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TECHNICAL SERVICES DIVISION

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<u>TITLE</u>: Experimental Tests with Orthogonal Transmission (MF)

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Abstract

Propagation tests indicate that the sky-wave field strength from a medium frequency broadcasting transmitter can be reduced by 16dB on paths to the north at mid-latitudes in the southern hemisphere, when vertically polarised transmission is replaced by orthogonal transmission. The reduction is observed to vary with time and path bearing, the variation with time being such that, during any one night, the median reduction is a maximum when the field strength is high, and a minimum when the field strength is low. Short term variations are considered to be consistent with a small variation in the limiting polarisation of the ionosphere, and ray deviations from the most direct path. Long term variations are considered to be due to changes in the nondeviative absorption from night to night. The observed change in improvement factor with path bearing is in agreement with that expected for the transmitting aerial configuration. Implementation of this system awaits the development of suitable transmitting aerials.

Experimental Tests with Orthogonal Transmission

Introduction

Sky-wave interference between common channel medium frequency broadcasting stations radiating different programmes is restricted in system design, either by common channel allocation to stations with adequate geographical spacing, or by the provision of directional transmitting aerials. A further method of sky-wave field strength reduction was proposed in 1965 with the development of orthogonal transmission[1], which involves a previously unexploited means of signal reduction. This system relies upon certain characteristics of radio wave propagation through the ionosphere for the reduction of sky-wave signals. Close coupling must exist between the radio wave incident upon the lower boundary of the E layer and the extraordinary mode of propagation through the lower E region. Transmission via the extraordinary mode, at frequencies close to the gyro frequency, is subject to considerably greater absorption than that via the ordinary mode, the latter usually being dominant for vertically polarised transmission. Orthogonal transmission is achieved by radiating a linearly polarised wave for paths in which the incident wave is perpendicular to the earth's magnetic field, and an elliptically polarised wave for all other paths.

Initial propagation tests, conducted to confirm theoretical predictions, were successfully completed in 1965. Over a period of several hours, the reduction of sky-wave field strength was observed to vary from 12dB when the field strength was low, to 20dB when the field strength was high, the median reduction being 16dB. This paper gives details of further tests arranged to determine the potential improvement in system performance available over a large area. Characteristics of the received signal are also discussed.

Propagation Test Procedure

As in the first series of tests, south north paths were investigated by operating alternatively with vertically polarised transmission(2 minutes), and with orthogonal transmission (3 minutes), the same power being transmitted from the vertical aerial in each case. For the purpose of evaluation, the improvement in system performance is taken as the ratio of median sky-wave field strength with orthogonal transmission $E_{(V+H)}$ to median sky-wave field strength during the preceding period of vertically polarised transmission $E_{(V+D)}$.

This ratio was previously termed the improvement factor. Its reciprocal, stated in dB, is referred to as the sky-wave reduction, and is a more convenient quantity to consider in some instances.

The same transmission equipment, optimum power division, and optimum phase change between aerial feed lines, were used as in the previous tests. Field strength recordings were made at Hillston, where optimum adjustments of the transmitter power division and phase change networks had been determined, and at five other locations dispersed generally along radials from Hillston. Figure 1 shows the position of the transmitting station and receiving points.

Details of conditions selected for the test are as follows:-

Transmission frequency: 1230Kc/s

Transmitter power: 2 KW

Transmitter location: Sydenham near Melbourne (50KW National broadcasting transmitters 3AR and 3LO are operated at this site)

Transmitting aerials:

Vertical - the 708 feet guyed mast used for 3AR and 3LO.

Horizontal - a half wave dipole slung from the vertical mast at a height of 445 feet, and supported by nylon cords tethered 1000 feet on either side of the mast at ground level (magnetic bearing of anchor points 88° and 268°),

Receiving Sites: Hillston, Deniliquin, West Wyalong, Harden, Cobar and Wilcannia.

Duration of test: transmission on five nights from 00 20 hrs to 0500 hrs E.S.T.

Table 1 contains information on the paths investigated and the median of results obtained on each night. Figures 2,3,4,5, 6 and 7 show the improvement factor variation with field strength. Two field parties were used so that recordings could be made simultaneously at Hillston and at one of the other sites.

The median sky-wave reduction measured on 50% of the nights at Hillston is 16dB. No significant change is apparent in this reduction on the northern or southern radials from Hillston out to a distance of 140 miles, but results obtained along the eastern radial and to the north west reveal a change in the median sky-wave reduction to 13dB at a distance of 100 miles from Hillston (path bearing 19° from the path Sydenham-Hillston) and to 8.5dB at a distance of 180 miles from Hillston (path bearing 34° from the path Sydenham-Hillston). These results are consistent with the expected trend for the transmitting aerial configuration. The decrease in sky wave reduction to the east and west of Hillston is due mainly to an incorrect inclination of the polarisation ellipse of the signal radiated in these particular directions.

TABLE 1

Date	Reception Site	Distance from Sydenham miles	Bearing of path relative to that of Sydenham-Hillston path	Distance and direction from Hillston miles	Median improvement factor $\frac{E_{(V+H)}}{E_{(V+D)}}$	Median field strength $E_{(V+D)}$ mv/m
8th March 1967	Deniliquin	151.5	4.5°W	144.5S	0.19	0.54
9th " "	West Wyalong	295	19° E	101 E	0.22	0.38
10th " "	Harden	295.5	34° E	178.5E	0.38	0.19
12th " "	Cobar	431.5	0.5°W	137.5 N	0.17	0.21
13th " "	Wilcannia	431	19° W	182 NW	0.22	0.16
30th August 1965	Hay	222	7.5°W	81 S	0.15	0.38
29th " "	Hillston	295	0	0	0.19	0.36
8th March 1967	"	"	"	"	0.16	0.40
9th " "	"	"	"	"	0.16	0.32
10th " "	"	"	"	"	0.09	0.25
12th " "	"	"	"	"	0.19	0.39
13th " "	"	"	"	"	0.12	0.18

Signal Characteristics

Results obtained at each location and on each night of both test series display much the same characteristic, in that the sky-wave reduction is a maximum when the field strength is high and a minimum when the field strength is low. This was previously reported to be due to the relatively steady median signal with orthogonal transmission. Reasons for this characteristic are considered later, but for the time being it is emphasised that the general statement on improvement factor variation refers specifically to results obtained during any single night. When the results for several nights are considered, a different variation is revealed. The upper curve in figure 2 shows the improvement factor on nights when the field strength $E_{(V+D)}$ is high. The lower curve shows the situation when the field strength is low.

This is the expected general form of the variation for a system in which most of the absorption is nondeviative. The ratio of absorption indices for the extraordinary and ordinary waves depends upon the collision frequency of electrons with heavy particles relative to the transmission frequency, and on the separation of the transmission frequency from the gyrofrequency. The absorption index ratio χ_-/χ_+ is a maximum when the transmission frequency coincides with the gyrofrequency.

An increase in nondeviative absorption for vertically polarised transmission, should be accompanied by a greater reduction in field strength with orthogonal transmission due to the exponential nature of wave attenuation an an ionized medium. This can be shown from the equations for wave attentuation.

In the case of reception at Hillston, the downcoming ordinary and extraordinary waves for one hop E are expected to be almost linearly polarised. Consequently, the extraordinary wave would not contribute to the received signal, due to a large coupling loss at the receiving aerial. However, if coupling exists between the ascending extraordinary wave and an ordinary mode, orthogonal transmission would produce a dominant ordinary wave even when no coupling errors exist at the base of the ionsphere. In the absence of such coupling between the extraordinary wave and an ordinary mode, there would

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be no discernible decrease in the sky-wave reduction with increase in field strength as shown in figure 2, other than that due to long term changes in the limiting polarisation. For the time being this possibility will be discounted in favour of the coupling concept. Such coupling would be produced by abrupt changes in refractive index resulting in refraction and partial reflection of the wave, as in the case of sporadic E layer reflection.

Only nondeviative absorption is considered in the following calculation.

$$\frac{E_+}{E_o} = e^{-\int_0^{l} \kappa dz} \qquad (1)$$

$$\frac{E_-}{E_o} = e^{-\int_0^{l/2} \beta \kappa dz} \; e^{-\int_{l/2}^{l} \kappa dz} \qquad (2)$$

where E_+ is the maximum field strength of the ordinary wave after passing through the ionosphere.

E_- is the maximum field strength after passing through the ionosphere, of the wave which begins as an extraordinary wave.

E_o is the maximum field strength of either wave upon entering the ionosphere (after coupling is established).

$\kappa = \frac{\omega}{c} \chi$, the absorption coefficient,

χ is the absorption index ,

$\beta = \chi_- / \chi_+$

l is the path length in the nondeviative absorption region.

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It therefore follows that

$$\frac{E_-}{E_+} = \left(\frac{E_+}{E_0}\right)^{\frac{\beta}{2}-\frac{1}{2}} \qquad (3)$$

$$d\left(\frac{E_-}{E_+}\right) = \left(\beta/_2 - 1/_2\right)\left(\frac{E_+}{E_0}\right)^{\frac{\beta}{2}-\frac{3}{2}} d\left(\frac{E_+}{E_0}\right) \qquad (4)$$

When the results in figure 2 are applied to equations 3 and 4, together with a reflection coefficient for the ionosphere derived from field strength predictions, the expected large value of β satisfies the equations only when the following assumptions are made:

(1) losses above the nondeviative region exceed the nondeviative absorption,

(2) the decrease in sky wave reduction with decrease in field strength is due to increased coupling errors at the base of the ionosphere, and consequently the appropriate improvement factor for this calculation is the effective minimum value i.e. that which corresponds to the upper decile of field strength,

(3) for the lower curve in figure 2, almost all the received signal during orthogonal transmission is due to coupling errors at the base of the ionosphere.

Because of these assumptions, it is impossible to determine a value for β from the measurements of field strength and improvement factor. What emerges from the calculation is a lower limit of 15 for β, the actual composite value probably being much in excess of this value.

For quasi longitudinal propagation, the relationship between β and the electron collision frequency is given by

$$\beta = \frac{(1 + Y)^2 + Z^2}{(1 - Y)^2 + Z^2} \qquad (5)$$

where $Y = \omega_H/\omega$

$Z = \nu/\omega$

ν = collision frequency of electrons with heavy particles,

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$$\omega_H = 2\pi f_H$$

f_H = gyro-frequency

The remaining characteristic to be considered is the change in improvement factor with change in field strength E (V + D) during any one night. Changes in the median improvement factor from night to night and the theoretical considerations discussed above, suggest that improvement factor variations throughout the night are not directly attributable to a variation in absorption properties of the ionosphere.

Extreme conditions are evident in the results for Hillston, where the median improvement factor varies from 0.1 to 0.25, and in results for Harden, where the median improvement factor varies from 0.22 to 0.7. Possible reasons for improvement factor variations are-

(1) changes in the limiting polarisation of the ionosphere with time,

(2) propagation along paths which deviate from the most direct path, due to scattering or ionospheric tilts,

(3) other processes of path deviation.

Recent measurements of the limiting polarisation of the ionosphere^2 at a low latitude station, show extreme variations in the polarisation ellipse axial ratio to be from 0.54 to 0.70 at vertical incidence, the transmission frequency being 3Mc/s. Variations of this magnitude would produce a change in improvement factor comparable with that observed at Hillston, but this explanation is not entirely satisfactory as it implies a correlation between changes in Mm (the polarisation ellipse axial ratio for the mode of propagation) and the sky-wave field strength. No measurements have been made to confirm this.

The generally small sky-wave reduction observed at Harden is obviously related to coupling errors produced by the transmitting aerial configuration. This is mainly due to an error in the polarisation ellipse tilt angle which amounts to 0.3 radians on this path. The change in improvement factor due to a variation in Mm with time is small compared with the residual value, and

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consequently changes in Mm with time could not produce the variation in improvement factor observed at Harden.

Figure 8 shows the calculated improvement factor with change in path bearing away from Hillston. Calculated values for West Wyalong, Wilcannia and Harden are in good agreement with the median measured values.

Variations due to changes in the direction of arrival must now be considered, but in order to proceed further, it is necessary to make certain assumptions regarding E region dynamics which are consistent with other forms of observation. Radio echo measurements [3] of meteor ionization have produced evidence of large scale turbulence and winds in the E region. Vapour trails ejected from rockets[4] also provide evidence of ionospheric winds. Munro and Heisler[5] reviewed the existence of perturbations in the ionosphere, but emphasised that very little is known concerning the formation, geographical distribution and global movement of large irregularities. It is therefore reasonable to postulate a travelling succession of extensive turbulent absorption regions embedded in a relatively stable and low absorption ionosphere. Conventional wave conditions may be expected to prevail when a stable low absorption region remains in the path, but during the passage of a large turbulent region, considerable scattering would occur, resulting in the reception of energy from regions of the ionosphere displaced from the most direct ray. Under these conditions, the signal received during orthogonal transmission would be from scattered waves arriving from parts of the ionosphere where coupling errors are greater than these along the most direct ray.

The received signal specular component would be lower than that during the period of stable conditions, but the scatter signal component would compensate for this, thereby producing a median signal which undergoes less variation than that observed during vertically polarised transmission. These are the field strength characteristics of orthogonal transmission.

The apparent direction of arrival (azimuth) at a transmission frequency of 1230Kc/s, varies considerably with time. Furthermore, this variation is greatest when the signal fades. There are two possible explanations of this phenomenon.

1. Two or more waves arrive from slightly different directions, producing a resultant magnetic field strength

$$H = H_1 \sin \Omega t + H_2 \underline{/\theta} \sin (\Omega t + \phi) \qquad (6)$$

where θ is the angle between the wavefronts when two waves are received, and ϕ is the phase difference between the two waves.

When $\phi \simeq 180^\circ$ and $H_1 \simeq H_2$, the apparent direction of arrival departs appreciably from the direction of arrival of either wave provided $\theta \neq 0$

When $\phi \simeq 0$ the apparent direction of arrival is between that of each wave.

2. Energy may arrive from the apparent direction of arrival due to scattering from turbulent regions or due to ionospheric tilts.

Figure 9 shows the apparent direction of arrival of 2NC (1230 Kc/s) observed at Melbourne. To be consistent with the hypothesis of scattering from a large area, and with the median results obtained at West Wyalong, Wilcannia and Harden, it would appear that measurements of the apparent direction of arrival have to be interpreted only as an indication that energy arrives from regions on either side of the most direct path, and not necessarily from only one side at any particular time. On the other hand, instantaneous values produce a dispersion of the improvement factor which is more in keeping with what would be expected when the wave arrives from the measured apparent angle of arrival. This can be seen in figure 10 which features a comparison of virtually simultaneous field strength values derived when switching between orthogonal transmission and vertically polarised transmission. A deviation of $\pm 12^\circ$ in the angle of arrival

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at Harden would be expected to produce an improvement factor varying from 0.24 to 0.75, whereas the same deviation at Hillston would merely increase the improvement factor to 0.15.

Single hop and two hop modes for the E layer and F layer further complicate the received signal component structure. Different errors in coupling for these modes and the variation of absorption with time and distance are expected to influence the correlation between instantaneous field strength values for orthogonal transmission and vertically polarised transmission. It is interesting to note that on paths with minimum residual coupling errors, no correlation exists between instantaneous values of $E_{(V+D)}$ and $E_{(V+H)}$, but a poor correlation is sometimes evident between median values. On paths containing an obvious coupling error, the degree of correlation between $E_{(V+D)}$ and $E_{(V+H)}$ is quite high for both instantaneous and median values. Instantaneous values are therefore almost as accurate as median values in determining optimum transmitter circuit adjustments for orthogonal transmission.

Figure 11 shows instantaneous field strength values for Hillston, Cobar, Wilcannia, West Wyalong and Harden. The influence of an ordinary wave component common to orthogonal transmission and vertically polarised transmission can clearly be seen with change in path bearing.

Though only partially substantiated by experimental observation, the influence of scattering, ionospheric tilts, changes in the limiting polarisation of the ionosphere with time, and the transmitting aerial configuration, provide an explanation of dominant features in the test results. During orthogonal transmission, the received signal may contain an ordinary wave component due to errors in coupling (constant and time varying), an ordinary wave component due to scattering from areas where coupling errors are more pronounced, and a component which originates from the extraordinary wave. All three components may be present during periods of low field strength $E_{(V+D)}$, whereas the scatter component may not be present when the field strength $E_{(V+D)}$ is high.

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Conclusion

The transmitting aerial system employed for these tests was designed primarily for propagation test purposes and not for broadcasting. This provided a convenient means of assessing some of the practical limitations imposed by the ionosphere and by the transmitting aerial system.

Orthogonal transmission has been shown to reduce the median sky-wave field strength by 16 dB on paths towards the north in the southern hemisphere. This reduction was evident over south-north paths extending from 151 miles to 431 miles, and is consistent with the transmitting aerial design which provided the required vertical radiation pattern ratio for angles of departure from 15° to 64°.

The reduction of sky-wave field strength decreased for paths with eastward or westward components, due to the transmitting aerial system design which produced excessive errors in the required transmitted signal polarisation ellipse tilt angle ψ_i. The calculated sky-wave reduction for such paths is close to the median measured value (13 dB at $\pm 19^\circ$, and 8.5dB at $+34^\circ$). With a more suitable design of the transmitting aerial system to permit transverse separation of the aerial phase centres, it should be possible to increase the area of maximum reduction, but practical difficulties may be encountered in providing a separation.

The results are consistent with a large ratio of the absorption indices χ_-/χ_+ only if coupling exists between the extraordinary wave and an ordinary mode after the first stage of nondeviative absorption, and if most of the loss within the ionosphere occurs above the region of nondeviative absorption. The results are also consistent with a small variation in the limiting polarisation of the ionosphere and the arrival of energy on paths which deviate from the most direct path when the signal fades.

Instantaneous changes in field strength between orthogonal transmission and vertically polarised transmission are almost as accurate as median values in determining optimum transmitter circuit

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adjustments for orthogonal transmission.

General conclusions reached for orthogonal transmission on paths to the north at mid latitudes in the southern hemisphere, should also apply for transmission to the south at mid latitudes in the northern hemisphere. However, where medium frequency sky-wave field strength values are generally lower than in Australia, a greater reduction would be expected.

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Legend to Figures

Figure 1	Map showing the transmitter location near Melbourne and the receiving sites.
Figure 2	Improvement factor derived from median values of $E_{(V + H)}$ and $E_{(V + D)}$ measured at Hillston. The upper curve relates to results obtained on nights when the field strength was high. The lower curve relates to results obtained on nights when the field strength was low.
Figure 3	Improvement factor derived from median values of $E_{(V + H)}$ and $E_{(V + D)}$ measured at Deniliquin.
Figure 4	Improvement factor derived from median values of $E_{(V + H)}$ and $E_{(V + D)}$ measured at West Wyalong.
Figure 5	Improvement factor derived from median values of $E_{(V + H)}$ and $E_{(V + D)}$ measured at Harden.
Figure 6	Improvement factor derived from median values of $E_{(V + H)}$ and $E_{(V + D)}$ measured at Cobar.
Figure 7	Improvement factor derived from median values of $E_{(V + H)}$ and $E_{(V + D)}$ measured at Wilcannia.
Figure 8	Calculated improvement factor variation with change in path bearing σ relative to the path from Sydenham to Hillston.
Figure 9	Magnetic bearing γ of the apparent direction of arrival for 2NC (1230Kc/s) signals observed at Melbourne.
Figure 10	Improvement factor derived from instantaneous values of $E_{(V + H)}$ and $E_{(V + D)}$ at the time of switching between orthogonal transmission and vertically polarised transmission.
Figure 11	Instantaneous field strength values for orthogonal transmission and vertically polarised transmission,

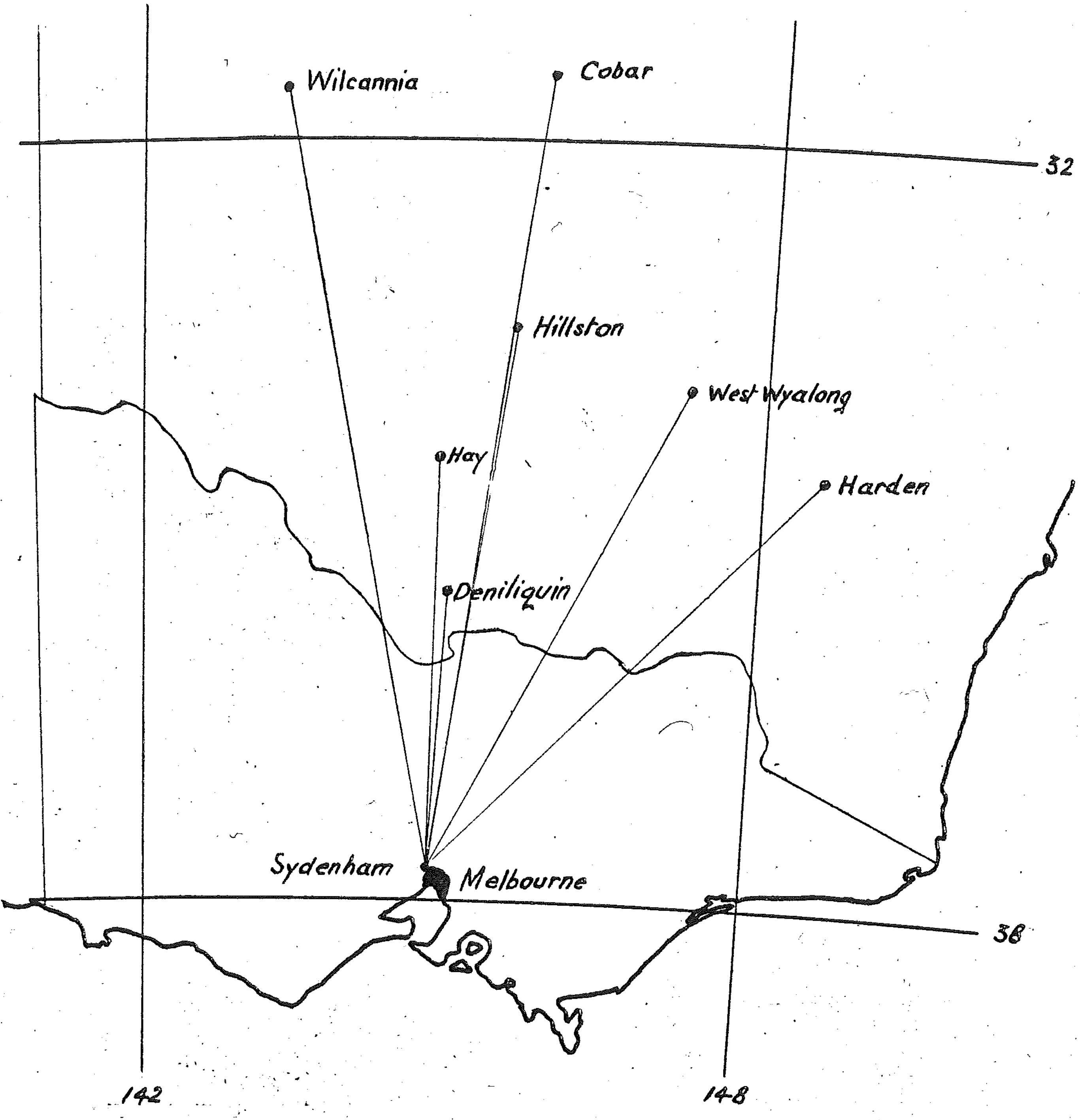

Wilcannia
Cobar
32
Hillston
West Wyalong
Hay
Harden
Deniliquin
Sydenham
Melbourne
38
142
148

FIGURE 1

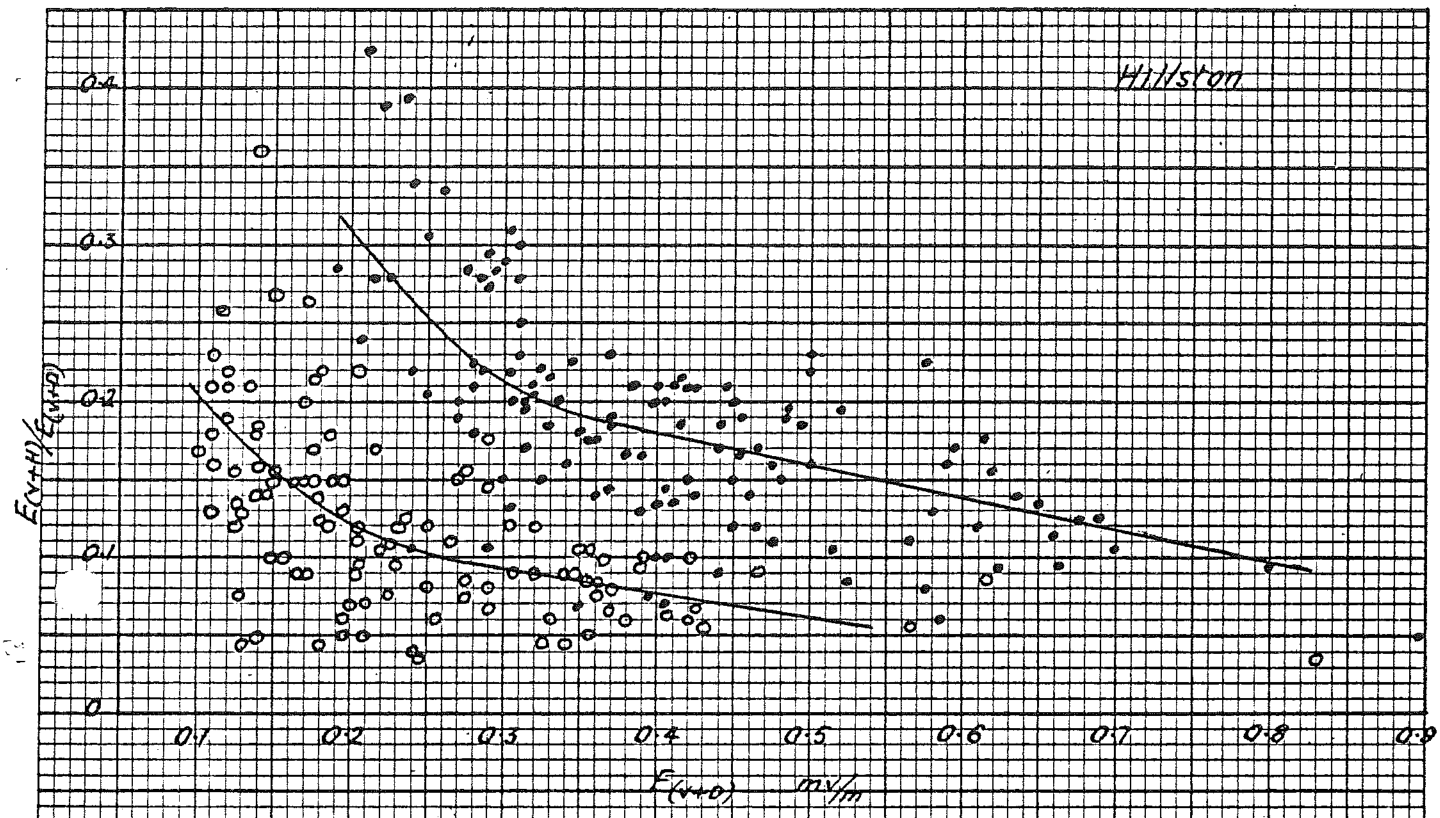


FIGURE 2

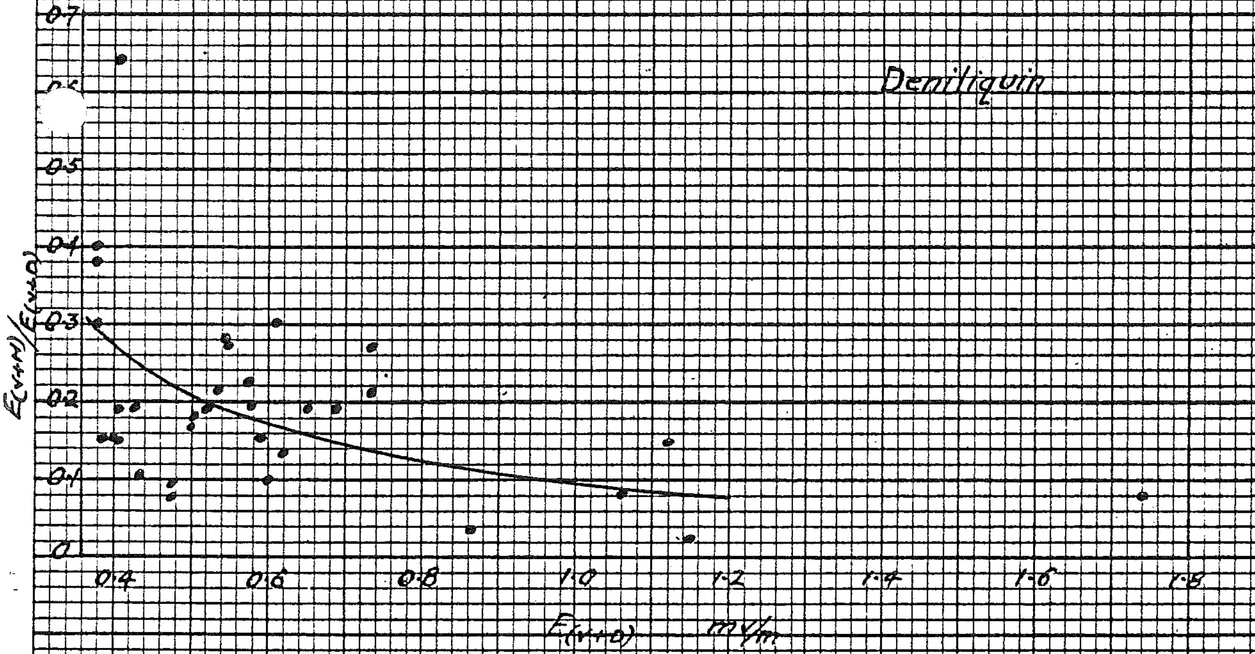


FIGURE 3

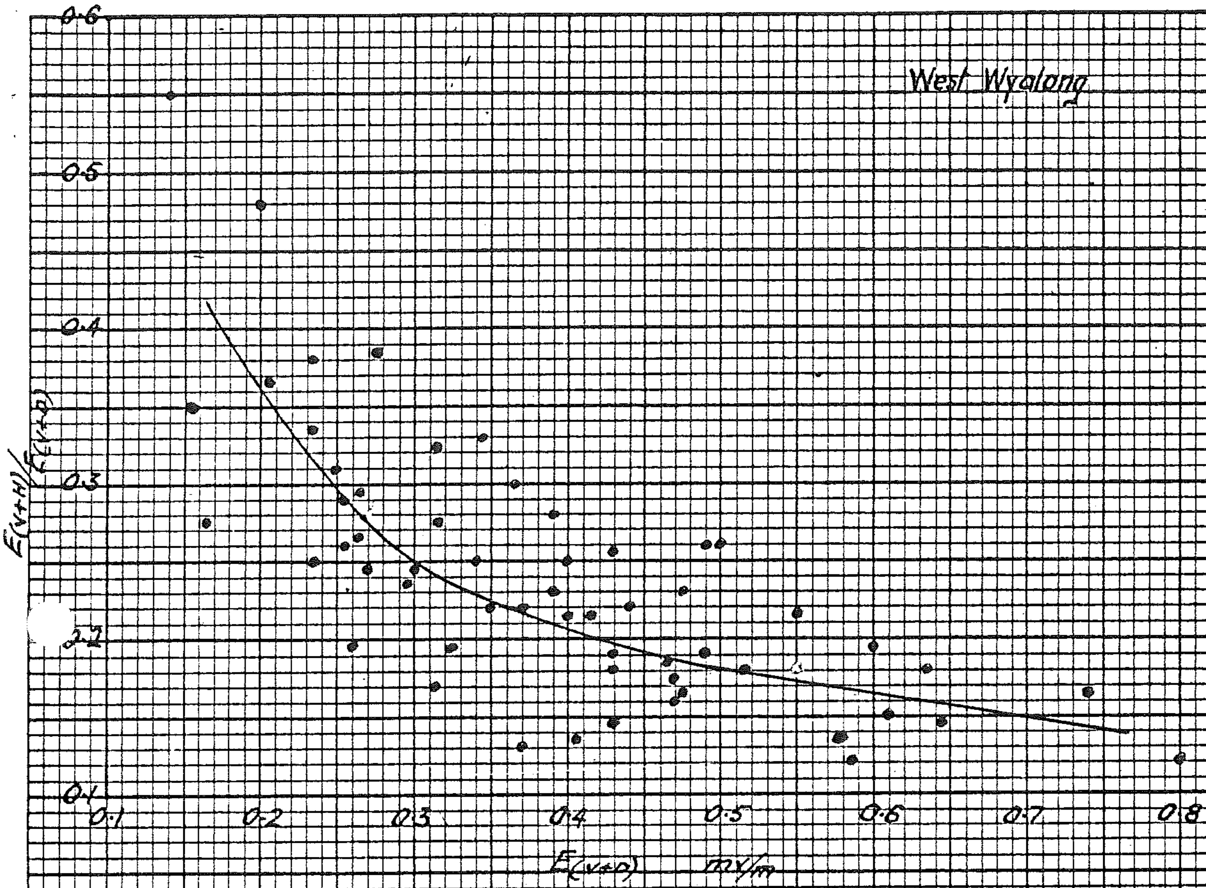


FIGURE 4

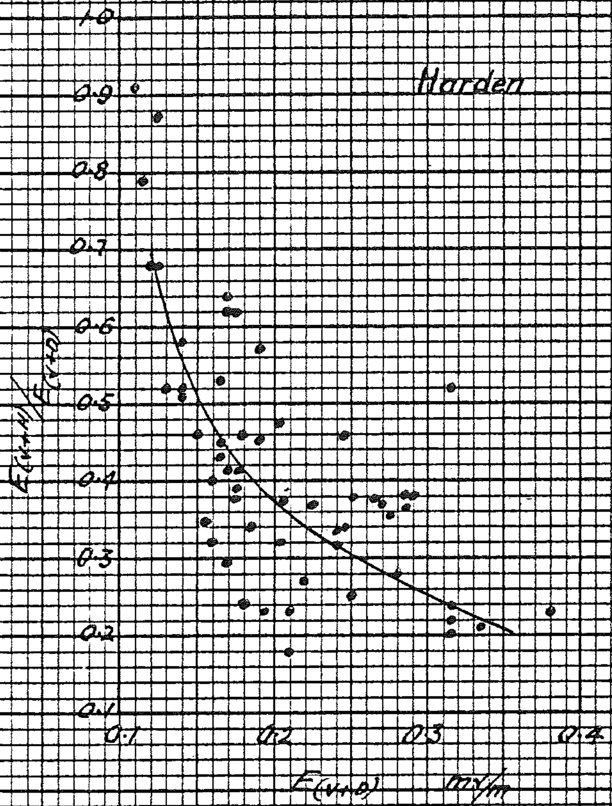


FIGURE 5

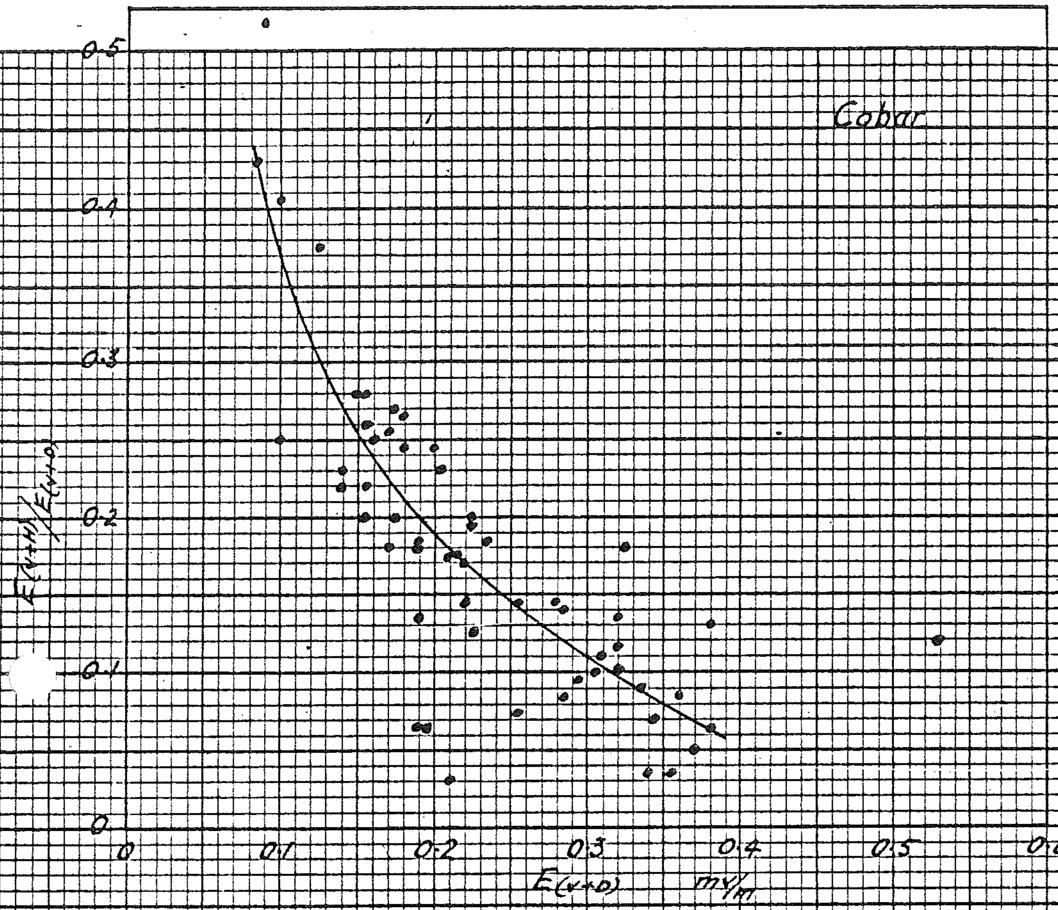


FIGURE 6

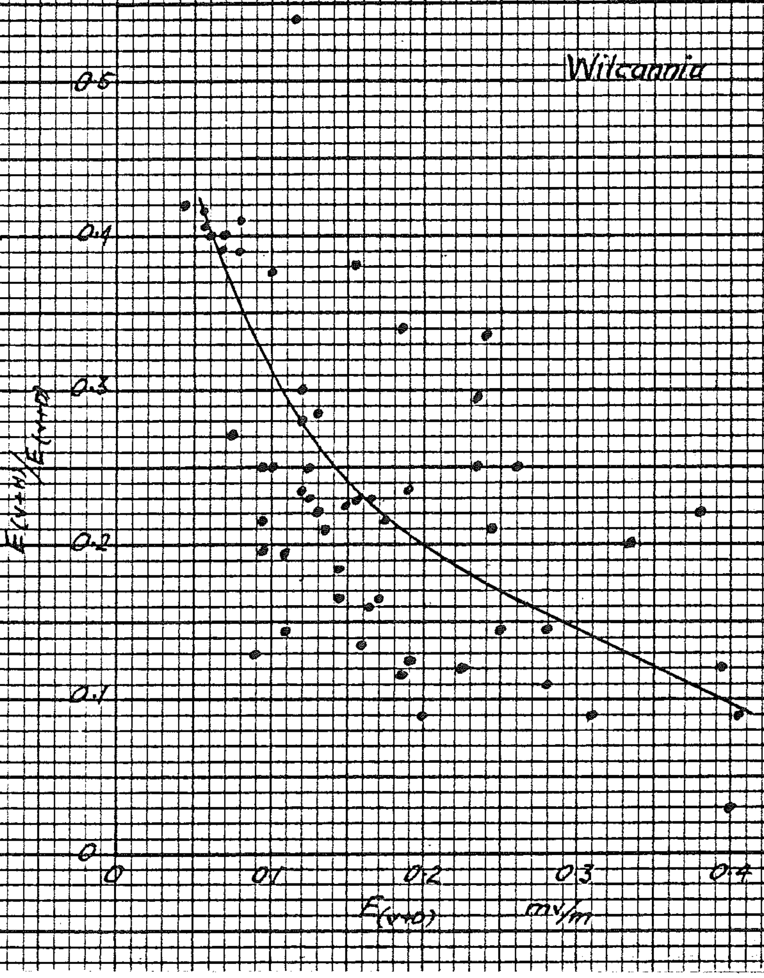


FIGURE 7

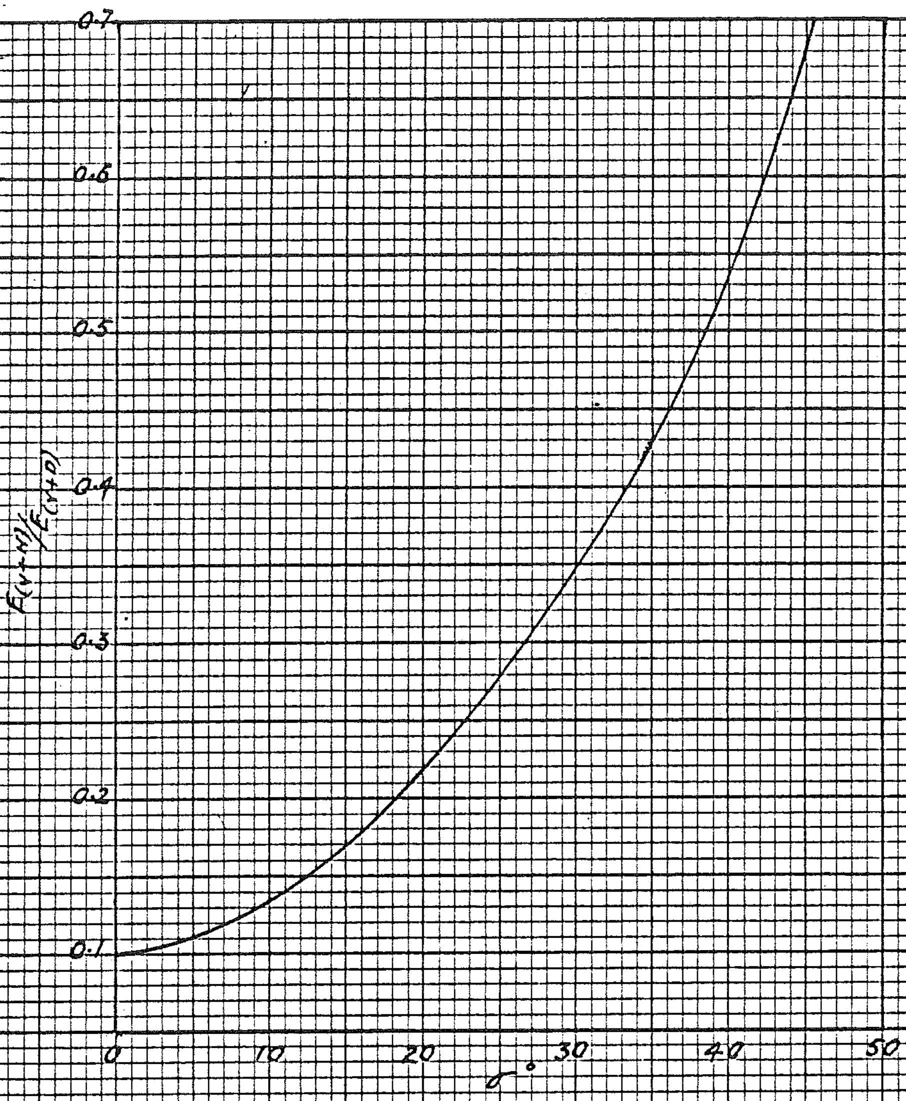


FIGURE 8

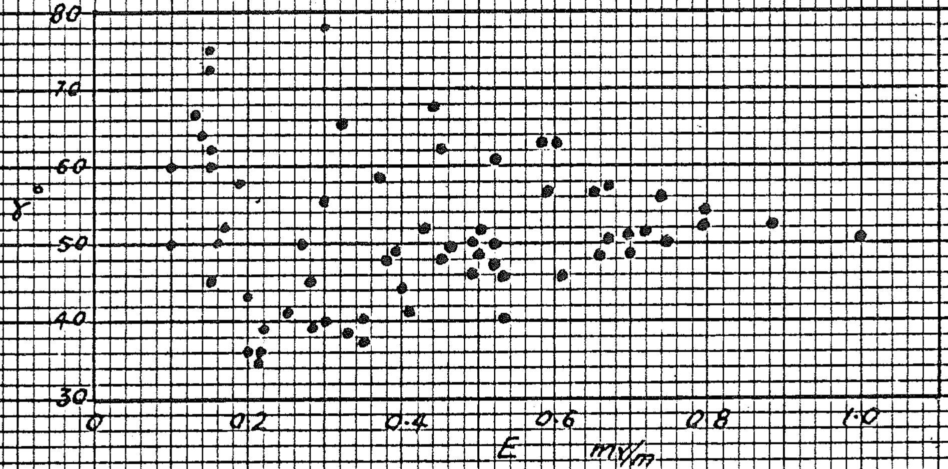
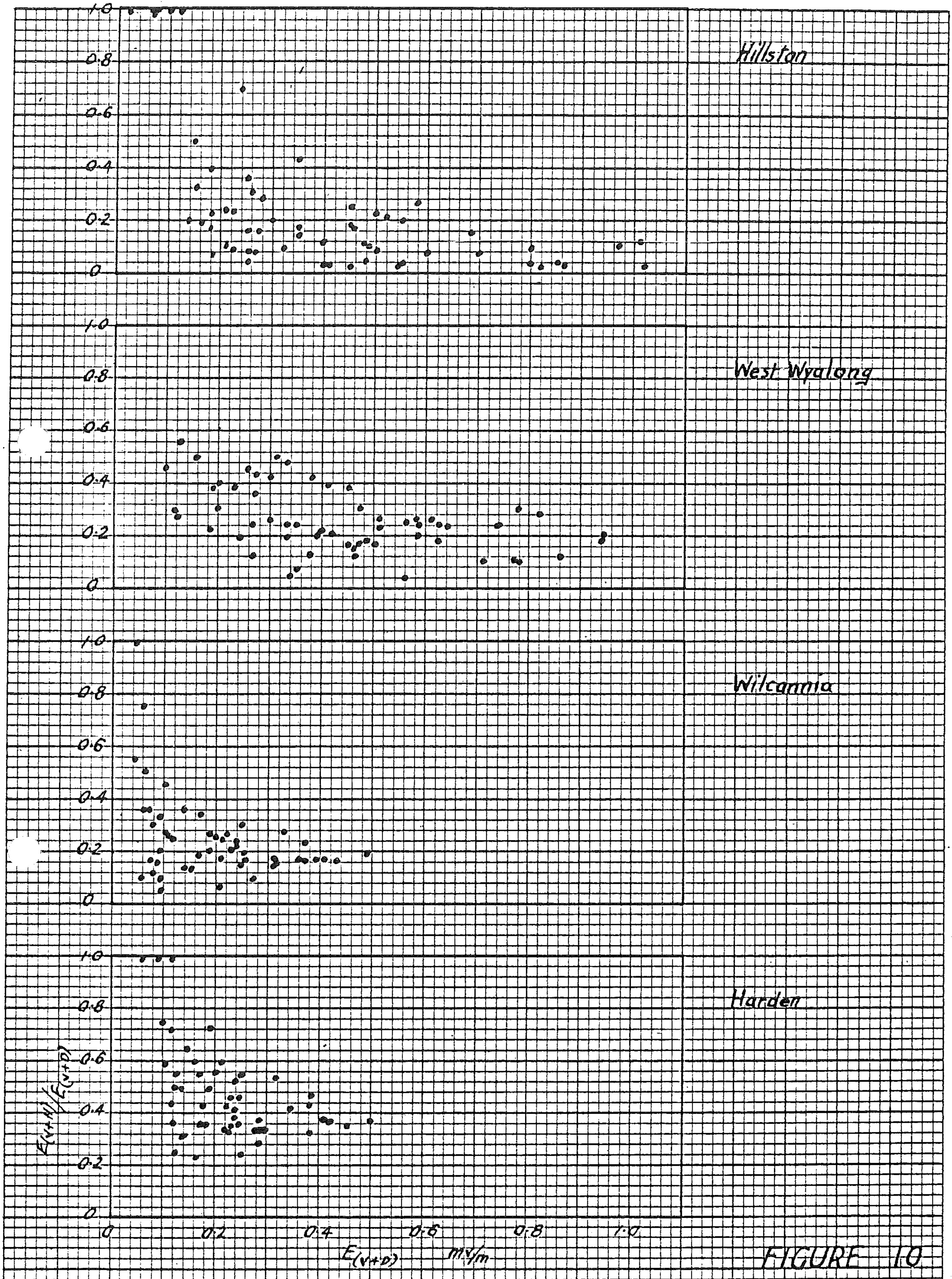


FIGURE 9


Hillston
West Wyalong
Wilcannia
Harden
1·0
0·8
0·6
0·4
0·2
0
0·2
0·4
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0·8
1·0
E(v+H)/E(v+D)
E(v+D) mV/m

FIGURE 10

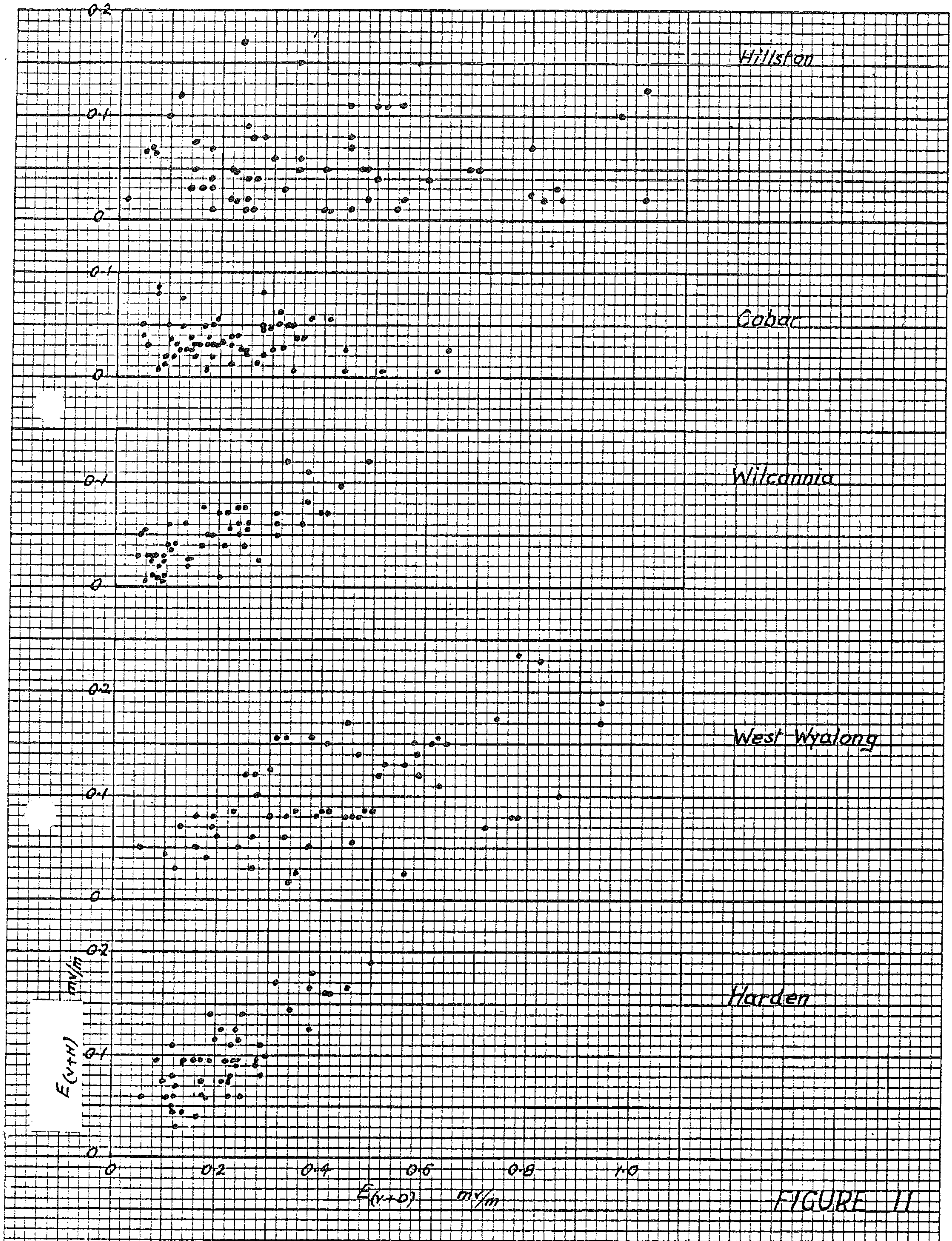
0·2
0·1
0
Hillston
0·1
0
Gobar
0·1
0
Wilcannia
0·2
0·1
0
West Wyalong
0·2
0·1
0
Harden
E(v+H) mv/m
0
0·2
0·4
0·6
0·8
1·0
E(v+D) mv/m

FIGURE 11