# HIGH-FREQUENCY BACKSCATTER OBSERVATIONS AT SALISBURY, SOUTH AUSTRALIA

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*Summary*

An improved pulse technique which permits simultaneous observation of time delay and elevation angle of arrival of ionospheric echoes has enabled recognition of seven different modes of backscatter propagation involving both ionospheric and ground origins. By the use of four transmitting aerials with differing directional characteristics, it is shown that land is a more prominent source of backscatter than sea at low angles of elevation and that extremely large changes in land roughness can be identified by the resultant increase of backscatter echo amplitude.

## I. Introduction and Historical Survey

If, for frequencies greater than the critical penetration frequency of the most densely ionized ionospheric layer, radio wave propagation via the ionosphere were limited to a series of specular reflections at the ionosphere and at the Earth's surface, no radio wave energy, other than that of the ground wave, would be detectable within the zone around the transmitter known as the skip zone. Nevertheless, it often has been possible to detect signals within the skip zone. In particular, signals have been detected by a receiver placed very close to the transmitter and employing the same aerial system. This apparently non-specular signal component has been named backscatter.

Theoretically, backscatter could originate in many ways, namely,

(i) Some of the upgoing wave energy may be scattered to points within the skip zone by irregularities in the $E$ region of the ionosphere, e.g. sporadic-$E$ ionization or the ionized trails of meteors.

(ii) After reflection at the level of the $E$ region, the downgoing wave may be partially scattered by irregularities on the Earth's surface and part of this scattered radiation may be returned to a receiver in the skip zone via the $E$ region.

(iii) Backscatter may be returned from irregularities on the Earth's surface after the wave has undergone more than one reflection at the $E$ region, i.e. higher order or multiple-hop echoes of the type (ii).

(iv) Backscatter may arise as in (ii) with the $F_2$ layer being the reflecting medium.

(v) Multiple-hop backscatter of type (iv) may occur.

(vi) After reflection at the $F_2$ layer, part of the downgoing wave energy may be backscattered by irregularities in the $E$ region.

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(vii) Backscatter may be caused by the scattering of part of the upgoing wave energy by irregularities in the $F_2$ region.

(viii) Energy may be backscattered, at frequencies higher than the critical penetration frequency of the $F_2$ layer ($f_0F_2$), from irregularities above the height of the maximum ionization density of the regular $F_2$ layer.

(ix) Combinations of all the above modes may operate to produce backscatter, e.g. an upgoing wave may be scattered and deviated by irregularities in the $E$ region and the scattered energy may travel up to the $F_2$ layer from whence it may be reflected back to ground within the skip zone.

These various backscatter types, (i)-(ix), are illustrated in Figure 1.

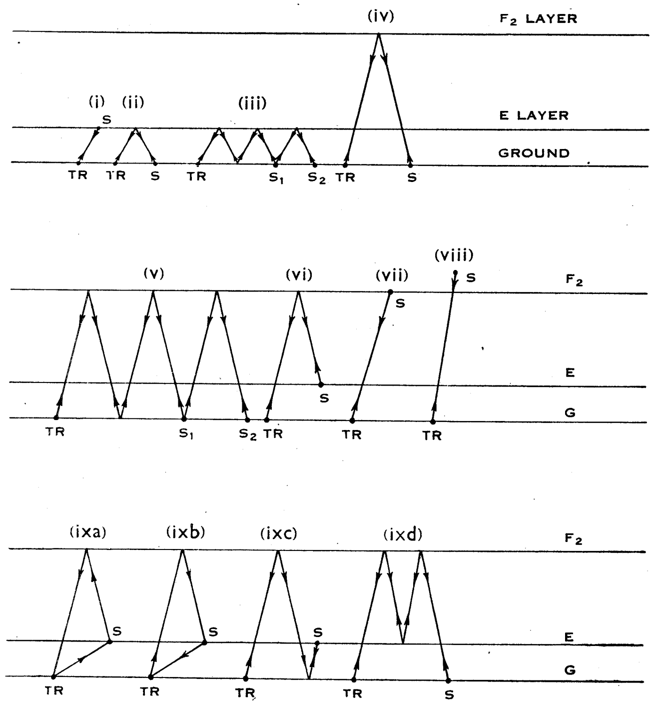


Fig. 1.—The possible sources of backscatter. *TR* denotes transmitter/receiver and *S* is the scatter source.

Backscatter was first observed about 1926, but it was almost neglected until Eckersley (1940) published a lengthy paper suggesting that backscatter could be divided into two classes, short and long scatter. The short scatter was supposed to arise in the manners (i) and (ix*b*) shown in Figure 1 and the long scatter in the manner (vi). Eckersley had neglected several factors in his work and Edwards and Jansky (1941) proposed, contrary to Eckersley, that the majority of long scatter arose in the manner (iv). However, the results of Edwards and Jansky were not regarded as conclusive owing to the inherent inaccuracy of their measurement technique.

Papers have been published subsequently reporting the occurrence of the various backscatter types. Most authors are agreed upon the origins of short scatter, stressing types (i) and (ii) as the most important. Regarding long scatter, Eckersley, Millington, and Cox (1944) rather inadequately supported the theory that type (vi) is the most prominent and Benner (1949), Peterson (1949, 1951), Hartsfield, Ostrow, and Silberstein (1950), Kono (1950), Abel and Edwards (1951), Dieminger (1951), Hartsfield and Silberstein (1952), and Silberstein (1953, 1954) supported the theory that type (iv) is the most prominent. The papers of Dieminger, Abel and Edwards, and Silberstein are most significant and will be discussed further.

Abel and Edwards (1951), operating on frequencies of 9, 12, 16, and 22 Mc/s, compared the echo from a transponder with long scatter. They used four transponders at distances of 700, 1000, 1500, and 2000 km from their transmitter/receiver. As the ground range of one transponder for one of the four frequencies passed through the skip distance, the transponder and backscatter echoes merged, indicating a common origin, the ground. This was the principal result of this paper. However, some cases of disagreement with the common ground origin were noted and Abel and Edwards attributed these to further causes.

Silberstein (1954) used a sweep-frequency technique which displayed the backscatter over a wide frequency range on the same record as the normal vertical incidence ionospheric sounding. This is illustrated in Figure 2 where the expected characteristics of types (iv) and (vi) backscatter are shown in relation to the normal vertical incidence data. Under usual ionospheric conditions, Silberstein principally obtained records conforming with the typical type (iv) behaviour. His results were difficult to interpret during ionospheric disturbances, but they suggested a number of cases where backscatter was apparently type (vi).

Dieminger (1951) has reviewed backscatter research up till 1951. He also described his own results obtained using two experimental methods. His principal technique was the sweep-frequency experiment described above. Using this, he compared the observed backscatter characteristics with those theoretically expected for the different types. He made additional observations over long periods of the behaviour of backscatter on fixed frequencies. He identified many of the backscatter types, but his results showed type (iv) to be the dominant long scatter type in winter at least.

All previous reliable backscatter data have been obtained in the northern hemisphere, principally during winter and between latitudes 40 and 60°, and on frequencies above the $F_2$ layer critical penetration frequency. These data suggest that the most common form of scatter observed in winter is type (iv). Few summer observations have been reported and these suggest that type (i) scatter is relatively common then, especially during the midday period.

Facilities existed at the Weapons Research Establishment which, with little difficulty, were capable of being adapted for studying backscatter. Equipment, including a high power transmitter in conjunction with four differing aerial systems and a cathode-ray direction finder, was made available on a part-time basis to the present author to enable him to examine several outstanding problems in connexion with backscatter. Principal among these problems were the identification and occurrence ratio of the various scatter types during summer and winter at a temperate latitude southern hemisphere station, a comparison of scatter from land and from sea, and the possible detection of scattered echoes from prominent land masses, such as mountains. Further, due to the available frequencies, it was possible to examine scatter below the $F_2$ layer critical penetration frequency.

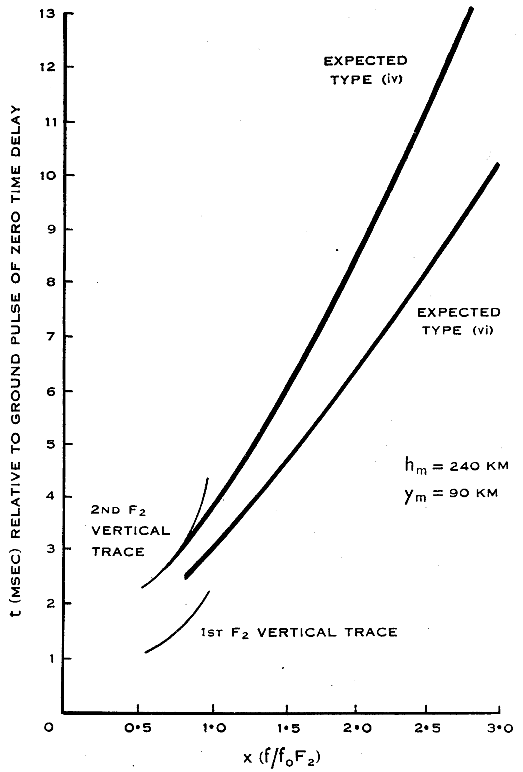


Fig. 2.—Theoretical behaviour of long scatter using sweep-frequency technique. ($h_m$ is height of $F_2$ layer maximum electron density and $y_m$ is the semi-thickness of the layer.)

## II. Equipment and Experimental Programme

A programme of measurement of the time delay $t$ relative to a ground pulse of zero delay and of the angle of elevation, $\alpha$, of the downcoming backscatter was commenced at Salisbury in October 1954. Observations were made on 28 days during October–December 1954 (summer) and on 40 days during May–July 1955 (winter). Most observations were made during the hours 1200–1400 L.M.T., but some observations were made during all hours from 0930 to 1930 L.M.T. The summer programme was carried out using only one transmitting aerial, while, during winter, four different aerials were used.

The outstanding feature of the adopted technique for examining backscatter was the comparative ease with which the various scatter types could be recognized. Two distinct sets of circumstances were encountered, namely, when $F_2$ vertical returns were present and when they were absent. The frequency and observational conditions were so chosen that the former condition usually prevailed. This meant that the theoretical and observed properties of backscatter could be related very easily to the properties and time delays of the observed $F_2$ verticals independently of any subsidiary vertical incidence ionospheric soundings. Also, observational conditions were selected so that the periods when no $F_2$ verticals were recorded were immediately preceded by

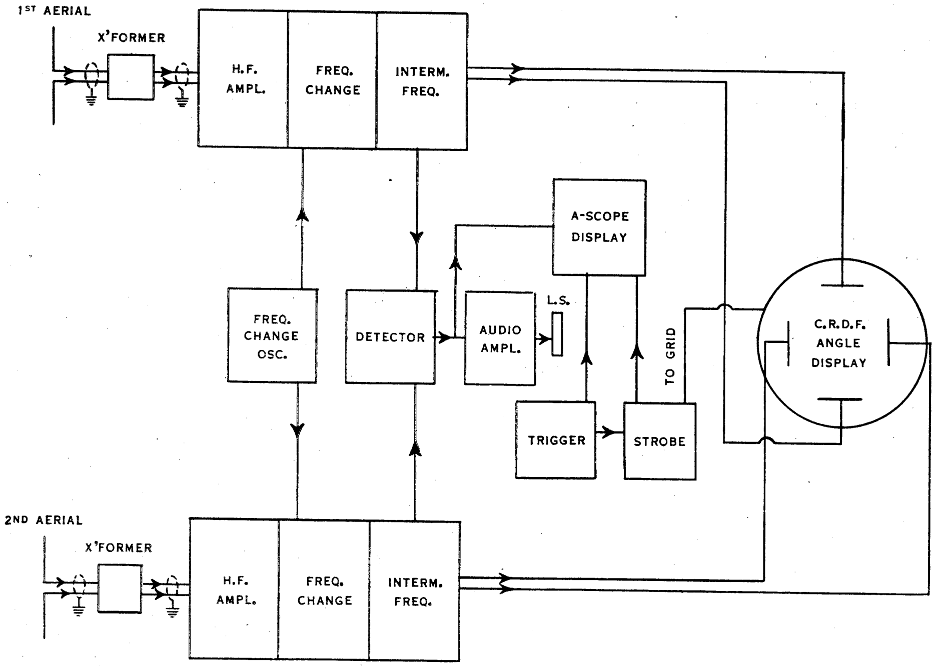


Fig. 3.—Block diagram of receiving equipment.

periods when $F_2$ verticals were present. Consequently, it was always possible to follow the different backscatter type echoes through the transition from one set of conditions to the other. These theoretical properties of the various backscatter types have been discussed at great length in the literature (Eckersley 1940; Dieminger 1951; Peterson 1951; McCue 1955) and they will not be described again here.

Attention was focused during the Salisbury experiments on scatter types (i)–(vii). It is possible that other scatter types occurred which escaped detection owing to attention being confined to the seven selected types which were expected to be most common.

The transmitter produced pulses the low frequency envelope of which was a half-sine wave of 300–600 $\mu$sec duration at a pulse repetition frequency of 50 c/s with a mean power of several hundred watts. The receiving system consisted of two vertically spaced parallel horizontal 30 ft dipoles at heights of 40 and 70 ft above the ground and coupled to the twin receiver channels of a cathode-ray direction finder (CR.DF) which is essentially a phase and amplitude comparator (de Walden *et al.* 1947). The CR.DF display was intensity-modulated by a strobe of variable width and time delay, enabling any specific part of the backscatter echo pattern to be examined separately. The strobe was added also to the time base of an A-scope display which was fed from a detector stage of the CR.DF—see Figure 3. The differing polar diagrams of the two dipoles enabled the elevation angle to be measured on the CR.DF, while $t$ was recorded from the A-display unit. All observations were made visually. The CR.DF

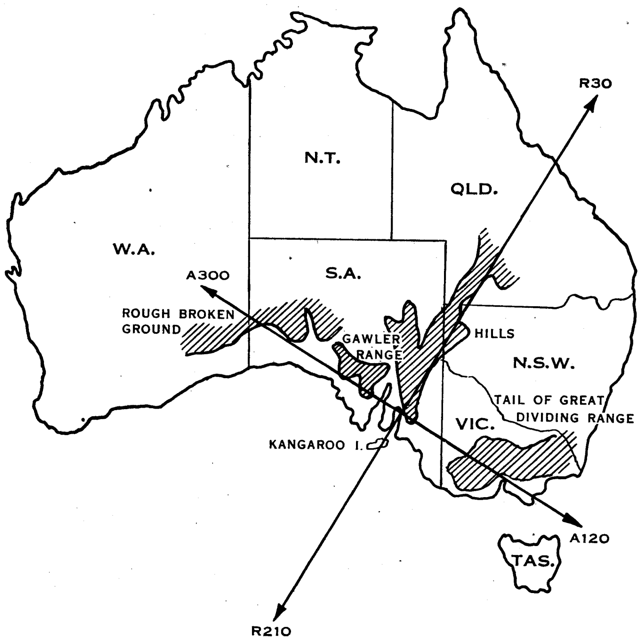


Fig. 4.—Map of Australia showing the orientations of the transmitting aerials used at Salisbury. The shaded areas indicate hilly or mountainous country.

display was calibrated against actual angle of elevation using a signal transmitted from an aeroplane whose position was measured using graduated binoculars. The CR.DF angle calibration curve was found to be independent of azimuthal direction.

The four transmitting aerials used during these experiments were:

(1) An array aerial which gave a unidirectional beam 15° wide in azimuth and about 70° wide in elevation. Its side lobes were down at least 10 dB on the main beam which was directed 120 °E. of N. from Salisbury, i.e. towards Melbourne. This was the aerial used during summer and will be called the A120 aerial throughout this paper.

(2) The above array reversed to point 300° E. of N. from Salisbury, i.e. towards the border of South Australia and Western Australia (denoted by A300).

(3) A rhombic aerial which was designed to have its maximum radiation directed at 23° to the Earth's surface and towards 210° E. of N. from Salisbury, i.e. over Kangaroo Island towards the Southern Ocean (R210).

(4) The above rhombic reversed to point 30° E. of N., i.e. towards Broken Hill (R30).

The orientations of these aerials are depicted in Figure 4, where the shaded areas on the map indicate hilly or mountainous country which may be prominent sources of backscatter. The rhombic polar diagram was not as simple as that of the array and allowance had to be made for this when interpreting the observations obtained using the rhombics.

## III. The Occurrence of the Various Scatter Types

Seven backscatter types, (i)–(vii), were observed at Salisbury during summer using the A120 transmitting aerial and during winter using the four aerials, A120, A300, R30, and R210. Type (iv) was by far the most commonly recorded scatter type during both seasons, independently of the aerial used and of the presence of $F_2$ verticals. Type (v) was the next most commonly observed type when $F_2$ verticals were present, but, when no $F_2$ verticals were to be seen, type (i) was more common than type (v). The rarest scatter type was (iii) followed by (vi), (vii), and (ii) in increasing rate of occurrence. Types (i) and (ii) appeared more common in summer than in winter.

The frequency used in these experiments was normally chosen in relation to ionospheric conditions to lie between $0 \cdot 8$ and $1 \cdot 2$ times the critical penetration frequency of the $F_2$ layer and the occurrence of the different scatter types is dependent upon the frequency used and its proximity to the $F_2$ layer critical condition. Consequently, if different frequencies had been used, slightly different results might have been obtained, e.g. if a sufficiently low frequency had been selected, types (i) and (ii) might have been more common. Alternatively, different results might have been obtained by selecting different observing times, e.g. night instead of day. Some observations continued into the night showed that, as the $F_2$ layer electron density decreased, the $F_2$ layer-dependent scatter types gradually moved out in time-delay range and decreased in elevation angle until they finally disappeared leaving only intermittent types (i) and (ii) echoes.

Usually, several backscatter types were simultaneously present and the scatter type combinations observed at Salisbury are listed in Table 1. Of these 17 recorded combinations, the four most commonly observed were, in decreasing order, (1) iv and v, (2) i and iv, (3) iv alone, and (4) i, iv, and v. All combinations involving types (iii) and (vi) were comparatively rare.

That other combinations were not observed does not deny their having occurred. It means only that they were not common and that they were not identified when they may have been present. The observed combinations are the simplest and they would be expected to be the most common. Two combinations which probably occurred and which escaped detection are (1) i, iv, vi and (2) i, iv, v, vi. These could have occurred without being recognized because of the extreme difficulty of simultaneously identifying the two essentially intermittent types (i) and (vi) in the presence of other types.

TABLE 1

OBSERVED SCATTER TYPE COMBINATIONS

| Number | Combination | Number | Combination |
|---|---|---|---|
| 1 | i | 10 | i, iv, v |
| 2 | iv | 11 | iv, v, vi |
| 3 | i, ii | 12 | iv, v, vii |
| 4 | i, iv | 13 | i, iv, vii |
| 5 | iv, v | 14 | i, ii, iii, iv |
| 6 | iv, vi | 15 | i, ii, iv, v |
| 7 | iv, vii | 16 | i, iv, v, vii |
| 8 | i, ii, iii | 17 | i, ii, iii, iv, v |
| 9 | i, ii, iv | | |

## IV. SCATTER TYPES (I), (II), (III), (VI), AND (VII)

While the principal purposes of these experiments at Salisbury were to compare backscatter from sea and from land and to detect scattering from prominent land masses using scatter types (iv) and (v), it was possible to make observations on other scatter types than those essential to these objectives.

Scatter types (vi) and (vii) were observed on a number of occasions and found almost exclusively between angles of 60 to 90° to the Earth's surface and principally from 75 to 90°. The elevation angle of type (vi) often varied through a wide range in a short time without appreciably altering in time delay, indicating the passage of sporadic-$E$ clouds and the ionized trails of meteors. Type (vii) was most commonly observed when the experimental frequency was passing through the $F_2$ layer critical penetration frequency and it was seen to form at the trailing edge of the first $F_2$ vertical echo.

Types (ii) and (iii) were observed over a wide range of angles from 22 to 90°. Too few measurements were made on type (iii) to enable more to be said concerning it than that it appeared to be the rarest of the recorded types. Type (ii) occurred intermittently and usually persisted for a period of seconds to minutes although, on one occasion at least, it appeared on-and-off with remarkable persistence for over an hour. It has always been observed in the presence of type (i), but the angular ranges of these two types often differed. Type (ii) was more common in summer than in winter.

Type (i) was very common, having been identified during 65 of the 68 observational periods during summer and winter. It was more common during summer than in winter, though it would not appear so common during the summer midday period at Salisbury as in Europe. It occurred intermittently at all angles from 15 to 90° with widely varying field strengths. Sometimes, it persisted for long periods and, when it did, it showed rapid and deep fading—particularly in winter. Also, it often showed the large angle changes in a short time with no appreciable time-delay change which suggest the passage of sporadic-$E$ clouds and the ionized trails of meteors. Some preliminary estimates of the speed of movement of the observed meteors indicated values between 30 and 50 km/sec.

Since the polar diagrams of the A120 and A300 aerials were so simple, an attempt was made to check the observed occurrence rate of type (i) echoes with elevation angle for these aerials against that expected if the scattering clouds of sporadic-$E$ ionization were random in spatial occurrence for frequencies between 6·0 and 7·5 Mc/s. In accordance with this hypothesis, the number of echoes received in a given $\alpha$-range should be proportional to the ionospheric area illuminated by the transmitted beam in this $\alpha$-range. This would be reasonably true only near the vertical where the effects of signal attenuation and of the physical mechanism producing the scatter would not vary appreciably with angle. It was considered that this would hold down to 50°. The $\alpha$-range, 51–90°, was subdivided into four divisions (51–60°, 61–70°, 71–80°, 81–90°) and the ratios of observed to expected occurrence rates were computed. The results obtained were in reasonable agreement with the stated hypothesis for the winter midday period at Salisbury. There were insufficient observations of the correct form to allow this comparison for summer. The winter ratios were :

(1) 0·84 for the $\alpha$-range 51–60°
(2) 1·08 for the $\alpha$-range 61–70°
(3) 0·84 for the $\alpha$-range 71–80°
(4) 0·94 for the $\alpha$-range 81–90°.

One effect of the presence of scatter types (i), (ii), and (iii) was to cause the amplitude of any simultaneously present types (iv) and (v) scatter to decrease and to fluctuate very rapidly. This was because part of the energy which normally would have produced scatter types (iv) and (v) had been used producing these other types. The presence of these three $E$ region scatter types did not always influence the whole of the observed types (iv) and (v) echoes, e.g. if type (iv) was observed over the $\alpha$-range 40–80° and a type (i) echo occurred with an $\alpha$-range from 60–70°, it was only the type (iv) echo in the $\alpha$-range of 60–70° which was affected. Sporadic-$E$ ionization was sometimes sufficiently dense, particularly during summer, and persistent to prevent any energy reaching the $F_2$ layer and, consequently, it prevented the occurrence of the scatter types (iv) and (v).

## V. Scatter Types (iv) and (v)

### (a) *General Observations*

Summer observations on scatter types (iv) and (v) were made using only the A120 aerial and the more comprehensive winter data were obtained using the four transmitting aerials. The more intense and more persistent sporadic-$E$ ionization in summer made observation of these two scatter types more difficult than in winter. Consequently, for these two reasons, the summer data are relatively incomplete compared to the winter data and the following discussion will refer only to the more comprehensive winter results. However, the summer and winter A120 measurements were in agreement on all points discussed below.

Most of the subsequent discussion, unless specifically stated otherwise, will refer to observing conditions when $F_2$ verticals were present. However, some comparison has been made between the scatter results when $F_2$ verticals were present and when absent. The principal observations were that, when no $F_2$ verticals were present:

(1) The $\alpha$-range of the scatter was less, usually depending upon how far the frequency used was above the $F_2$ layer critical frequency.

(2) The scatter at the lower angles was stronger, i.e. below about 40°. This was undoubtedly due to the time-delay focusing of the rays at lower angles.

(3) As the $F_2$ layer electron density decreased, the types (iv) and (v) scatter, observed on a given frequency, moved out in time-delay range and decreased in elevation angle until type (v) disappeared and finally type (iv) disappeared.

It was normal to make observations using at least two of the four transmitting aerials on each day and type (iv) scatter was observed during all the winter observing periods. Type (v) was identified on 36 of these 40 days.

The angle of elevation frequency distributions for these two scatter types for the four differing transmitting aerials are shown in Figures 5–9 and these data form the principal basis of most of the subsequent discussions. These angle distribution curves give the total number of occasions or observations during all observing periods when scatter of a given type was observed at each elevation angle for each aerial when $F_2$ verticals were present. Observations were recorded at approximately 10-sec intervals and the angle was read with an accuracy of $\pm 1°$. The data sampling method was designed to produce comparable results for each scatter type on the four aerials. In the diagrams presented, no results are quoted for angles greater than 83° as, above this angle, the returned signals were not considered to be scatter but to be reasonably specular reflections.

The type (v) angle distribution characteristics were the same as those of type (iv), as was expected, with one exception. The lowest angle at which scatter was observed was lower for type (iv) than for type (v). Overall, type (iv) was observed at all angles from 22 to 83°. This low-angle discrimination was expected since scatter was generally weaker at the lowest angle and, in the case of multiple-hop scatter, this weaker low angle scatter would be the first to fall below the sensitivity of the receiving equipment.

It was also essential to understand the problems incurred by the use of four differing transmitting aerials before comparing the results obtained using them. The A-scope time delays and the CR.DF $\alpha$-ranges observed at any given time were different on each of the four aerials. The three possible causes of this were examined and allowance was made for them when interpreting the experimental results, namely,

(1) the different aerial polar diagrams,
(2) the different scatter sources involved,
(3) the different ionospheric conditions with direction of transmission.

Additional complexity was introduced into the experimental technique by high-angle ray effects and ordinary/extraordinary ($o/x$) wave component effects.

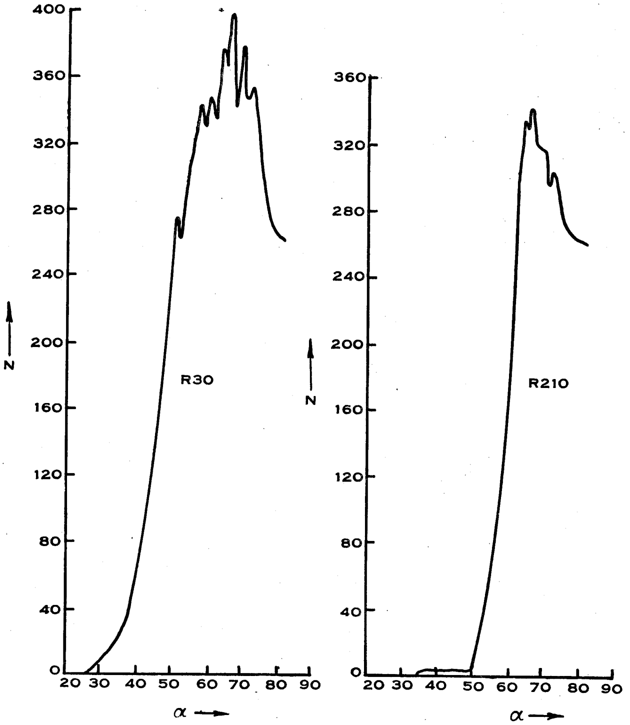


Fig. 5.—Number of occasions, $N$, during winter 1955 when scatter type (iv) was observed at various elevation angles ($\alpha$) on the R30 and R210 aerials using scatter of all amplitudes.

High-angle ray effects were comparatively rare and were seen usually when the operating frequency was very close to the $F_2$ layer critical frequency and below it. One case of this effect was noted when the operating frequency was approximately $1 \cdot 2$ times the $F_2$ critical frequency. This effect was readily identified when present by the typical increase of elevation angle with time delay and was normally noted when only one wave component could be distinguished.

The $o/x$ wave-component separation was observed frequently and, when it occurred, it was usually simple to identify the component producing the scatter. This was because the time-delay separation of the components was large enough, when associated with the time-delay focusing of the rays, to enable the $o/x$ scatter components to be separated.

### (b) *Scatter from Land and from Sea*

Backscatter from land and from sea were compared using the types (iv) and (v) elevation angle measurements made on the R30 and R210 aerials. The R30 aerial was directed over rough hilly ground towards Broken Hill and the R210 aerial was directed towards the Southern Ocean, i.e. mainly over sea. Two cases were examined, i.e. when $F_2$ verticals were present and when they were absent.

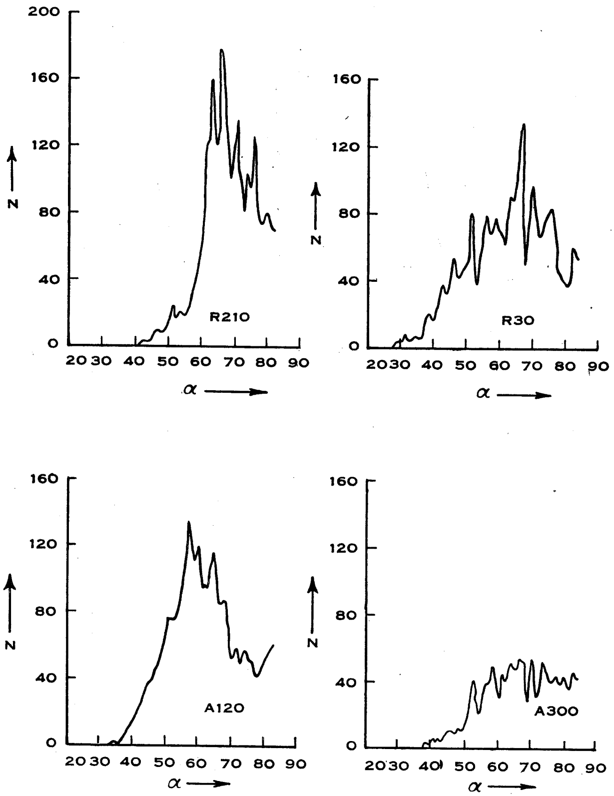


Fig. 6.—Number of occasions, $N$, during winter 1955 when scatter type (iv) was observed at various elevation angles ($\alpha$) on the four aerials using only scatter amplitude maxima.

Considering the case when $F_2$ verticals were present, it can be seen from Figure 5 that, using backscatter of all amplitudes, the lowest angle at which type (iv) scatter was received using R30 was 29°, while, for R210, it was 43°. This was a difference of 14°. Similarly, from Figure 6, using only the observed amplitude maxima of type (iv) scatter, the lowest angle for R30 was 27° and, for R210, it was 35°—a difference of 8°. From Figures 7 and 8, it can be seen that for type (v) scatter, these differences are both 16°, with the R30 minimum being the lower in each case.

It was difficult to compare results when the operating frequency was greater than the $F_2$ critical frequency because there was no accurate method available at Salisbury for determining the $F_2$ critical frequency at any time. However, some comparison was possible for times when the frequency used was known to be very close to the $F_2$ critical frequency. Under these conditions, there was still a 10–12° difference between the lowest angles observed on the two R-aerials with R30's value the lower.

The general conclusion from the above observations is that the sea is not so pronounced a scatter source as is the land at low angles of elevation. This is certainly true for the present example. The complex polar diagram properties

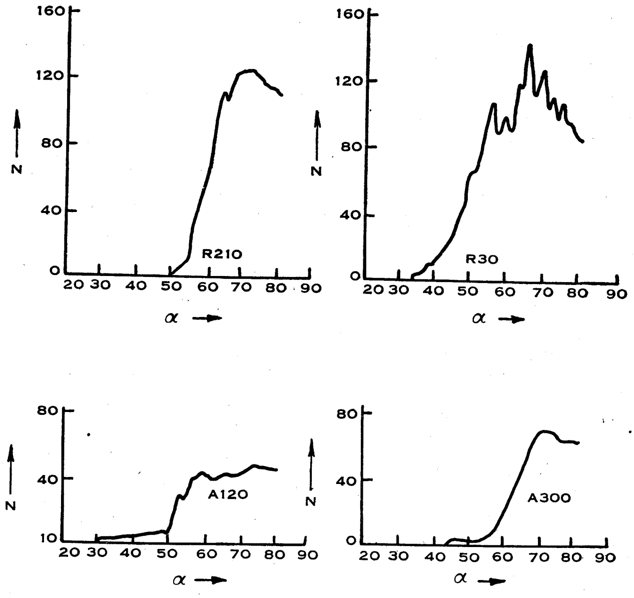


Fig. 7.—Number of occasions, $N$, during winter 1955 when scatter type (v) was observed at various elevation angles ($\alpha$) on the four aerials using scatter of all amplitudes.

of the rhombics were examined and they do not influence this result, as the major side lobes were approximately in the forward direction, i.e. over land for R30 and over sea for R210.

### (c) *Scatter from Prominent Land Masses*

It was thought that the scattering effects of prominent land masses, such as mountain ranges, should be discernible in the A120 and A300 winter elevation angle data. Data, obtained only when $F_2$ verticals were present, were used to enable full use to be made of the broad polar diagram patterns of the array aerials in the elevation plane. These polar diagrams were measured to be reasonably uniform over the $\alpha$-range from 22 to 90°. The data from R-aerials were not used in this study as they were used to demonstrate the land/sea difference and their polar diagrams were too complex to permit any detailed analysis of their corresponding angle data.

As for the land/sea comparison, the first point arises from an examination of the angle minima at which types (iv) and (v) scatter were received using the two A-aerials. It can be seen from Figure 9 that, using scatter of all amplitudes, type (iv) was received at 22° on A120 and the lowest angle for A300 was 31°. From Figure 6, using only the observed amplitude maxima, type (iv) was received at 34° on A120 and its lowest angle for A300 was 37°. It can be seen from Figure 7 that, using scatter of all amplitudes, type (v) was received at 31°

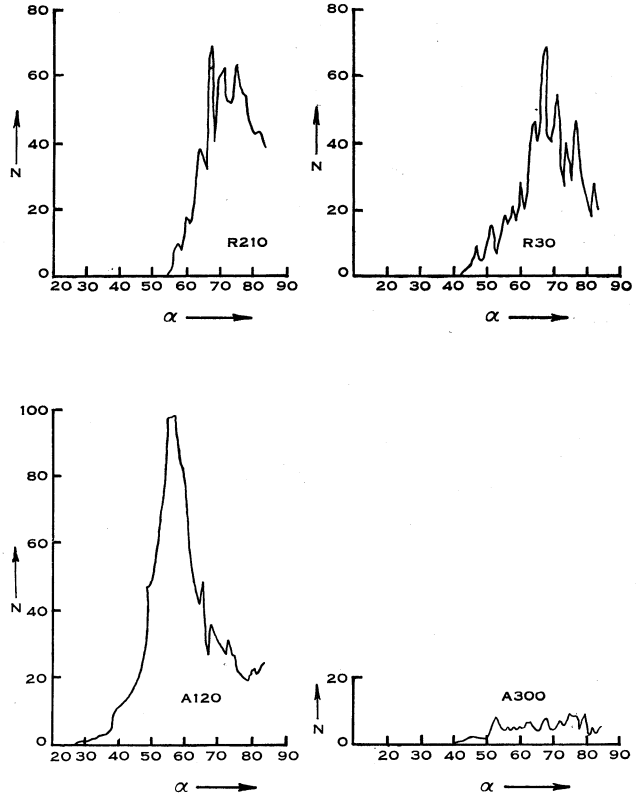


Fig. 8.—Number of occasions, $N$, during winter 1955 when scatter type (v) was observed at various elevation angles ($\alpha$) on the four aerials using only scatter amplitude maxima.

for A120 and its lowest angle for A300 was 46°. Again, using only amplitude maxima, Figure 8 shows type (v) to have been received at 28° on A120 and at a minimum angle of 41° on A300. These observations suggest that there were more prominent land scattering sources at distances corresponding to low angles of elevation along the direction 120° E. of N. from Salisbury than along 300° E. of N. This was verified by the nature of the terrain as shown in Figure 4.

As indicated previously, the backscatter echo pattern when viewed on the A-scope display, presented a ragged appearance with definite amplitude maxima. Angle measurements were possible on all echoes seen on the A-display independently of their amplitude or only on the amplitude maxima echoes. The A120 and A300 type (iv) angle distributions shown in Figure 9 were examined. The A120 measurements show a maximum occurrence rate at 58° and there tends to be another maximum towards 90°. The A300 data show an occurrence maximum between 65 and 74° and there again tends to be another maximum towards 90°. These 90° maxima were due to the occurrence of the second-order $F_2$ vertical reflections, but the other maxima must be due to the presence of prominent scattering sources on the ground at distances corresponding to these angles. The possibility that these maxima could have been due to receiver aerial characteristics was examined and a negative result was obtained. The

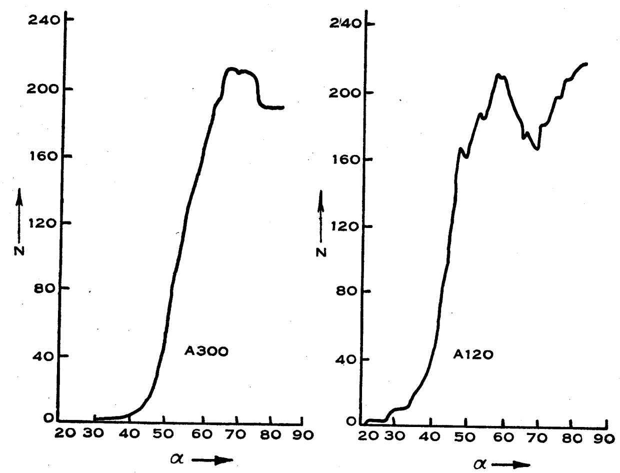


Fig. 9.—Number of occasions, $N$, during winter 1955 when scatter type (iv) was observed at various elevation angles ($\alpha$) on the A300 and A120 aerials using scatter of all amplitudes.

same occurrence maxima can be observed if the type (iv) amplitude maxima data are used, as seen in Figure 6. Figures 7 and 8 show that the type (v) observations present this same result.

A search for the possible scatter sources which would produce these occurrence and amplitude maxima revealed that an excellent correspondence was obtained if the A120 scatter maxima at 58° were caused by the Grampian mountains at the end of the Great Dividing Range and if the A300 scatter maxima between 65 and 74° were caused by the Gawler Range—see Figure 4.

The possibility that these occurrence and amplitude maxima were merely apparent and due to the blanketing effects of sporadic-$E$ ionization was also examined and found to be unimportant. It was concluded that, if any sporadic-$E$ blanketing effect did occur, it would tend to minimize the effects described. Also, the recurrence maxima at 68° for type (iv) scatter on the R-aerials were not significant as they were due to subsidiary maxima in the polar diagrams of these aerials.

## VI. Canberra and Salisbury $F_2$ Layer Critical Frequencies

There is an ionospheric observatory at Canberra which is approximately 1000 km due east of Salisbury. It was thought possible that the Canberra vertical incidence data would be suitable for comparison with the Salisbury backscatter data. However, it was found that the $F_2$ layer critical penetration frequencies measured at Canberra were nearly always less than those indicated at Salisbury by the presence of $F_2$ layer vertical returns on various frequencies when adjusted to the same L.M.T.'s.

On about 30 occasions during the summer midday period when a comparison was possible, the Canberra $F_2$ critical frequency was of the order of 1 Mc/s less than the indicated Salisbury value. On about 70 occasions during the winter midday period when a comparison was possible, the Canberra $F_2$ critical frequency was of the order of $0 \cdot 6$ Mc/s less than the indicated Salisbury value. The magnitude of this difference, which was not expected, prevented the suggested comparison. This observation may be of particular interest to users of ionospheric communication circuits.

## VII. Concluding Remarks

High-frequency backscatter was examined experimentally at Salisbury during summer 1954 and during winter 1955 using a pulse technique which consisted of simultaneously measuring the elevation angle of arrival and the time delay (with respect to a ground pulse of zero delay) of the scatter. Observations were confined mainly to conditions when the frequency used was between $0 \cdot 8$ and $1 \cdot 0$ times the $F_2$ layer critical penetration frequency.

Seven backscatter types were distinguished which showed both ionospheric and ground origins. The most common of these was backscatter from the ground via the $F_2$ layer—type (iv). Combinations of backscatter types were observed and the most complex of these was a combination of types (i), (ii), (iii), (iv), and (v). A comparison of scatter from land and from sea revealed the land to be the more prominent scatter source at low angles of elevation. Further, scatter from outstanding land masses was identified during the observations on types (iv) and (v).

The effects of aerial polar diagrams on backscatter were examined and found to be important. High-angle ray and ordinary/extraordinary wave component effects were studied as also was the influence of the occurrence of scatter types (i), (ii), and (iii) on the amplitude and occurrence rates of types (iv) and (v).

An unexpected result, found in connexion with this backscatter investigation, was that the $F_2$ layer critical penetration frequency at Canberra was almost invariably significantly lower during the midday period than that at Salisbury.

## VIII. Acknowledgments

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