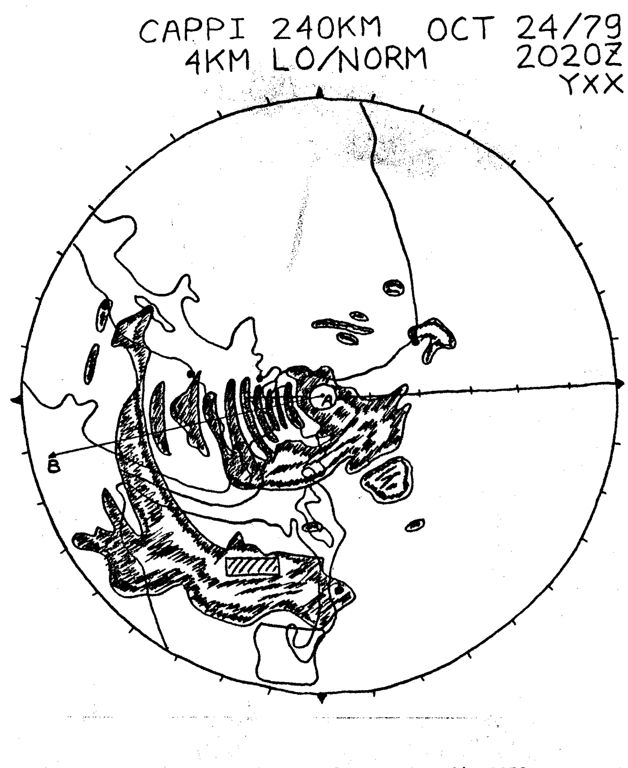


Fig. 2. The CAPPI display for October 24, 1979. Note the series of concentric rings formed by the rear edges of the radar echoes.

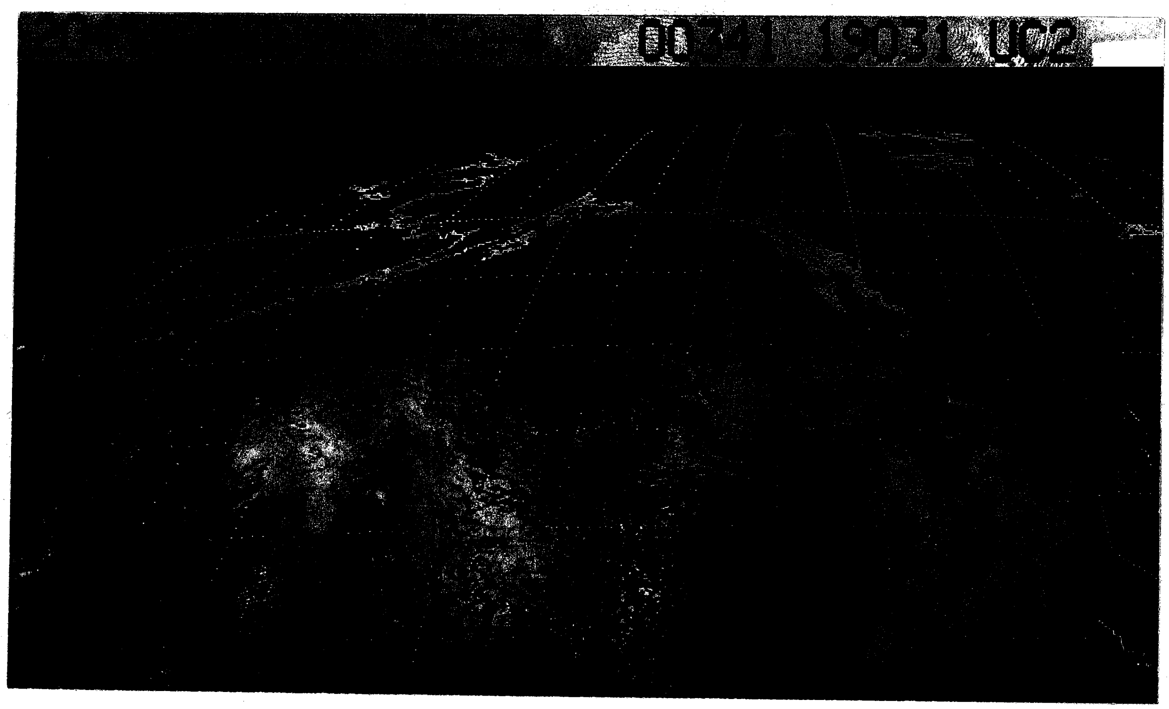


Fig. 3. Satellite picture for October 24, 1979 at 2045Z. Note the warm-frontal cloud mass over Vancouver Island.

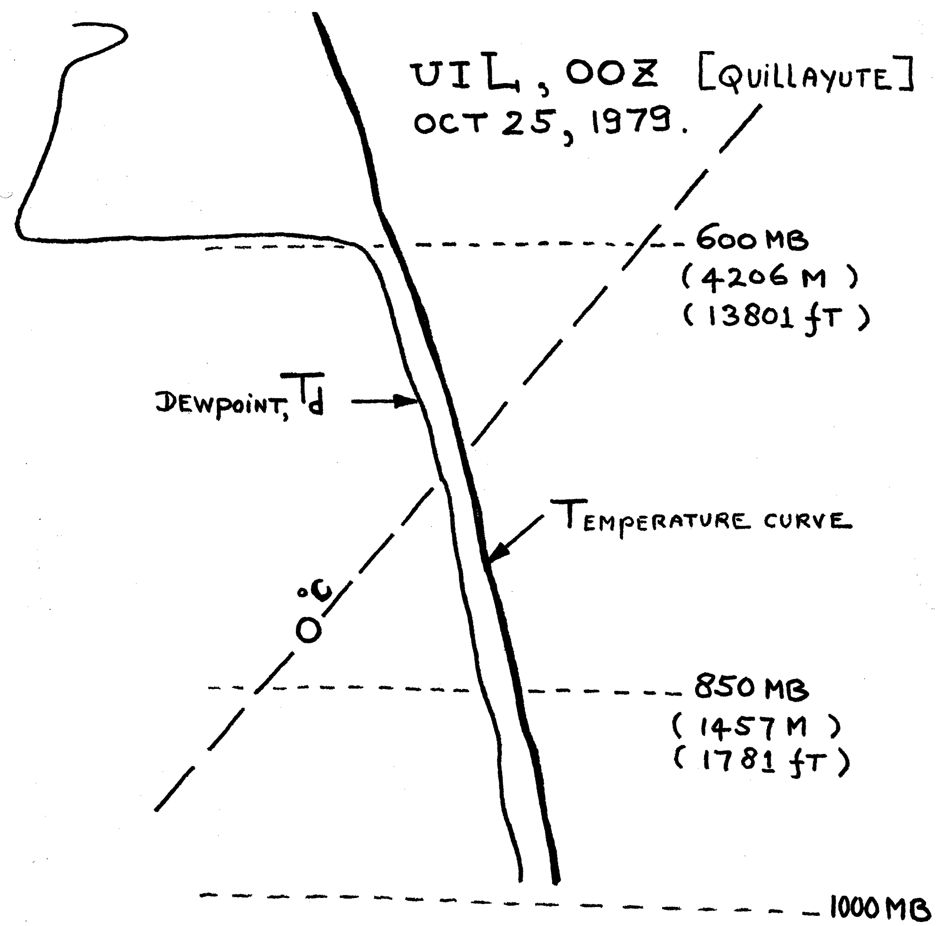


Fig. 4. The upper air sounding for Quillayute.

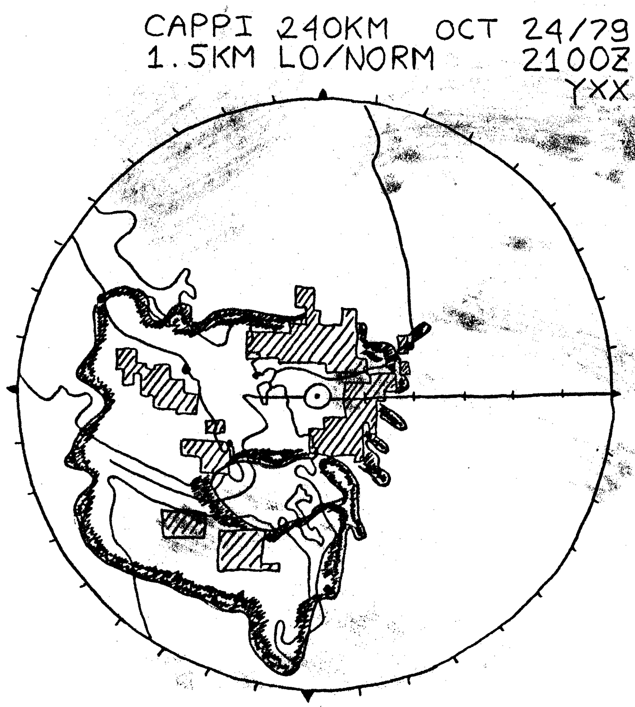


Fig. 5. CAPPI Display.

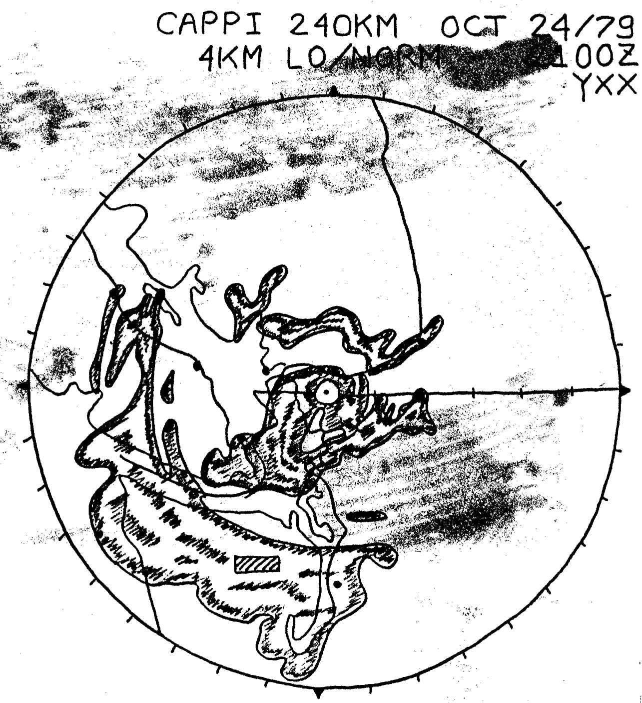
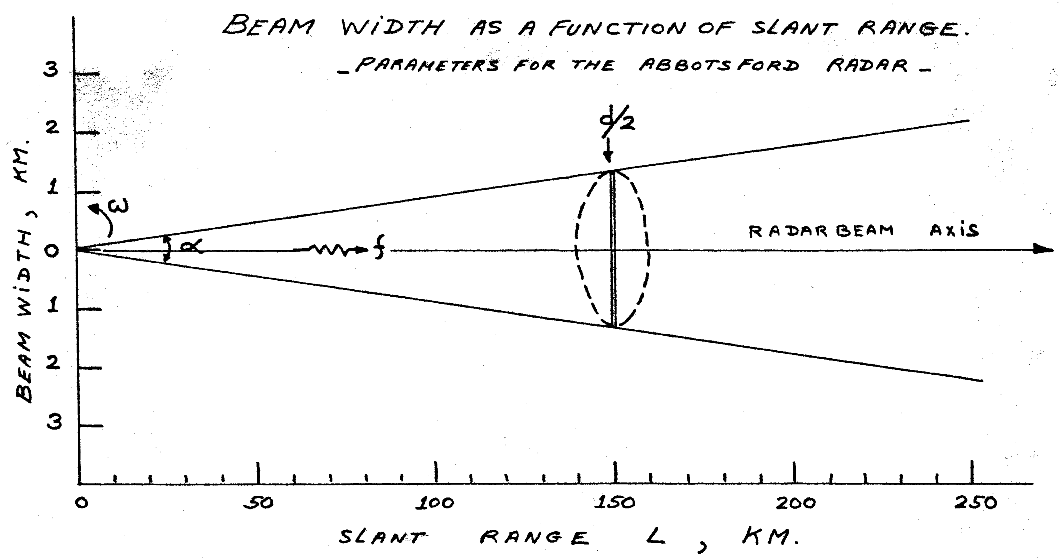


Fig. 6. CAPPI Display.



ω = Azimuth scan rate, 6 RPM.

α = Beamwidth, 1°, computed width using Lα, α in radians

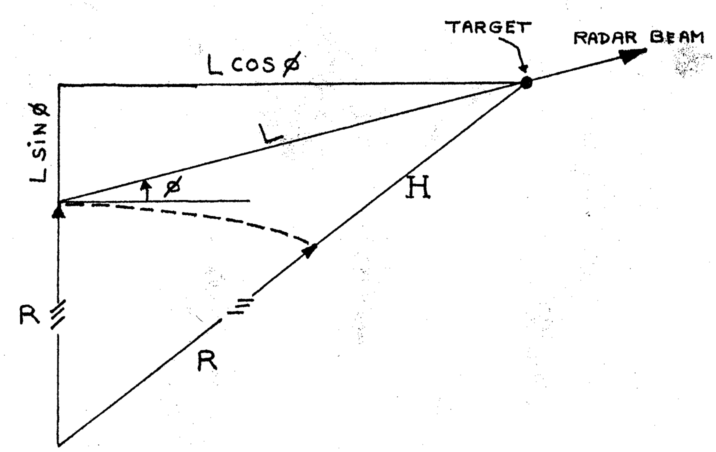
d = Pulse width, 2 μs.

d/2 = Pulse volume width, 1 μs or 300 m, invariant with range.

f = Pulse repitition frequency, 324 pulses/sec. or 3240 pulses per revolution.

Fig. 7. Beam width versus range.

RAY GEOMETRY.



R = EFFECTIVE EARTH RADIUS (4/3 TRUE RADIUS ≅ 8500 KM)
L = DISTANCE FROM ANTENNA TO TARGET (SLANT RANGE)
ø = ELEVATION ANGLE
H = HEIGHT OF RAY

USING THE RELATIONSHIP $(R+H)^2 = (R + L\sin\phi)^2 + (L\cos\phi)^2$, MAY FIND

$$L = R\left\{\sqrt{\sin^2\phi + \frac{2H}{R} + \frac{H^2}{R^2}} - \sin\phi\right\};$$

AND

$$H = L\sin\phi + L^2/2R, \quad \text{PROVIDED} \quad H/R \ll 1.$$

FIG. 8. *RAY TRAJECTORY IN THE STANDARD ATMOSPHERE. (FROM SYCHRA, 1971).*

CAPPI TECHNIQUE.

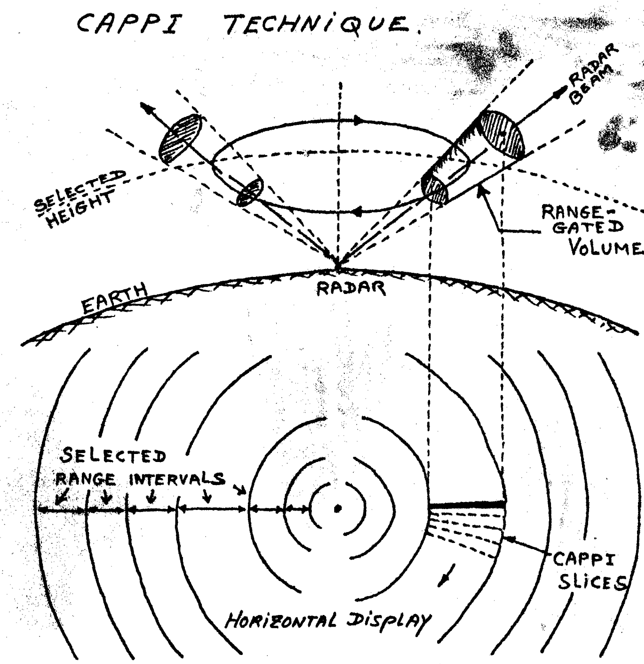


Fig. 9. A schematic to portray the system for synthesizing the radar returns. The antenna is rotated at a constant elevation angle. By selecting the proper range interval an annular ring is swept out centred at the desired height. Elevating the antenna an adjacent annular ring is swept out, centred at the same height. Continuing this process the CAPPI display can be completely filled. Each CAPPI slice is in reality composed of a cone which is tilted and whose thickness and width increase with range (after Crozier, 1975).

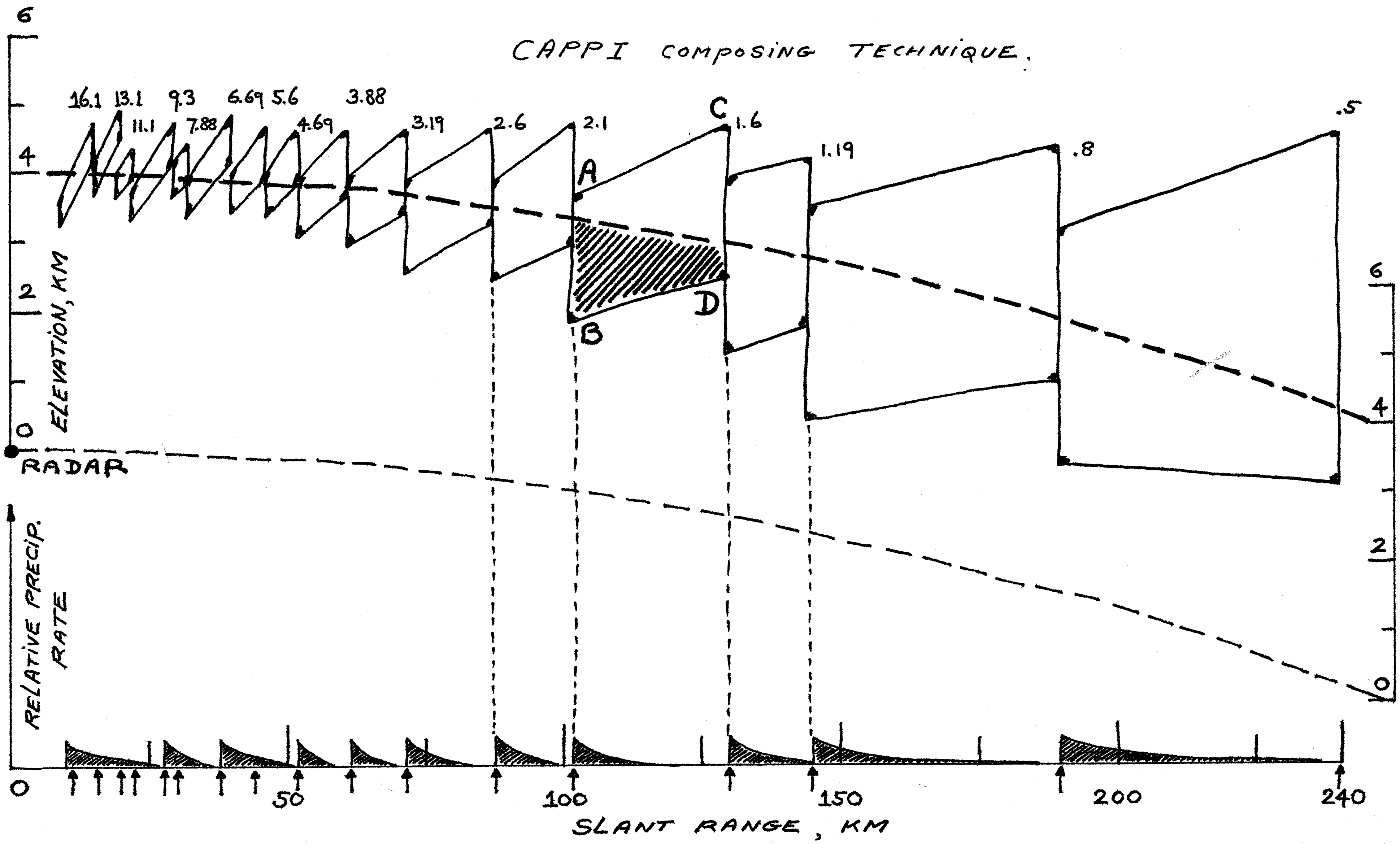
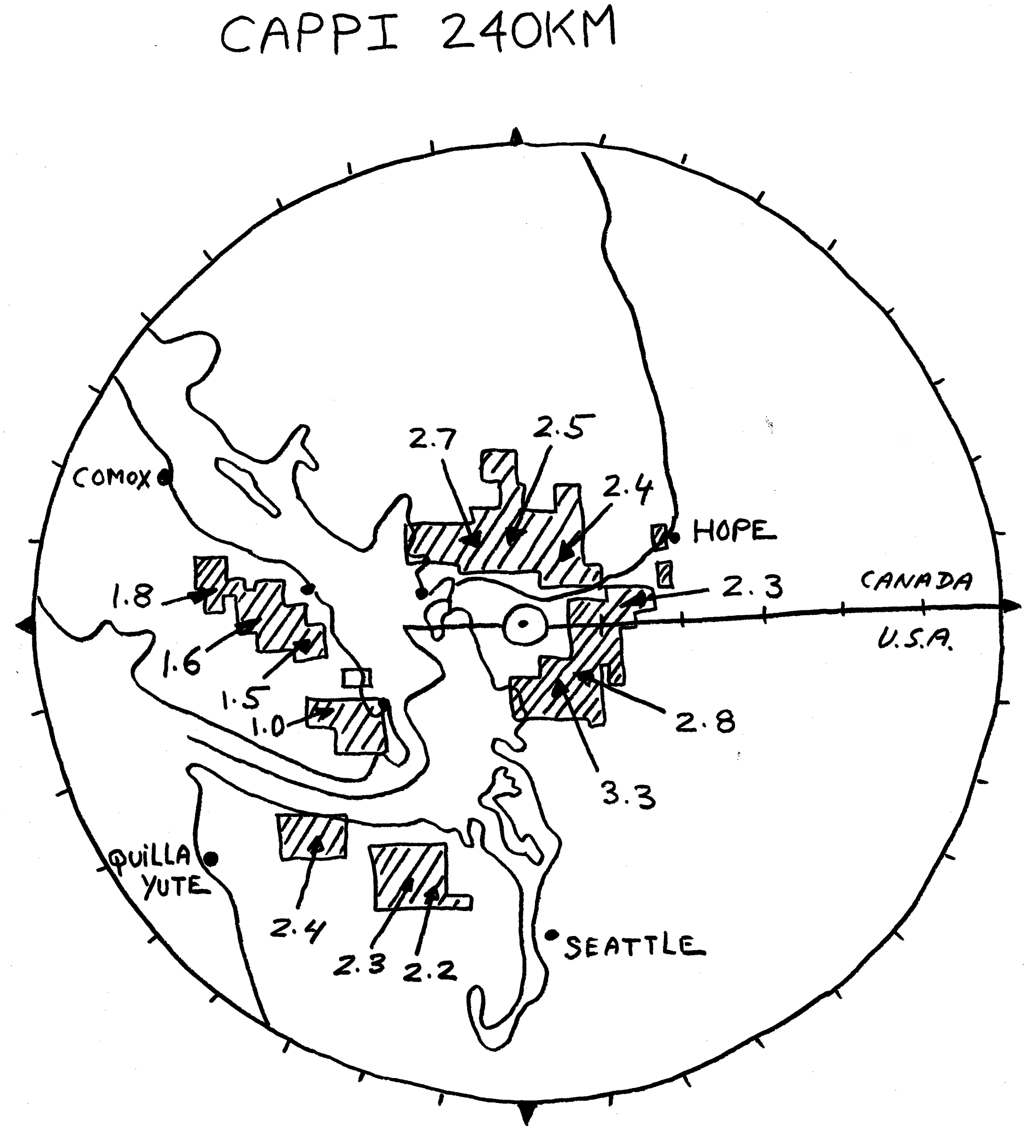


Fig. 10. A schematic diagram showing a crossection through the CAPPI display and the corresponding CAPPI range gated slices from which the rings are derived. The number accompanying each slice gives the elevation angle (degrees) of the radar beam and the small arrows below the corresponding range interval.



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CAPPI 240 KM.

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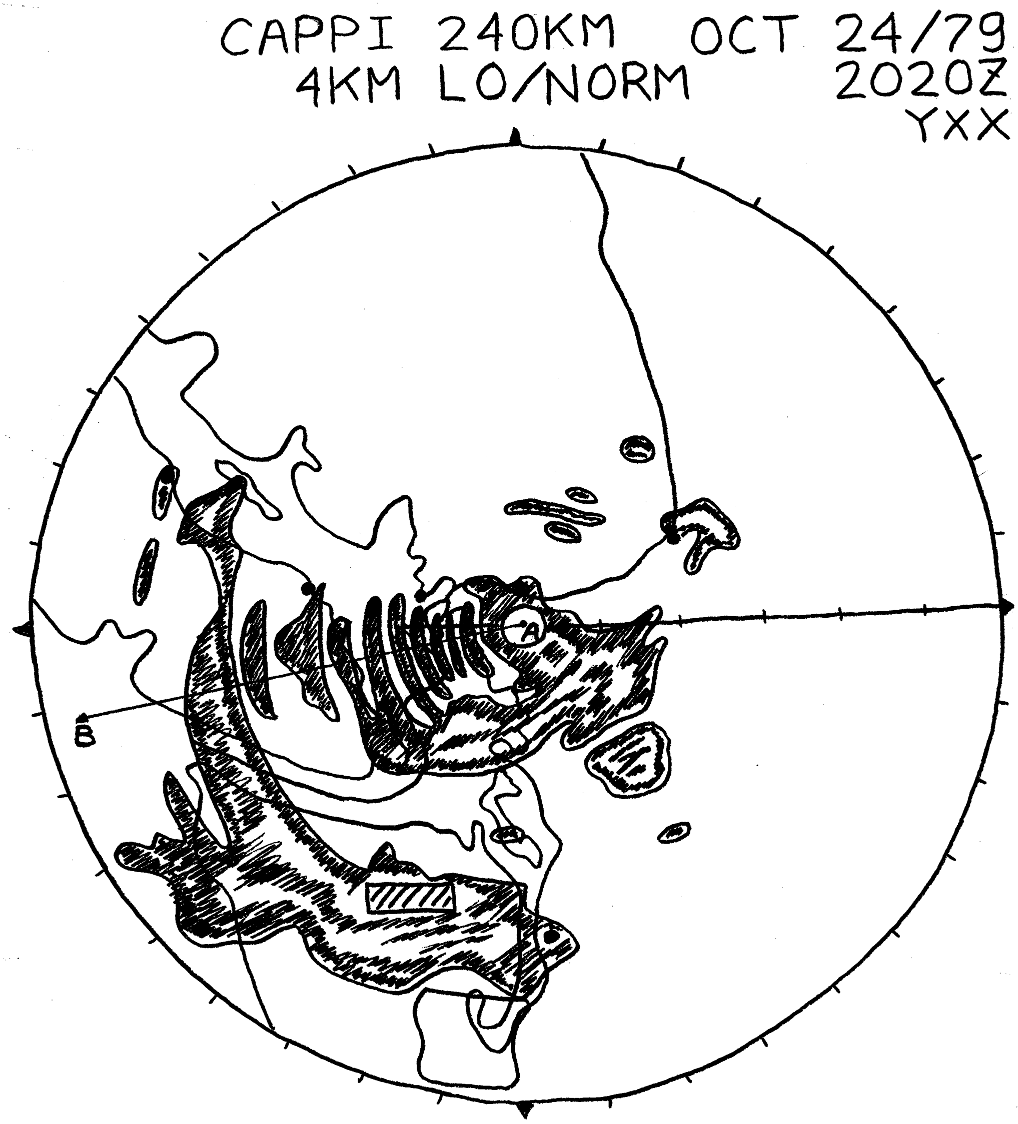

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(Place beneath CAPPI 240 km at 24/79, 2020Z)

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(Place beneath tephigram UIL)

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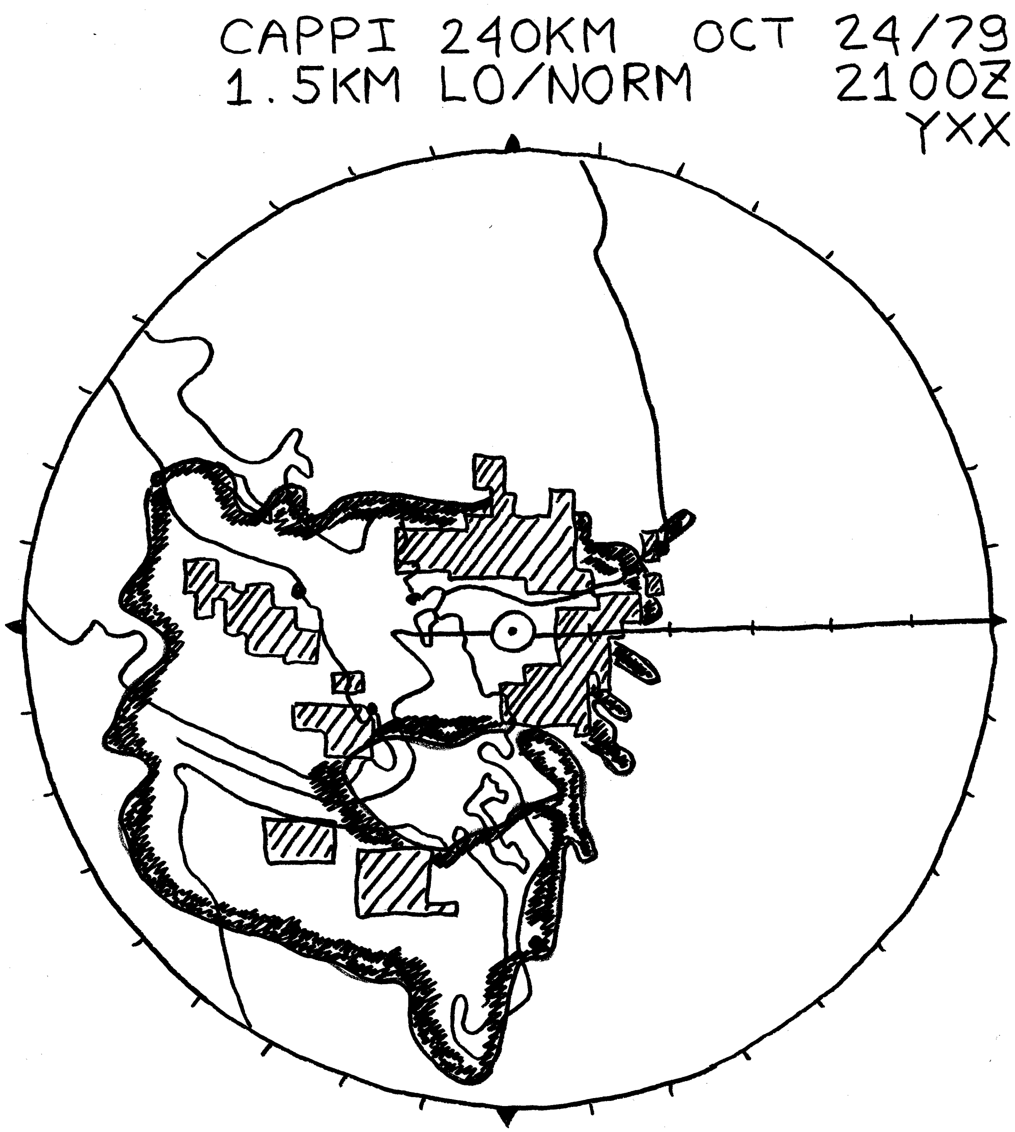

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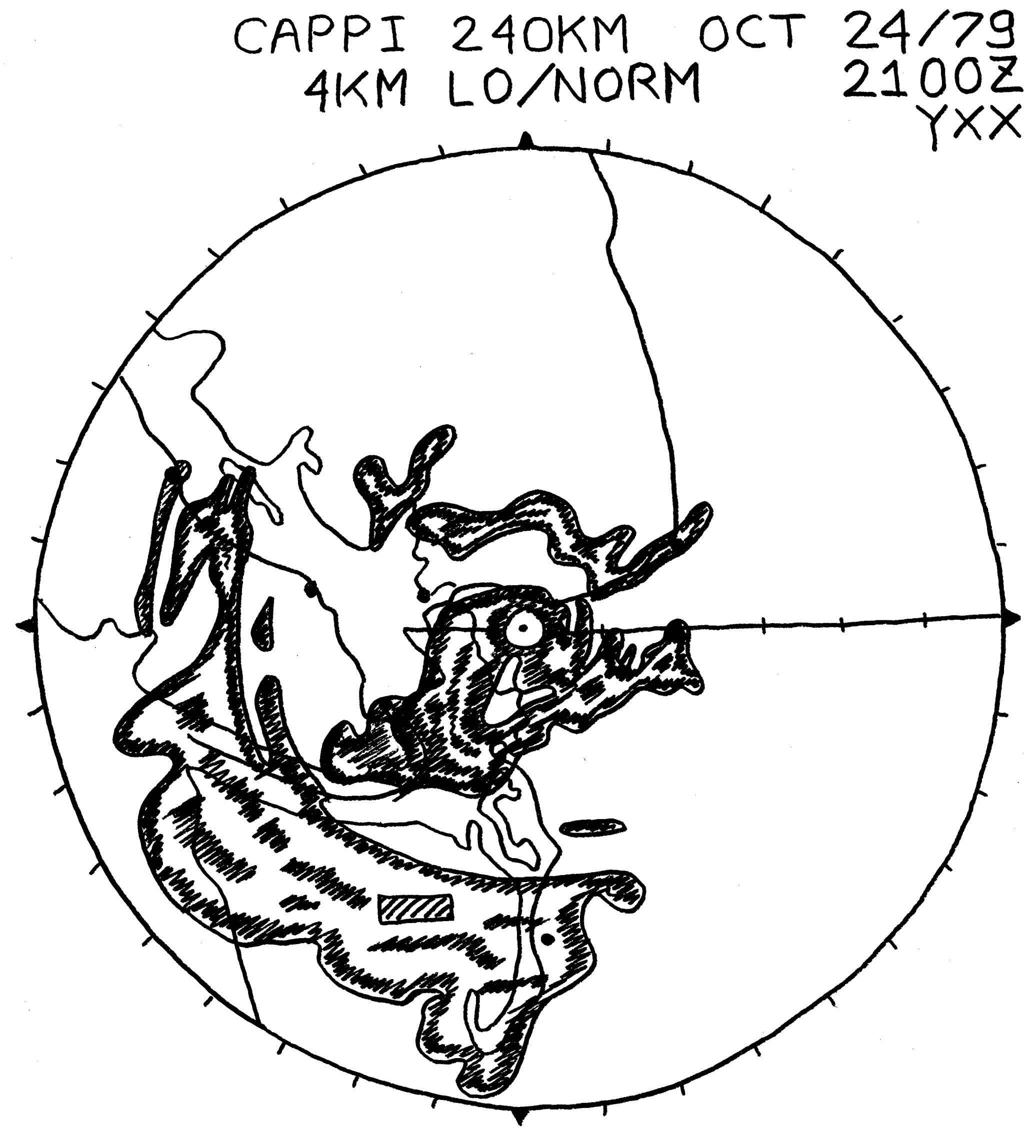

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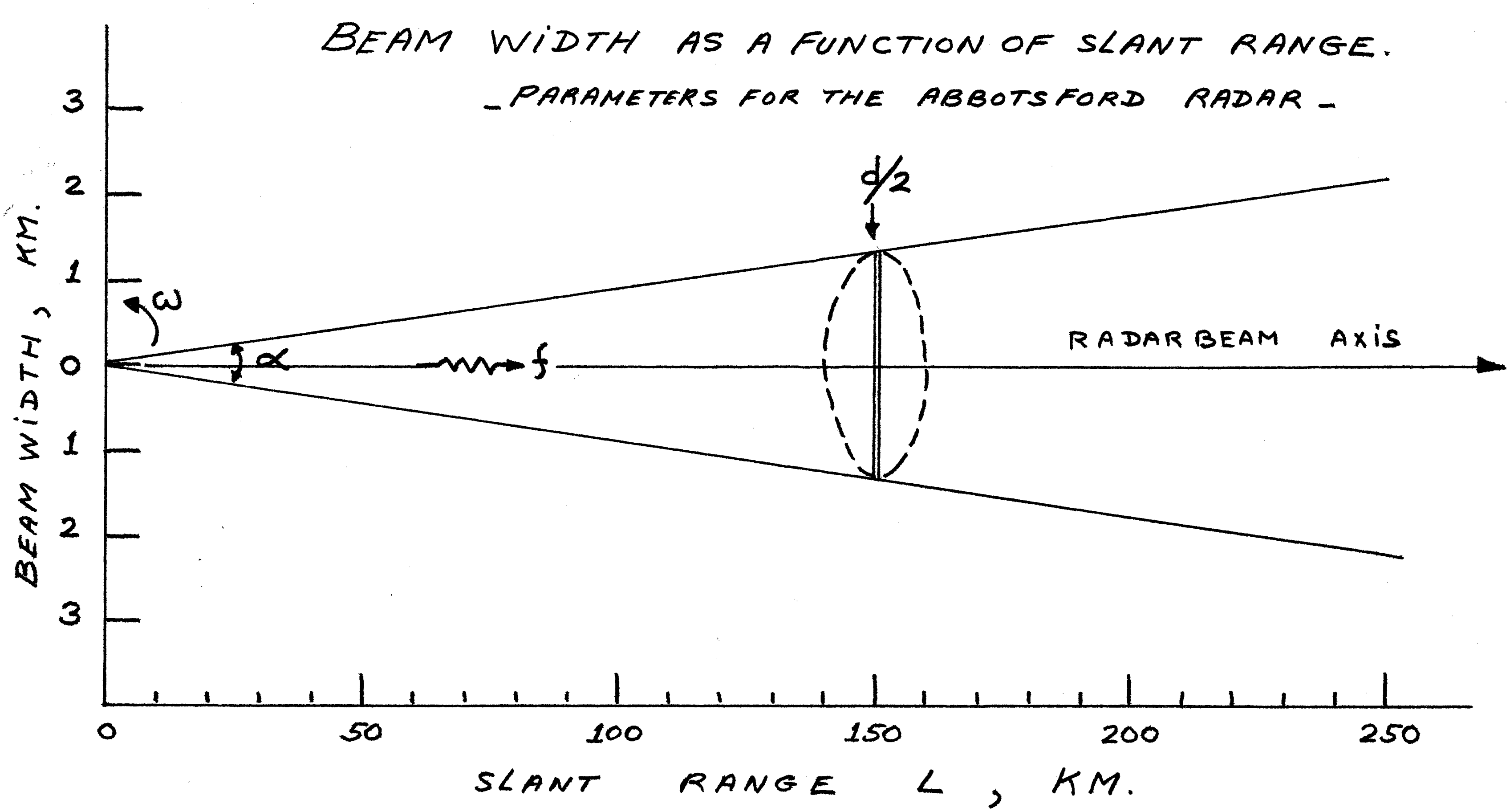

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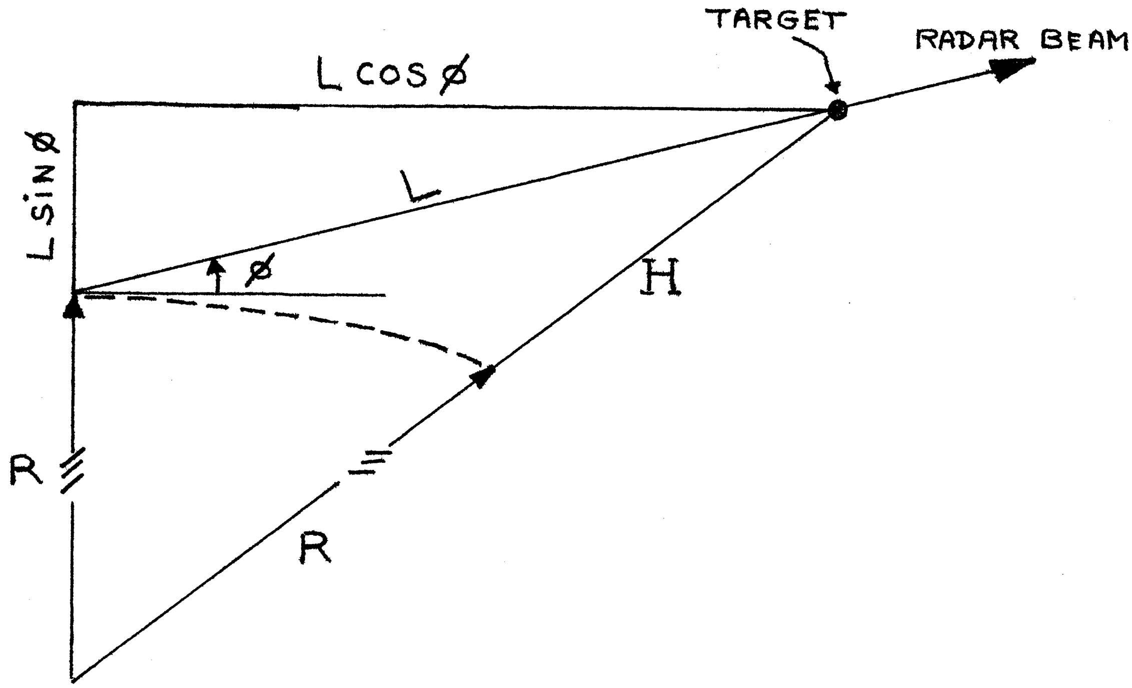

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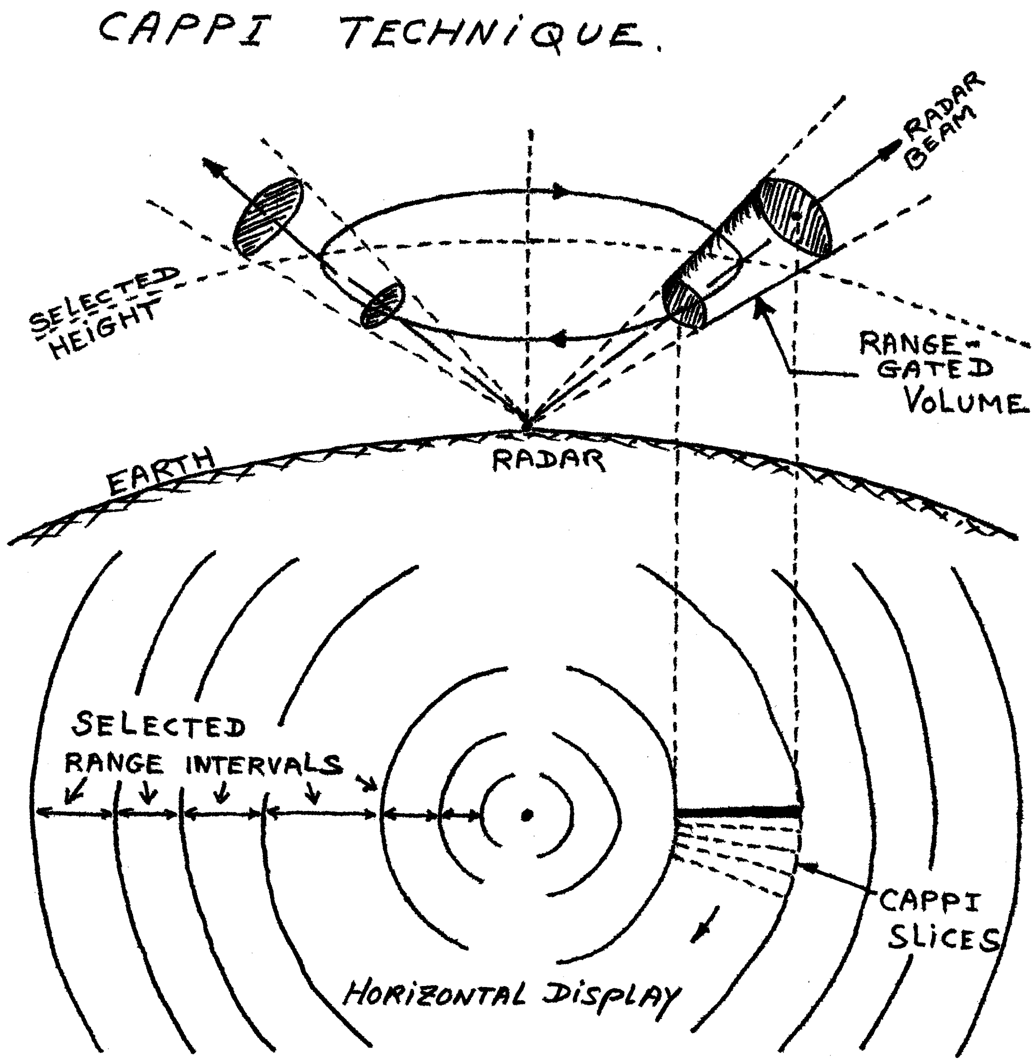

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