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TECHNICAL MEMORANDUM

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LAND NAVIGATION IN THE KIMBERLEYS UTILISING DIFFERENTIAL OMEGA

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S U M M A R Y

Field trials were carried out in July/August 1985 to test the efficacy of Differential Omega for land navigation in the East and West Kimberley regions of Western Australia. To this end a base station was set up in Broome and movements undertaken between a local survey mark and similar marks at ranges of up to 700 km. This Technical Memorandum describes the nature of the exercise and discusses the results obtained.

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1. INTRODUCTION

In 1980 a Differential Omega field trial was carried out in the Pilbara region of Western Australia(ref.1). At that time the Australian Omega transmitter had not been commissioned and circumstances required that a range/range navigational technique be adopted, based upon observation of transmissions from Omega Japan and Omega Reunion. The relevant clock error was calculated by linear interpolation between mobile and base clock readings at the start and end of each sortie.

The commissioning of Omega Australia in August 1982 rendered hyperbolic (or range/range/range) navigation feasible, and this approach was adopted during sea trials carried out off the south coast of WA in 1983(ref.2). Subsequently, a suggestion that a further trial be carried out in the north-west of WA, utilising the currently available hyperbolic or range/range/range option, gained the support of DCDS, and was incorporated in Task DST 84/077.

After due consideration of the logistical requirements of such an exercise it was decided that the base station should be set up in Broome and that movements should take place as far south as Port Hedland and as far north as Lake Argyle. An approach to the Overseas Telecommunications Commission (Aust) resulted in the generous offer of base station accommodation within the local OTC coastal radio station complex (Broomeradio).

A reconnaissance was carried out in Broome in May 1985 with the primary objective of determining the optimum siting, within the precincts of Broomeradio, of the Omega receiving antenna, with a view to avoidance of interference both from power mains and OTC transmissions, and for the purpose of choosing an appropriate datum point from which movements could proceed. The coordinates of the datum point were subsequently determined by the Perth branch of the Australian Survey Office, which was also responsible for the establishment of additional marks, as required, at intermediate points of the movements.

The ERL trials team, comprising R.S. Edgar, J.H. Silby and A.R. Padgham, together with trials vehicles, were transported by an RAAF Hercules aircraft from Edinburgh to Broome on 17 July 1985; the trial proper began on 22 July and ended on 30 August.

Each of two sorties was undertaken twice:

Broome/Sandfire Flat/Pt Hedland/Sandfire Flat/Broome

and

Broome/Fitzroy Crossing/Halls Creek/Dingo Springs/Halls Creek /Fitzroy Crossing/Derby/Broome

The routes followed are shown in figure 1. Sandfire Flat lies halfway between Broome and Port Hedland, while Dingo Springs is located 30 km south east of Kununurra.

2. NATURE OF TRIAL

The 1980 land navigation trial in NW Australia involved movements between numerous sites of known coordinates. At each site navigational readings were averaged over a period of 16 min prior to movement to the next site. Post-trial considerations led to the conclusion that averaging time should be reduced in subsequent trials to values more likely to obtain in normal practice, and that recording should be carried out at any given site over a considerable period to permit of a better appreciation of the manner in which correlation between base and mobile positions varied with time. This approach was adopted in the present trial where averaging time was reduced to about 5 min and where hand readings were taken throughout normal daylight working hours at each site. The number of sites visited was correspondingly reduced.

The range/range/range method of operation has been described elsewhere(ref.2) and need only be summarised here. The apparent changes of radial range from three Omega transmitters (Japan, Reunion, Australia) which result from the movement are computed from the observed differential phase increments of incoming signals relative to oscillators (clocks) maintained at base and in the navigation vehicle. In the absence of relative clock drift and with correct choice of signal phase velocity the circular lines of position (LOPs) computed for the mobile intersect at a point corresponding to its true position. In the presence of clock error alone the lines of position, corresponding to the three signals observed, form an error triangle whose in-centre may be shown to be the true position. The clock error may be calculated from the distance of the in-centre from any side. In these circumstances the result is that which would have obtained had a hyperbolic approach been adopted and the computations been carried out on the basis of measured variations of phase difference between incoming signals taken in pairs.

The situation becomes more complicated in the presence of LOP errors due either to ionospheric decorrelation of diurnal phase shift between base and mobile units or an incorrect choice of phase velocity in the computations. In these circumstances an error triangle obtains in the absence of clock error. While we continue to take its in-centre as the nominal position of the mobile, since this eliminates any superimposed clock error, we cannot relate the distance of the in-centre from the true lines of position to the individual LOP errors. Of course, if the clock error can be calculated, the observed lines of position can be modified accordingly and individual LOP errors computed. This situation prevailed in the earlier sea trial(ref.2) where clock error was calculated from the mean rate of growth of the error triangle over a period of days while the ship remained at anchor, it being assumed that diurnal differential variations would not contain a secular component. This technique could not be utilised in the present instance because of limited stop-over time in each position and because of suspicions concerning the stability of the mobile frequency standard when subject to long-term mechanical vibration. Thus, although clock error is automatically eliminated when the in-centre of the error triangle is taken to represent the mobile position, the accompanying ionospheric errors are neither eliminated nor uniquely resolvable. In consequence there is no unequivocal procedure available for retrospective error reduction by modification of individual phase velocities.

3. ANALYSIS OF RESULTS

The trial was carried out utilising two independent Omega frequencies, viz 11-1/3 kHz and 13.6 kHz. In order to make use of real-time computing facilities it was necessary at the outset to choose working values of phase velocity appropriate to propagation on each frequency. The values chosen were:-

11-1/3 kHz $v = 1.0021c$
13.6 kHz $v = 1.0003c$

based on a sea water path during daylight hours(ref.3). It was appreciated that these figures would require subsequent modification for land propagation but it was not considered likely that any major problem would arise from anomalous propagation. In the event, polar error plots printed out post-trial exhibited site errors typically of the order of a few hundred metres, and thereby confirmed the efficacy of Differential Omega in the Kimberley region when utilising transmissions from Omega Japan, Reunion and Australia. Unfortunately, absolute error data for Dingo Springs are unavailable; during each sortie, equipment malfunction led to the loss of continuity of incremental phase integration.

In looking for an immediate explanation of residual errors we note that propagation between the Omega transmitters and (a) base station (b) field sites may involve land, sea or mixed paths. Only in the case of Omega Australia are the paths wholly over land.

At the risk of an overly simplistic treatment we will assume that the equiphase fronts of transmissions from Japan and Reunion are normal to the great circle bearings on approach to the Australian mainland, and that discrete phase velocities apply to the land and sea path components as measured on a map. Thus for transmission from Japan it is easily shown that the associated LOP at Fitzroy Crossing, based upon measurement of incremental phase and the initially-assumed value of phase velocity, will be displaced too far south by:-

$$(d_3 - d_2)\left[\frac{v'}{v_1} - 1\right] - d_1\left[\frac{v'}{v_s} - 1\right]$$

where d_1 = length of great circle sea path between Broome and the latitude at which the great circle path to Fitzroy Crossing crosses the coast line

d_2 = length of land path to Broome from above position

d_3 = length of land path to Fitzroy Crossing from above position

v' = assumed phase velocity over sea

v_s = true phase velocity over sea

v_1 = true phase velocity over land

In particular, if $v_s = v'$ then for the case under consideration

$$\text{error} = 3 \times 10^5 \left(\frac{1.0003c}{v_1} - 1\right) \text{ m at 13.6 kHz}$$

It will be seen from figure 3, reference 3 that phase velocity over land is a function of conductivity and that an appropriate figure in the present instance would be 1 part in 10^3 less than sea velocity, corresponding to $\sigma = 10^{-3}$ mhos/m. The LOP error therefore becomes 300 m. On applying the above phase velocity correction to the difference in radial distance between Omega Australia and Broome and Fitzroy Crossing in turn we find that the Australian LOP must be moved away from Omega Australia by 250 m.

Finally, we find that if we assume that the true sea velocity is 1.0003c at 13.6 kHz then the Reunion LOP at Fitzroy Crossing will be too far from Reunion by $d\left(\frac{v'}{v_1} - 1\right)$ where d is the land path to Fitzroy Crossing (about 460 km) whence we would expect a corresponding error of 460 m.

Figure 2 shows the original error plot for Fitzroy Crossing on 13.6 kHz based on v/c = 1.0003. When we apply the above modifications to the individual LOPs and recompute the in-centre of the error triangle we find that the mean error in the original plot is largely eliminated (figure 3) provided that we apply only about 20% of the suggested correction for Reunion.

Figure 4 shows the uncorrected error plot for Fitzroy Crossing on 11-1/3 kHz and figure 5 the corrected plot based on a land velocity factor of 1 part in 10^3 less than the assumed sea velocity and applied to each transmission in turn. Figures 6 to 13 represent error plots for the other field sites when identical correction factors are employed. Of all the modified plots only Derby on 13.6 kHz and Pt Hedland on 11-1/3 kHz exhibit particularly poor results. The adjusted figures are displayed in the form of error histograms in figures 14 to 17.

The scatter observed in the polar plots, being directly related to the perturbations obtaining in the differential radial ranges to the three Omega transmitters, is a function of the degree of ionospheric decorrelation between the base and field sites. Figures 18 to 59 relate to this aspect of the investigation. These figures have been plotted automatically from phase data recorded continuously on floppy disc at the base and field sites, unlike the polar error plots which were derived from discrete observations of real-time displays.

Figures 18 to 23 comprise typical diurnal phase plots, as recorded at Broome, for the three Omega transmissions of 13.6 kHz and 11-1/3 kHz. It will be observed that these plots exhibit angular closure discrepancies of about 40° over a 24 hour period. This is due to an error in the base station frequency standard of about 1 part in 10^{10}. The effect on navigational accuracy is, of course, negligible since it is only the relative drift rate between base and mobile oscillators which is significant (and then only for range/range working).

The corresponding differential plots for the various sites are shown in figures 24 to 59 for daylight hours. In interpreting these plots it should be borne in mind that identical phase variations on each transmission at a given frequency does not give rise to a positional shift; we are consequently concerned with three-station rather than individual trends. Indeed, individual plots as displayed may have suffered skewing as a result of drift between base and mobile clocks.

A second set of plots, not reproduced here, has been derived from data gathered during the repeat movement between Broome and the out stations. While there is general agreement between corresponding plots, there are sufficient discrepancies in the fine structure (and, in one or two cases, in major trends) to lead to the conclusion that day to day differentials are not sufficiently reproduceable to warrant detailed study. (Note that the polar error plots include both sets of readings taken about a month apart.)

However it is clear that random phase variations of the order of a degree obtain throughout the day on individual phase records with periods of perhaps an hour or less, and that these are superimposed on diurnal variations which become excessive outside the interval 0900 to 1600 local. It consequently now becomes necessary to address the subject of night-time accuracy.

4. IONOSPHERIC DECORRELATION AT NIGHT

Figures 60 to 71 are differential phase records for Broome/Sandfire Flat and Broome/Dingo Springs taken over 24 hour periods. These plots demonstrate the considerable degree of decorrelation which occurs at night. Thus in figures 60 and 63 we find peak/peak phase excursions for Omega Japan of some 120° although daylight variation amounts to only a degree or so (figure 24). Decorrelation for both Reunion and Australia is considerably less than for Japan, amounting to 20° peak/peak or less on each frequency. The discontinuities on the Reunion and Australia curves corresponds to movement from the survey mark to motel accommodation and back; the effect is missing for Japan since the movement involved was almost exactly normal to the radius vector to that transmitter. There is an artifact of unknown origin at 0000 hours near the end of each trace. This has been sufficient to cause a cycle slip in the on-board computer when registering the phase of Australia on 11-1/3 kHz (figure 65).

The Dingo Springs differentials in figures 66 to 71 exhibit a considerably greater discontinuity due to vehicle movement at the end of the working day; in this case motel accommodation was located some 30 km from the survey mark in the direction of Reunion. It is evident that during the movement the radial distance from Omega Australia at first increased (phase retarded) and subsequently decreased by about the same amount.

Bearing in mind that 1° change of differential angle corresponds to a radial LOP movement of about 60 m at 13.6 kHz and 74 m at 11-1/3 kHz we find that the peak night positional error at Sandfire Flat could reach 3 km and rather less at Dingo Springs because of the reduced perturbation in Japan. It is evident that there is no simple relationship between night time decorrelation and distance between base and mobile at least over the range 250 to 670 km considered here.

5. CONCLUSIONS

It has been demonstrated that Differential Omega provides effective daylight navigation in the Kimberley region of Western Australia when utilising transmissions from Omega Japan, Reunion and Australia. Of the measurements carried out on two occasions between the hours of 0830 and 1630 local on 13.6 kHz at Sandfire Flat, Pt Hedland, Fitzroy Crossing and Halls Creek (with the base station located at Broome), 89% fell within 250 m of the true position; this figure degraded to 81% when readings taken at Derby were included. Of the readings taken on 11-1/3 kHz at Sandfire Flat, Fitzroy Crossing, Halls Creek and Derby, 93% fell within 250 m; the figure degraded to 72% when Pt Hedland readings were included.

In the computations standard values were assumed for phase velocity over sea paths; for land paths values of 1 part in 10^3 lower were assumed, corresponding to earth conductivity of 10^{-3} mho/m except in the case of the Reunion transmission on 13.6 kHz where a better fit was obtained for a figure of 2 parts in 10^4.

Ionospheric decorrelation between base and field sites was found to be severe at night with degradation setting in during late afternoon. Positional errors of up to 3 km could be expected from this cause.

6. ACKNOWLEDGEMENTS

Thanks are due to the Overseas Telecommunications Commission (Australia) for provision of base station accommodation within Broomeradio and to Mr D. White, H. Willemsen and staff for assistance during the course of the trial; to the Australian Survey Office, Perth, for the tagging of airport reference pegs and the setting up of additional survey marks; and to the Department of Aviation, Perth, for permission to operate equipment within Fitzroy Crossing, Halls Creek, Derby and Pt Hedland airports.

REFERENCES

No.	Author	Title
1	Edgar, R.S.	"Land Navigation in North-West Australia Utilising Differential Omega". DSTO Technical Report ERL-0218-TR, October 1981
2	Silby, J.H.	"A Seaborne Navigation Trial Utilising a Differential Omega System". DSTO Technical Memorandum ERL-0295-TM, December 1983
3	Lynn, K.J.W.	"A Note on Phase Velocities for VLF Navigation". DSTO Technical Report ERL-0016-TR, June 1978

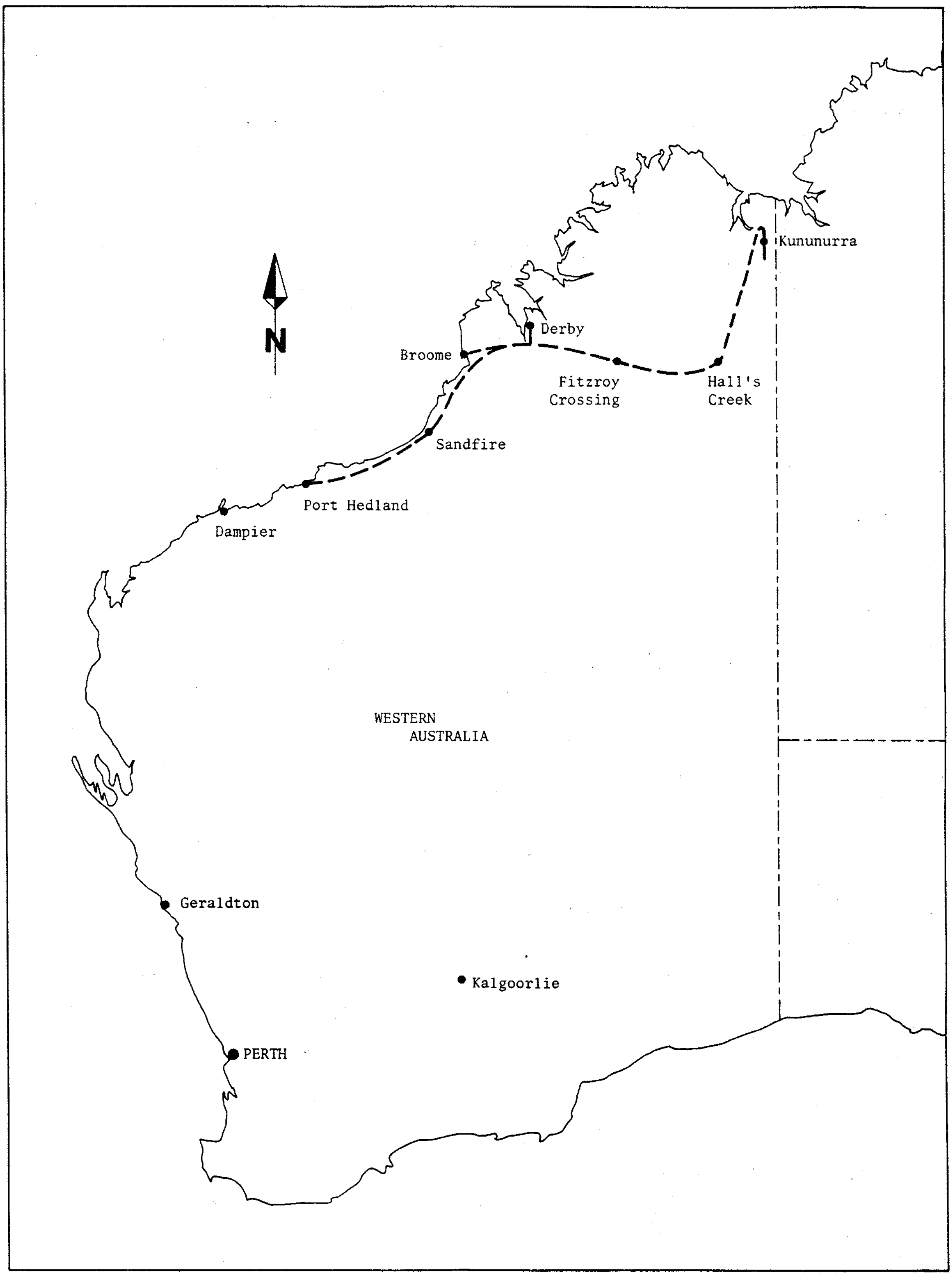


Figure 1. Map showing movements undertaken

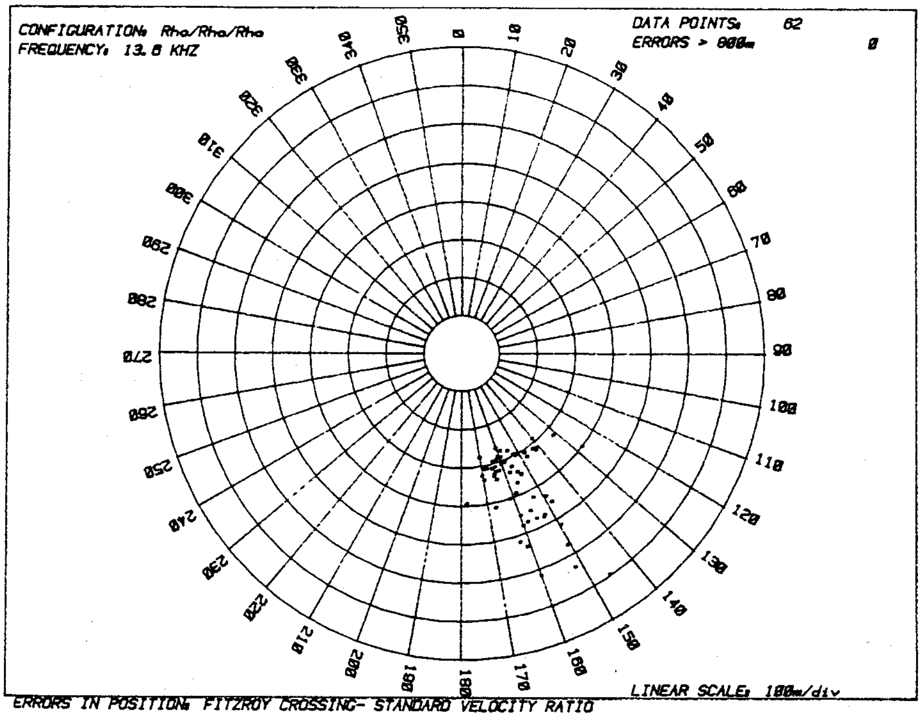


Figure 2. Unadjusted polar error plot, Fitzroy Crossing, 13.6 kHz

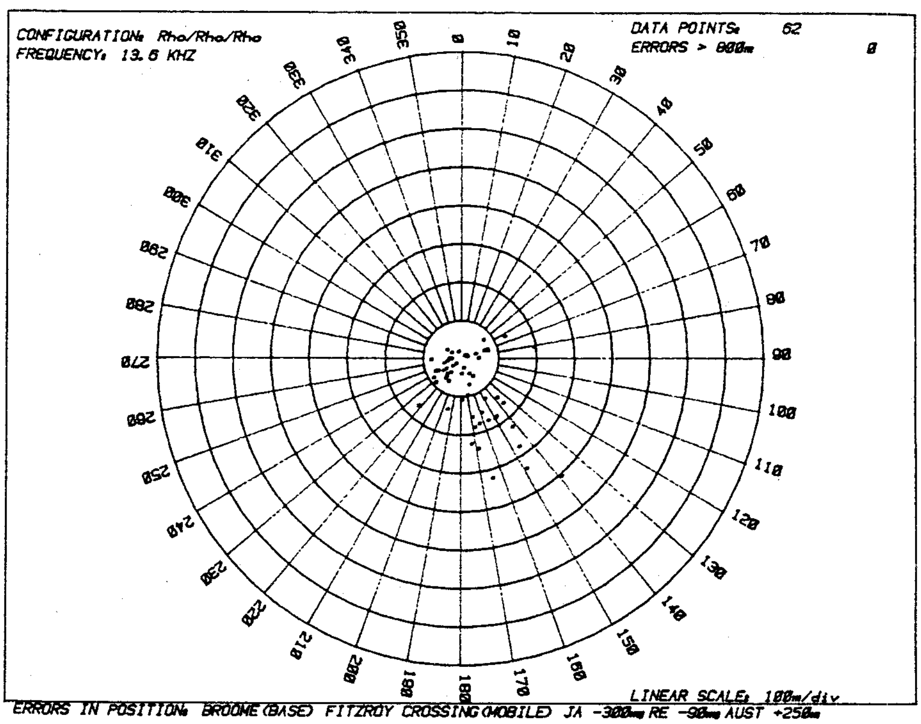


Figure 3. Adjusted polar error plot, Fitzroy Crossing, 13.6 kHz

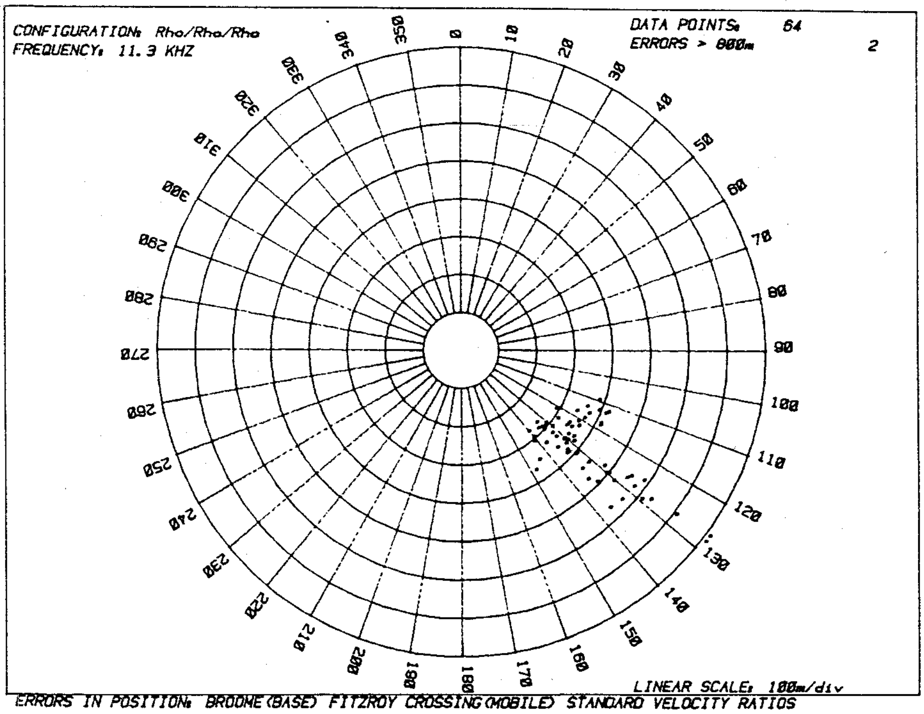


Figure 4. Unadjusted polar error plot, Fitzroy Crossing, 11-1/3 kHz

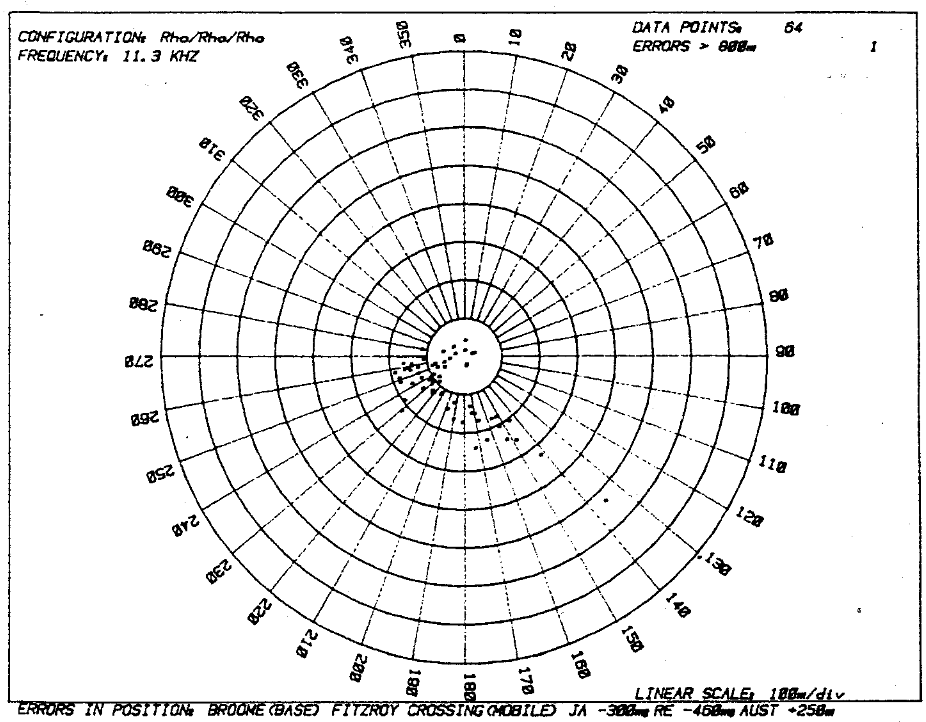


Figure 5. Adjusted polar error plot, Fitzroy Crossing, 11-1/3 kHz

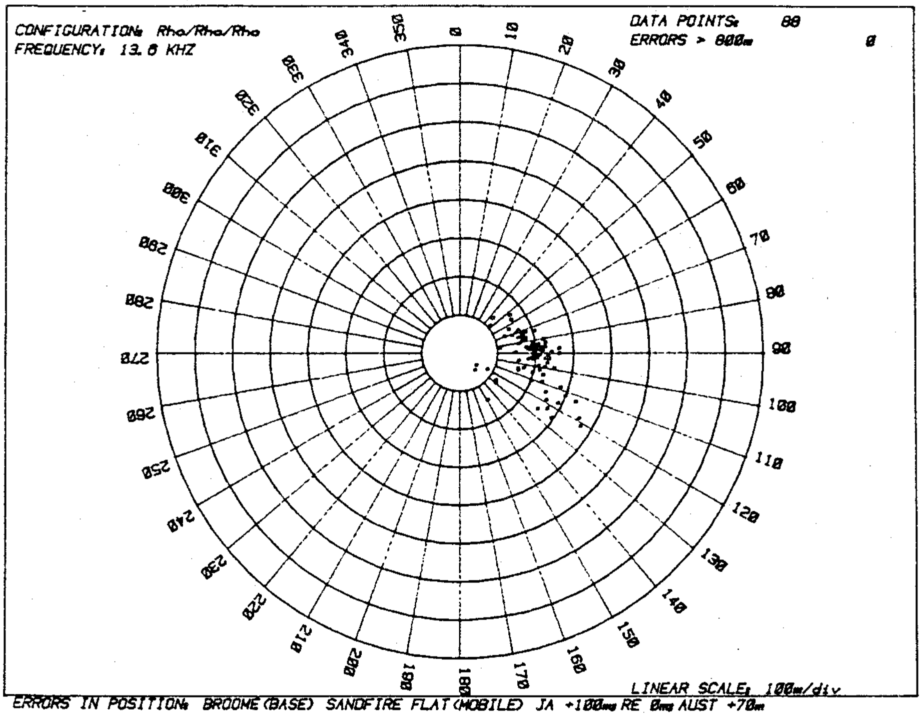


Figure 6. Adjusted polar error plot, Sandfire Flat, 13.6 kHz

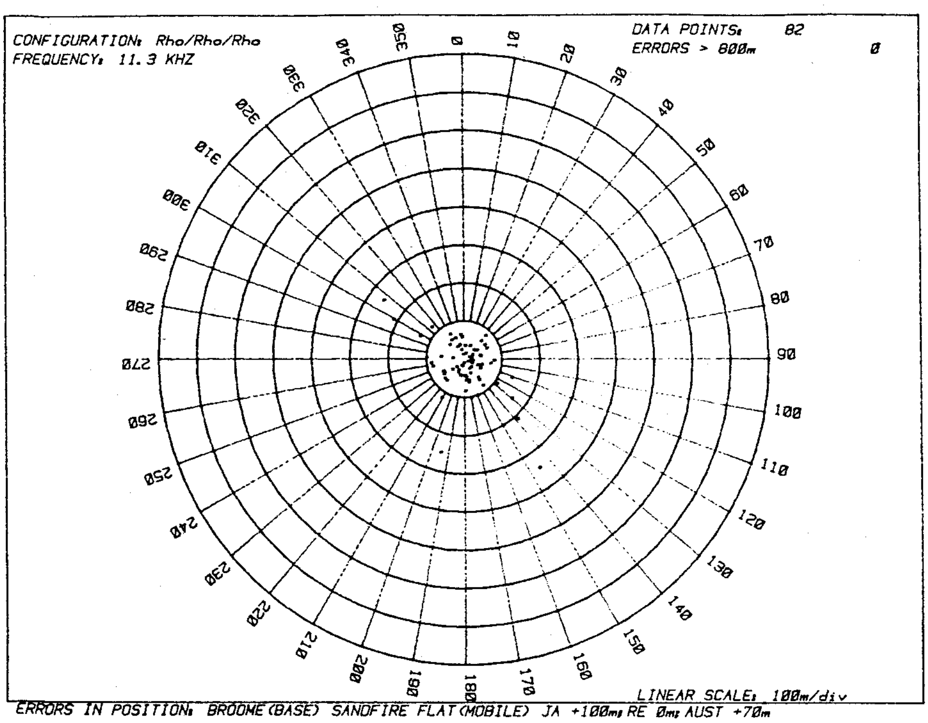


Figure 7. Adjusted polar error plot, Sandfire Flat, 11-1/3 kHz

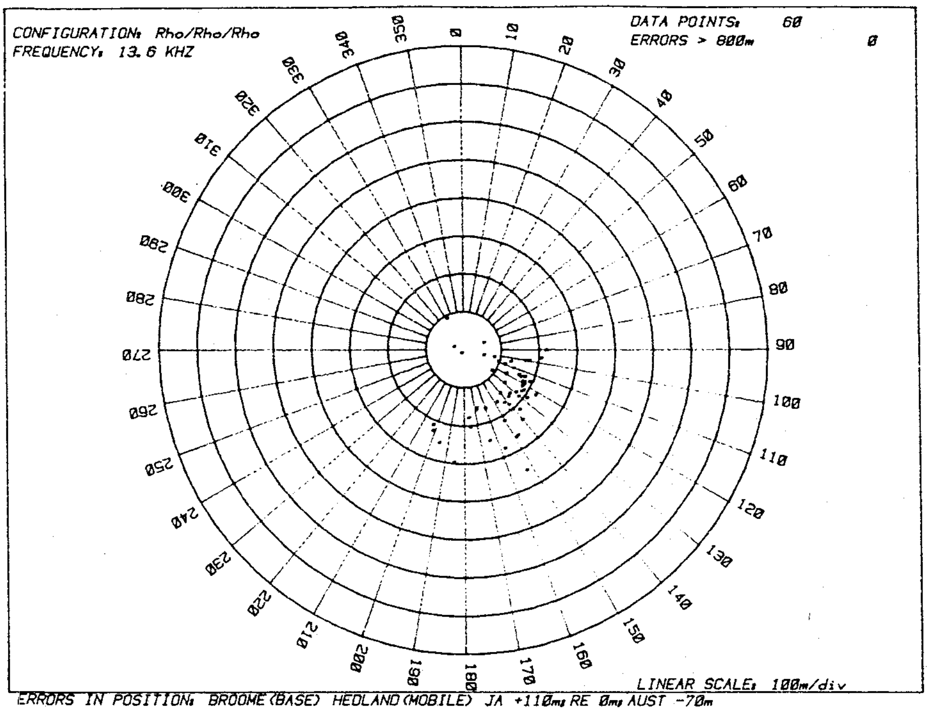


Figure 8. Adjusted polar error plot, Pt Hedland, 13.6 kHz

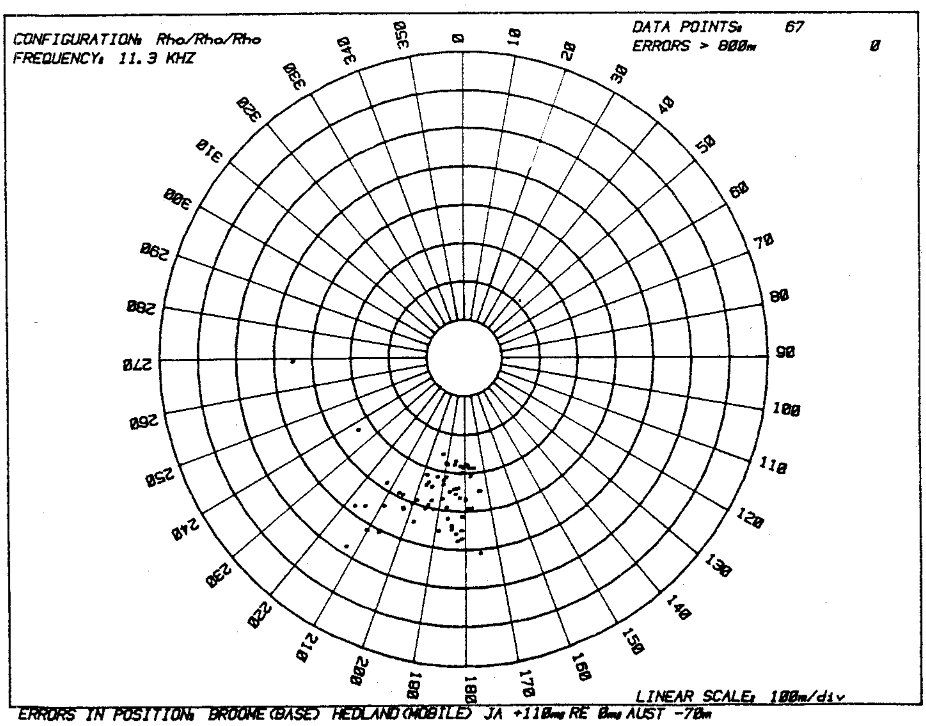


Figure 9. Adjusted polar error plot, Pt Hedland, 11-1/3 kHz

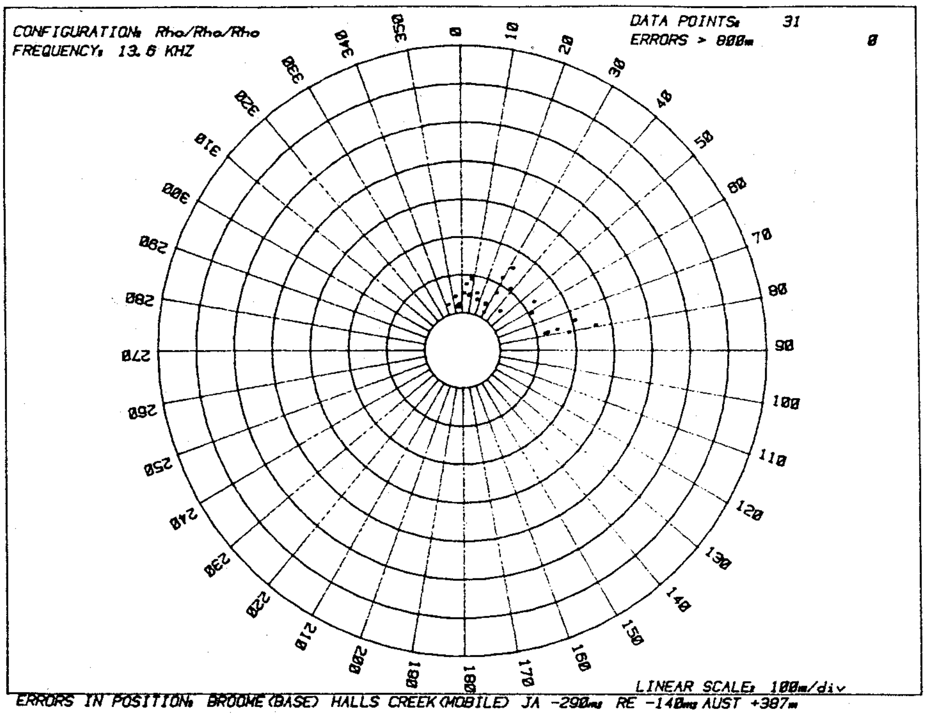


Figure 10. Adjusted polar error plot, Halls Creek, 13.6 kHz

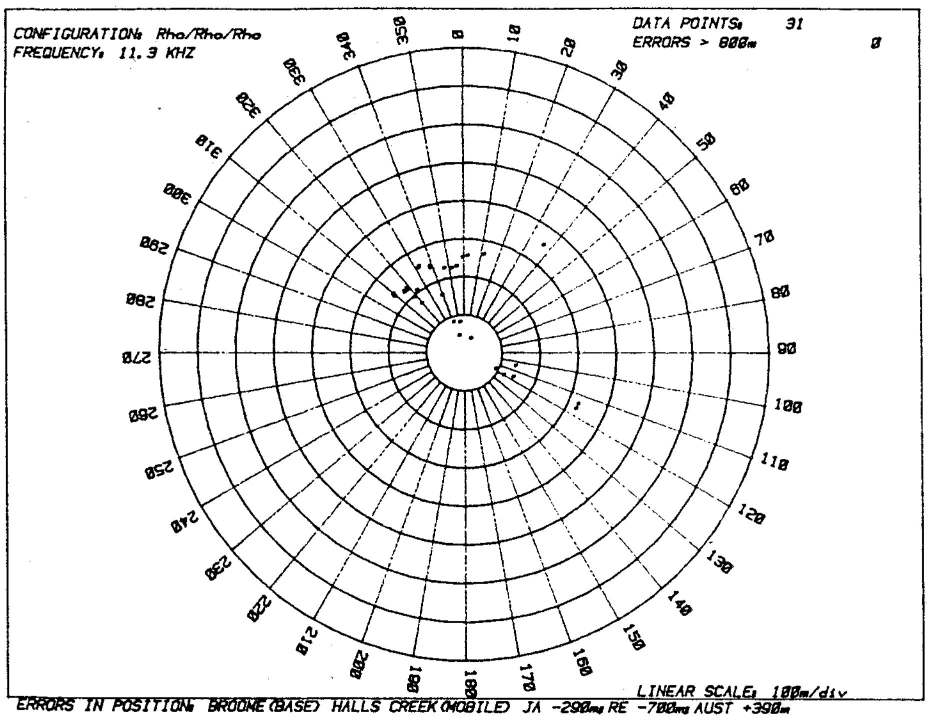


Figure 11. Adjusted polar error plot, Halls Creek, 11-1/3 kHz

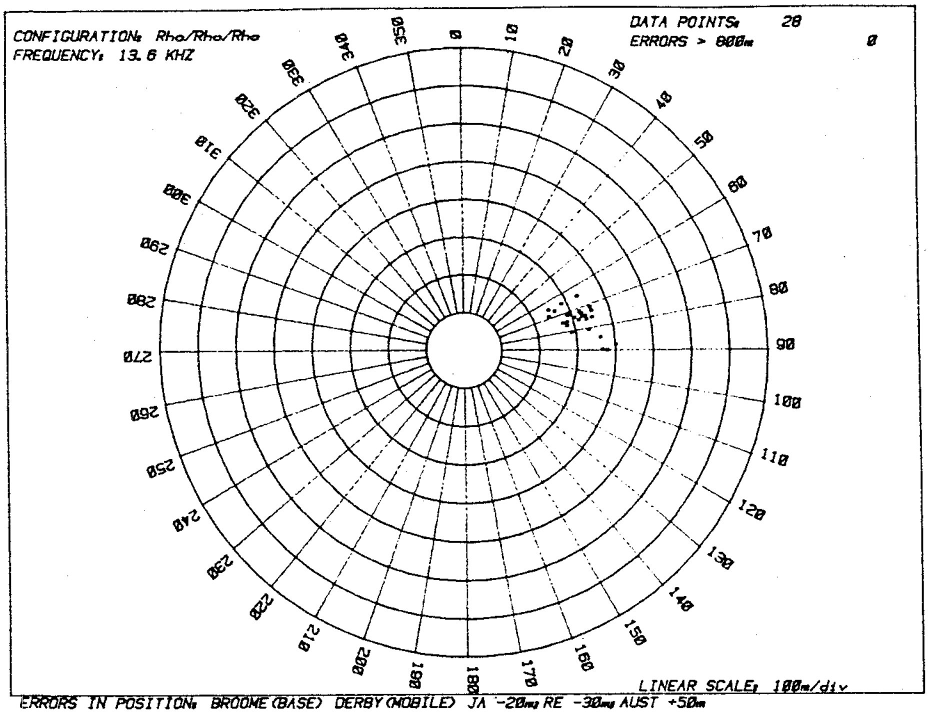


Figure 12. Adjusted polar error plot, Derby, 13.6 kHz

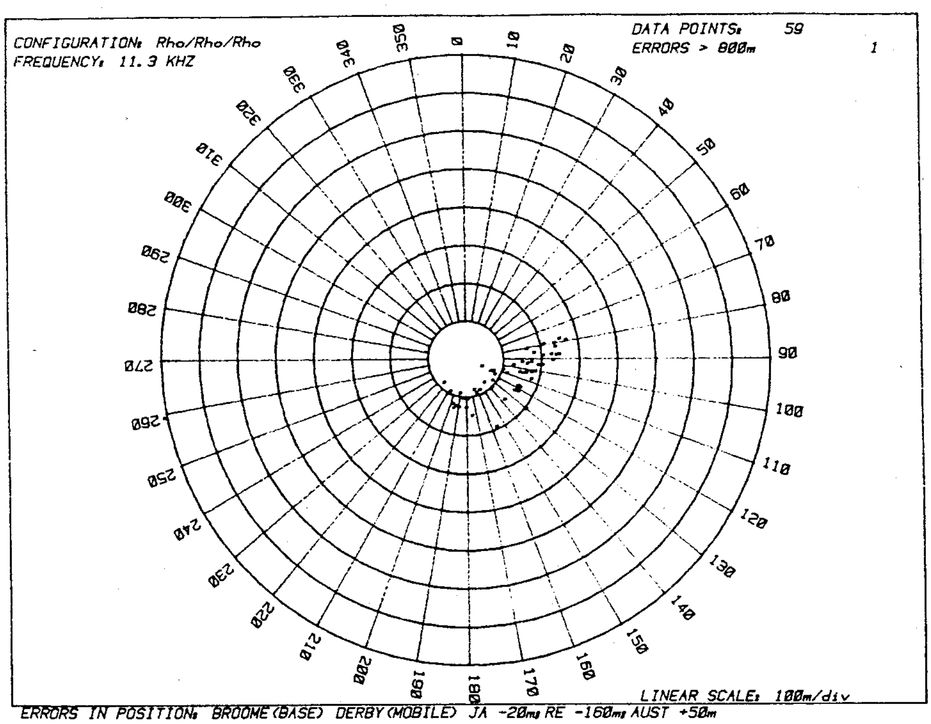


Figure 13. Adjusted polar error plot, Derby 11-1/3 kHz

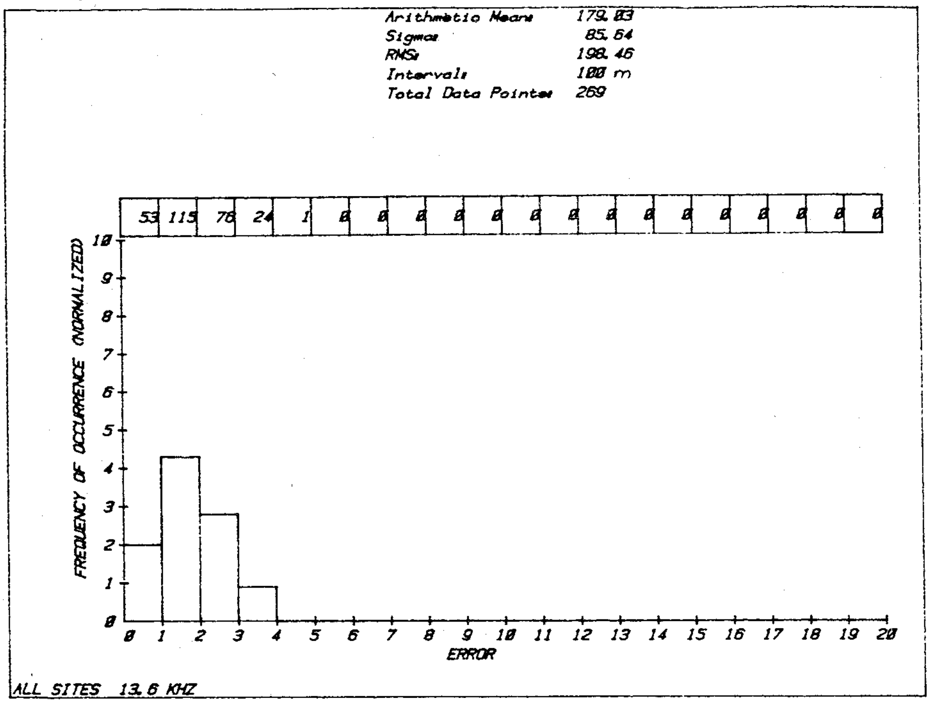


Figure 14. Error histogram, all sites, 13.6 kHz

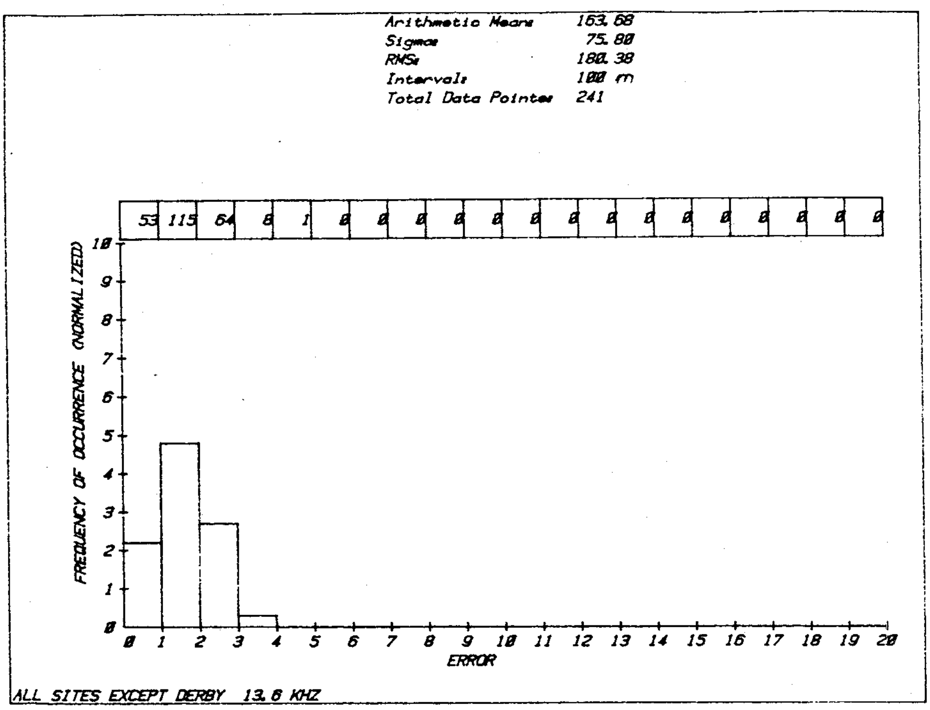


Figure 15. Error histogram, all sites except Derby, 13.6 kHz

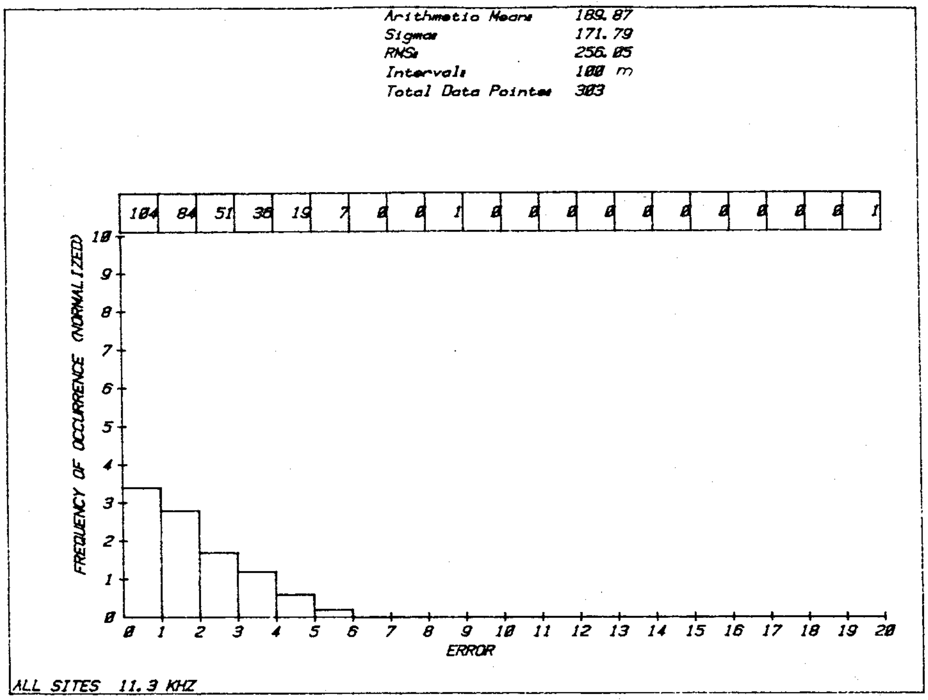


Figure 16. Error histogram, all sites, 11-1/3 kHz

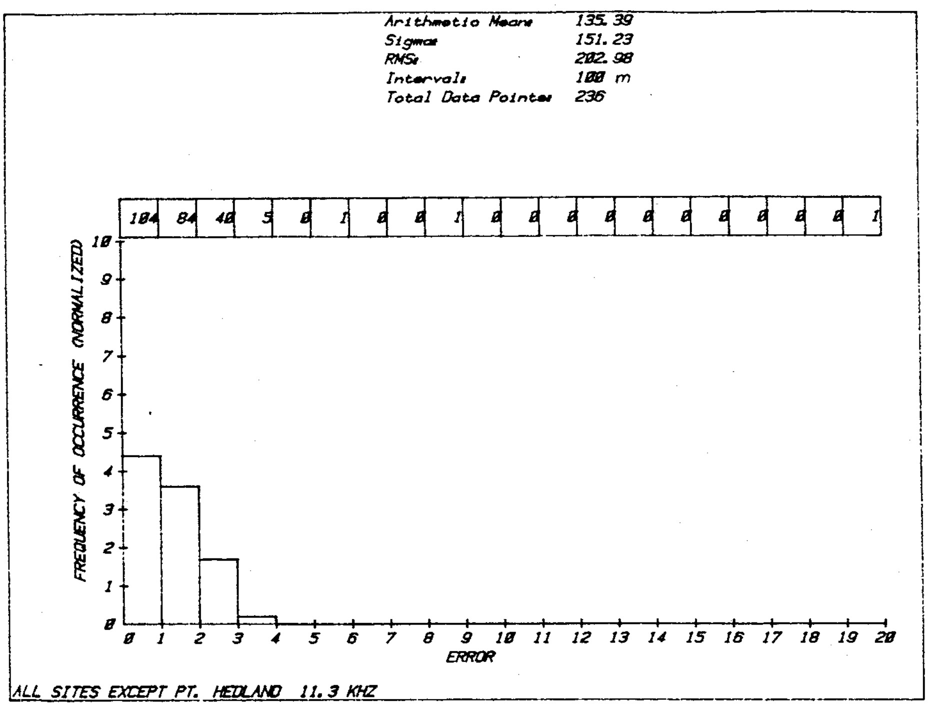


Figure 17. Error histogram, all sites except Pt Hedland, 11-1/3 kHz

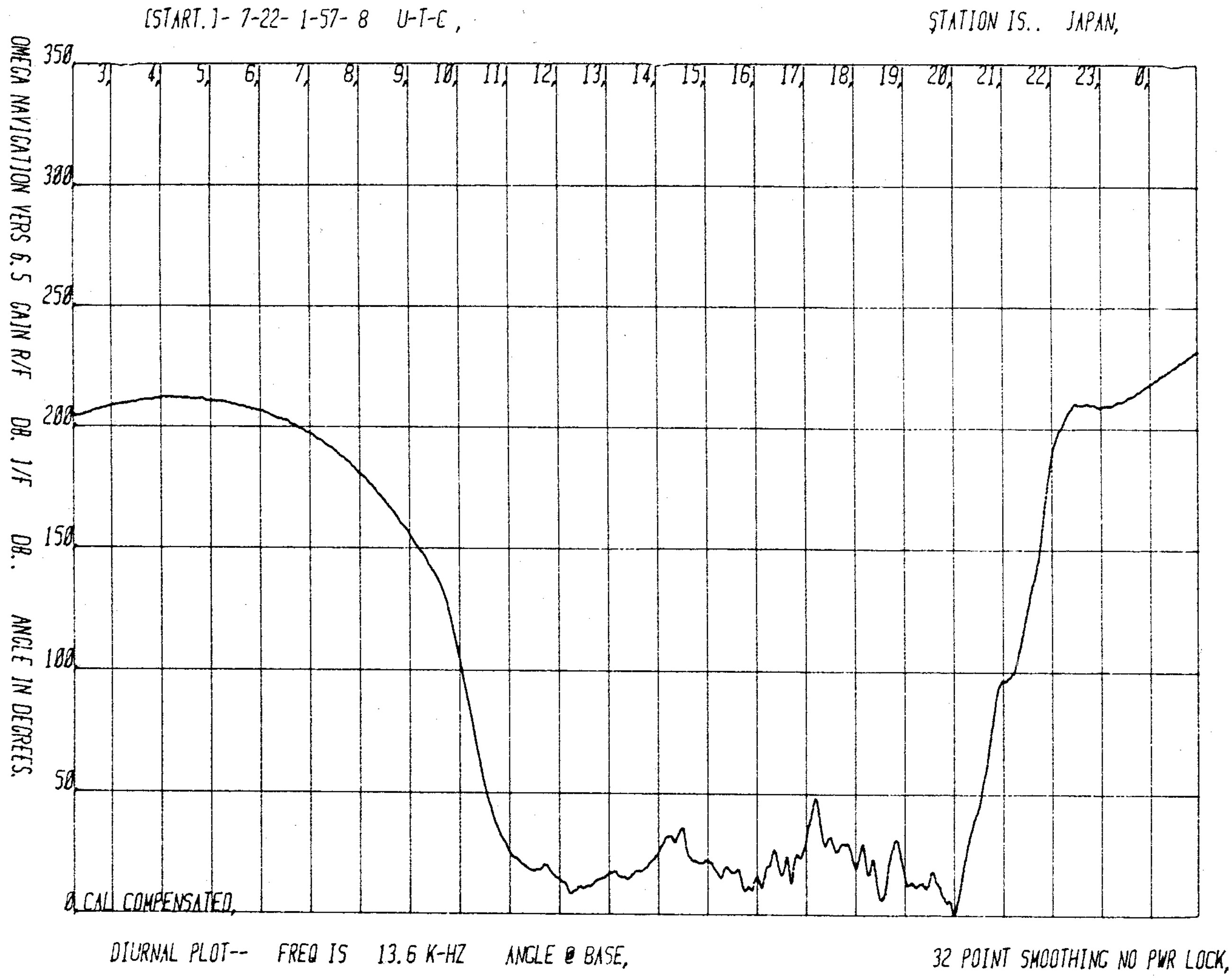


Figure 18. Diurnal phase plot, Omega Japan, 13.6 kHz

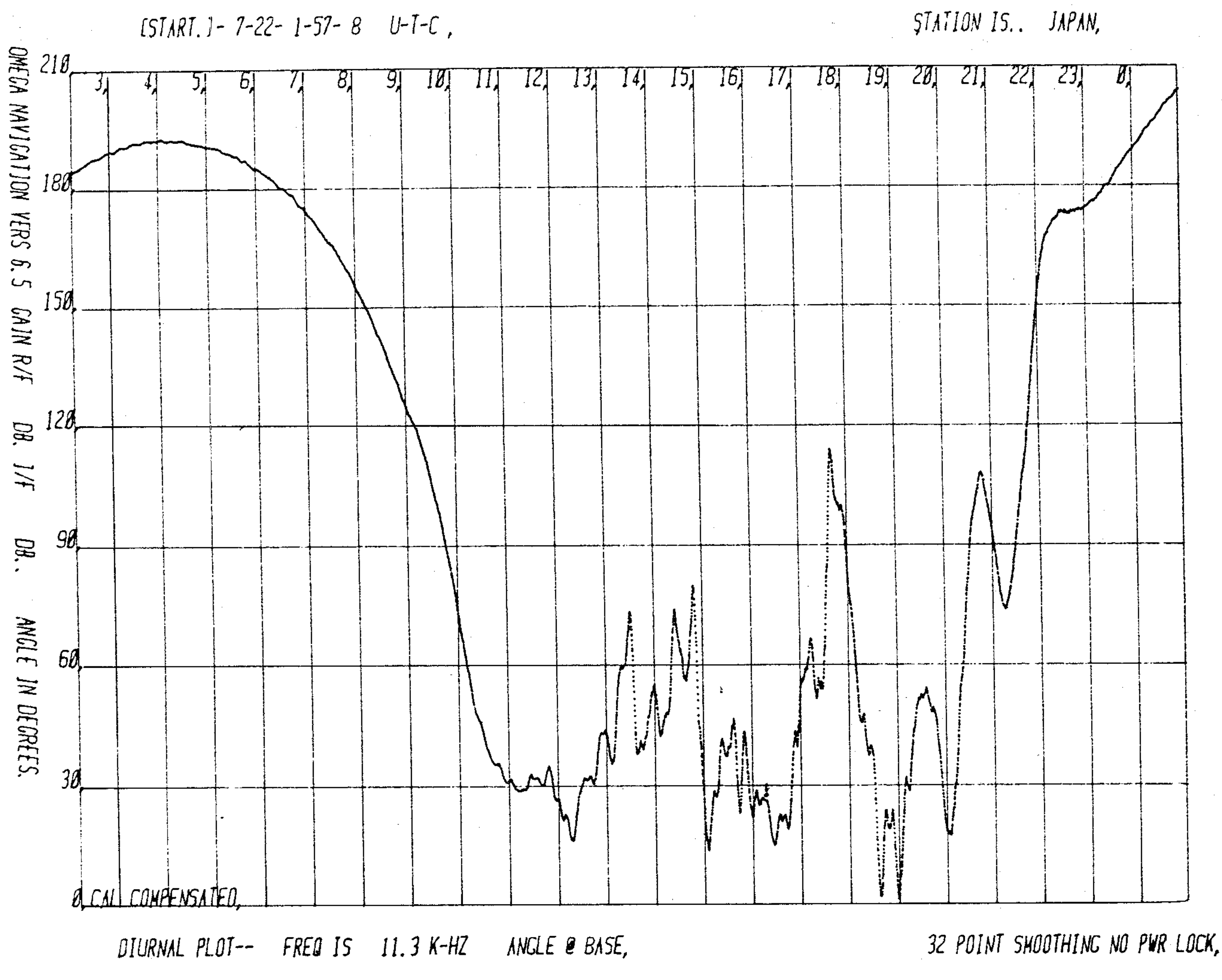


Figure 19. Diurnal phase plot, Omega Japan, 11-1/3 kHz

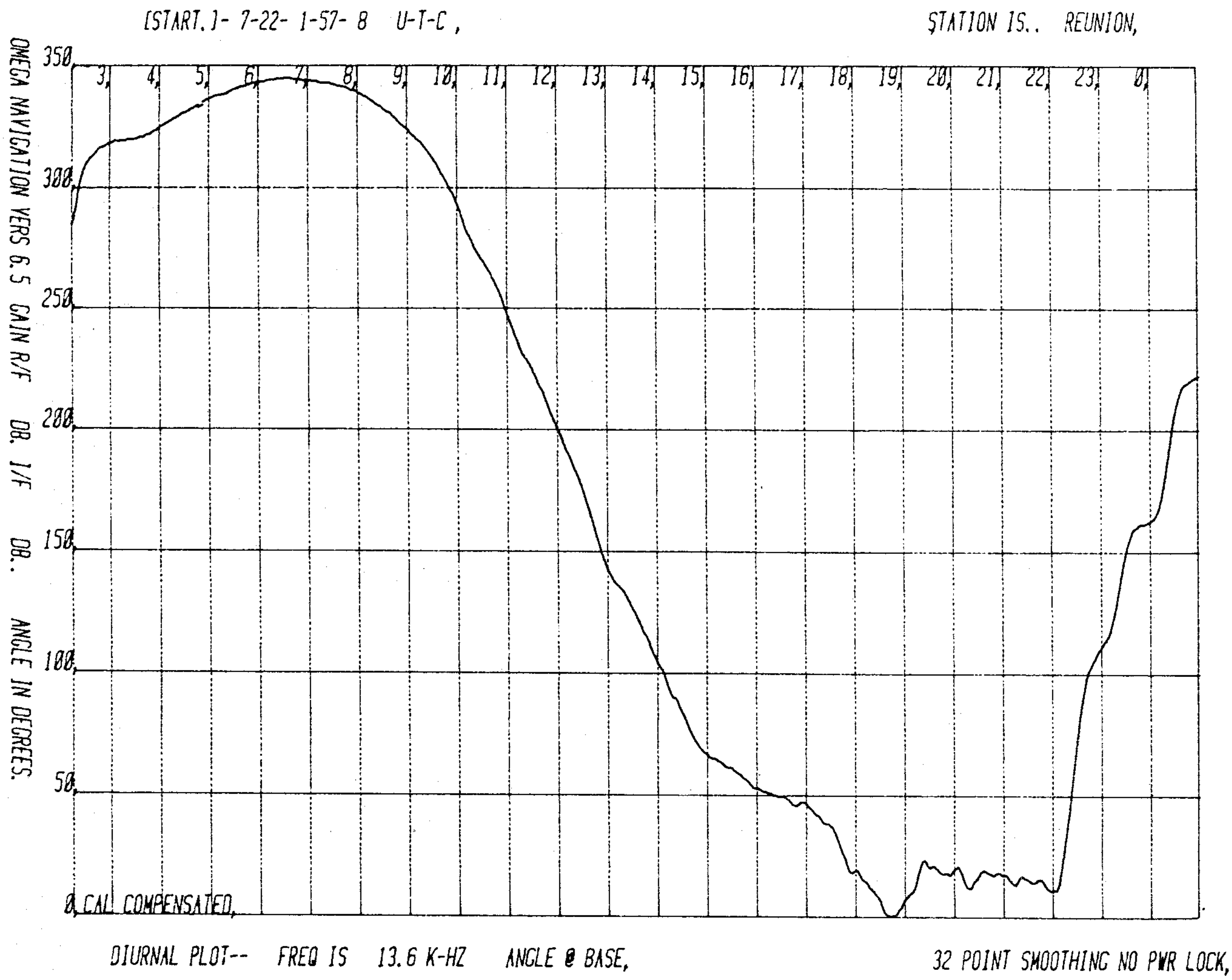


Figure 20. Diurnal phase plot, Omega Reunion, 13.6 kHz

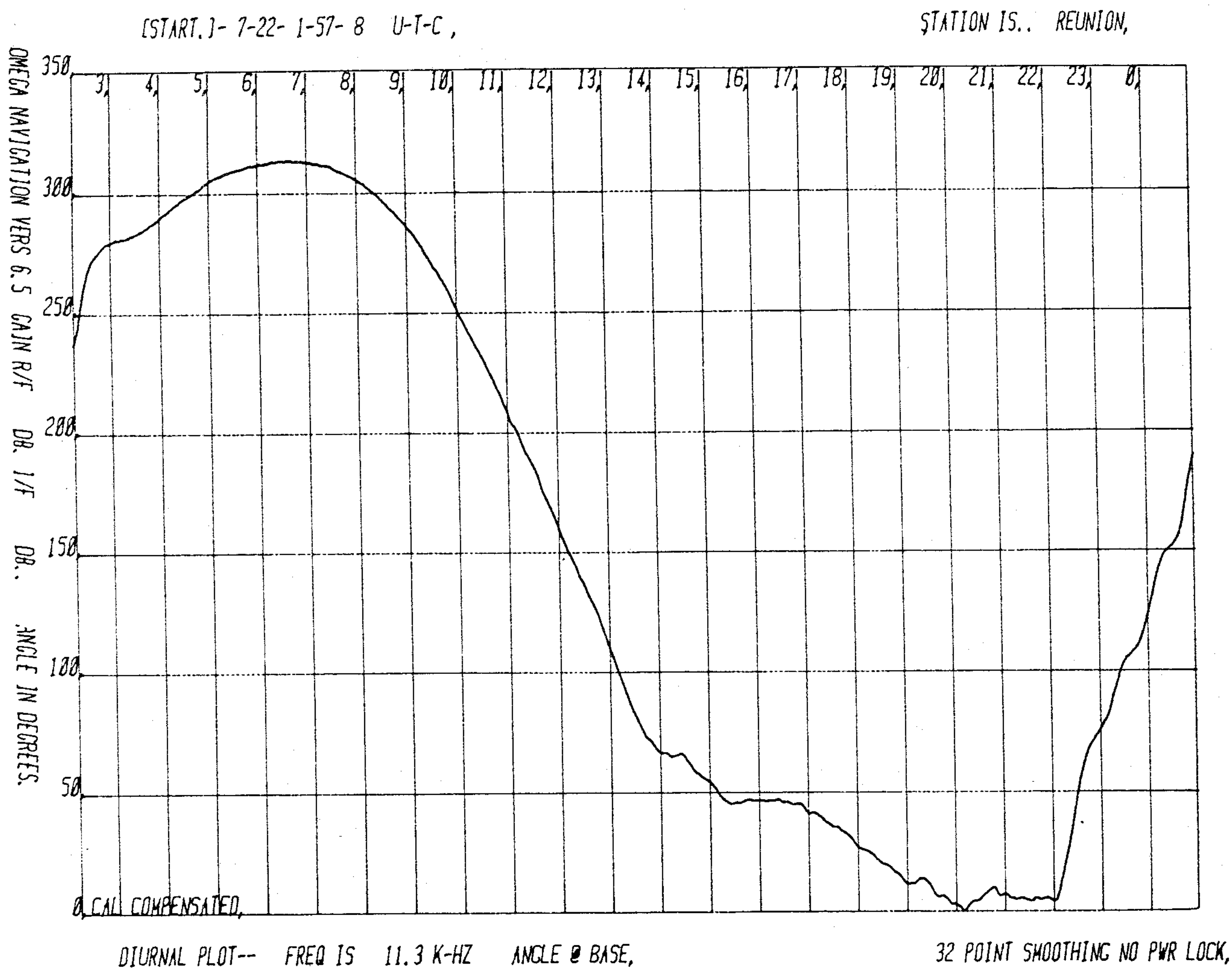


Figure 21. Diurnal phase plot, Omega Reunion, 11-1/3 kHz

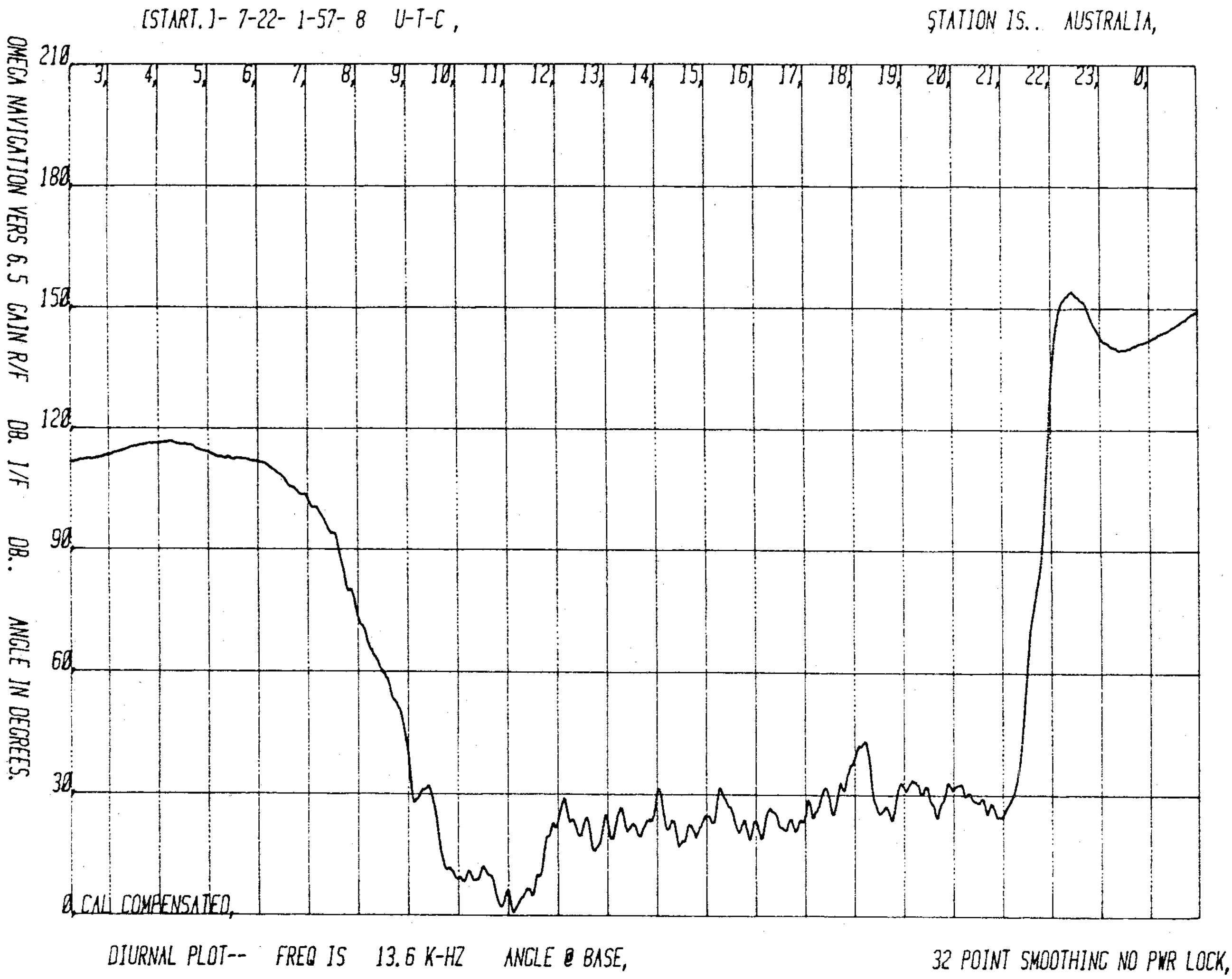


Figure 22. Diurnal phase plot, Omega Australia, 13.6 kHz

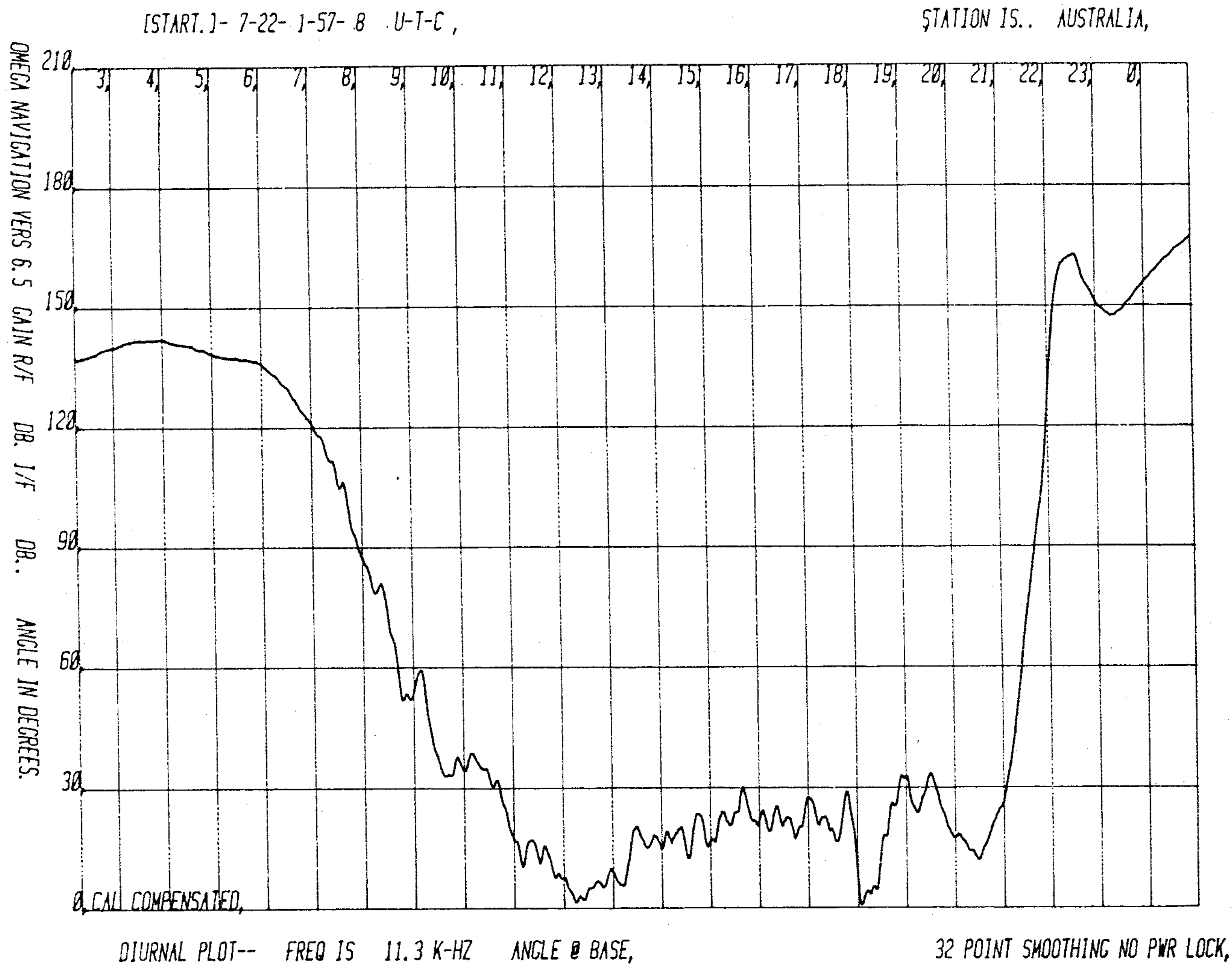


Figure 23. Diurnal phase plot, Omega Australia, 11-1/3 kHz

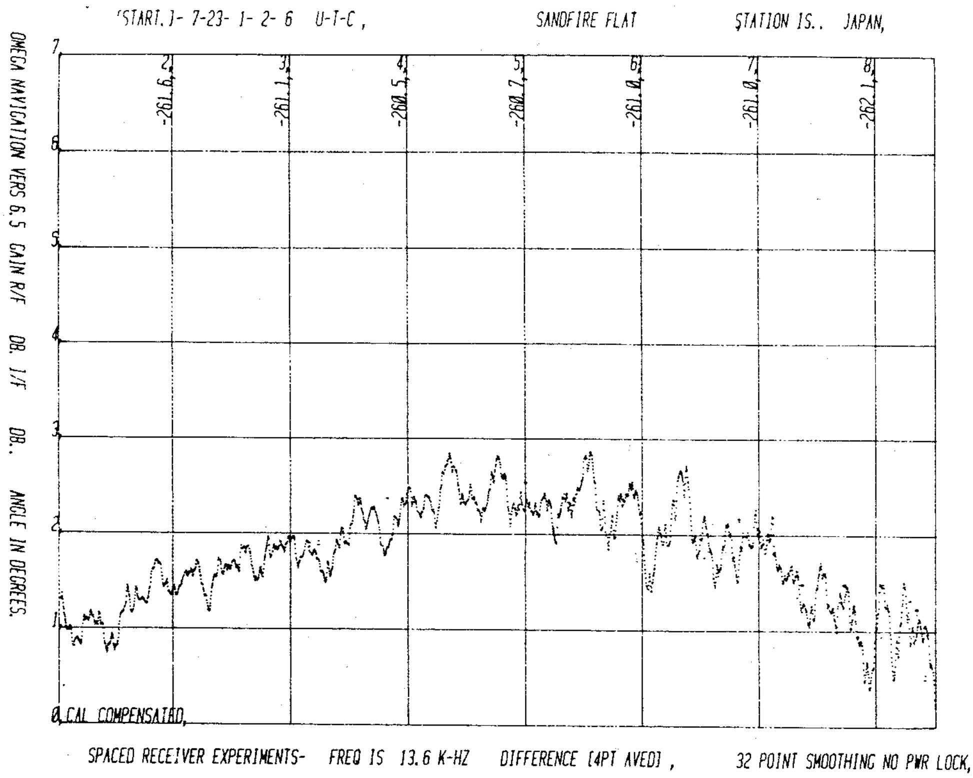


Figure 24. Sandfire Flat, Japan, 13.6 kHz

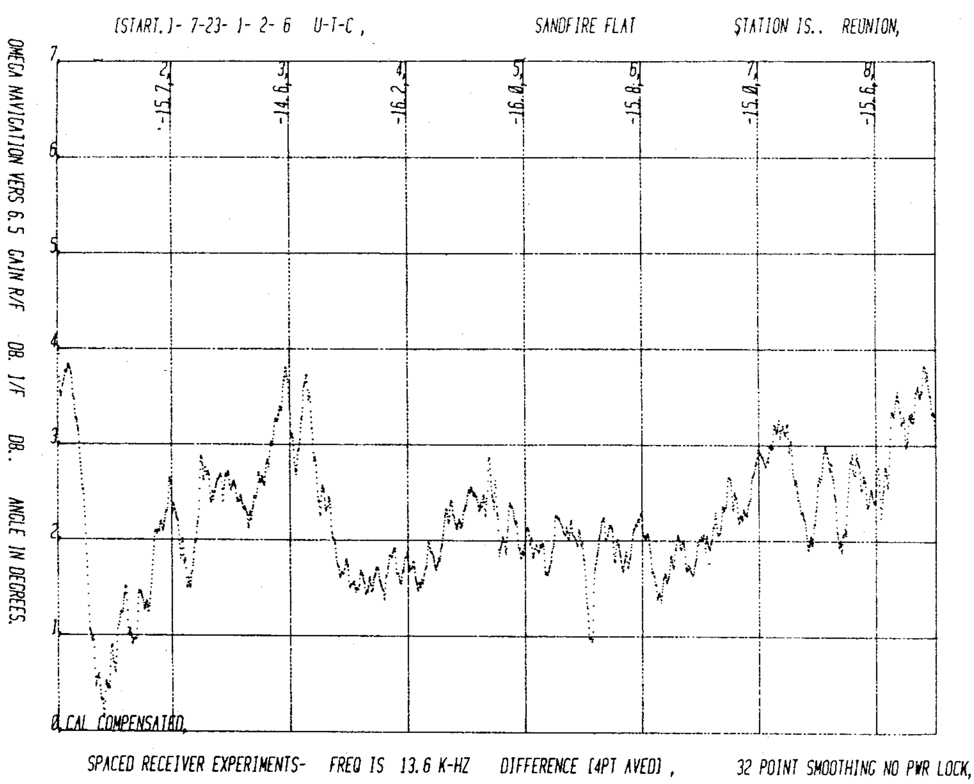


Figure 25. Sandfire Flat, Reunion, 13.6 kHz

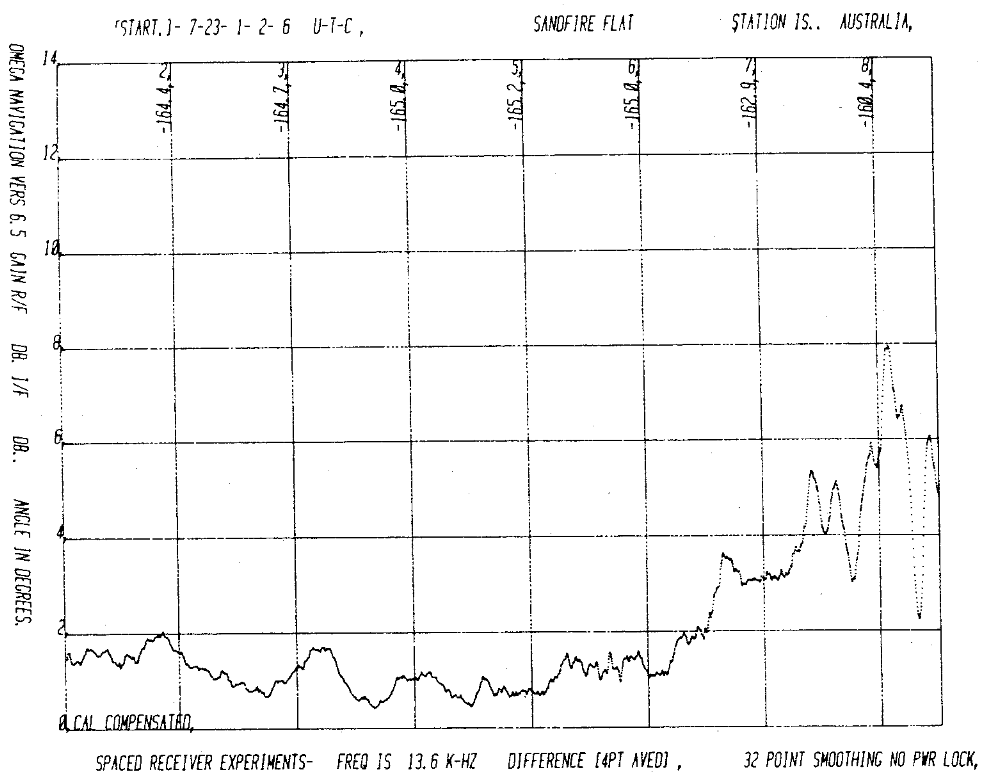


Figure 26. Sandfire Flat, Australia, 13.6 kHz

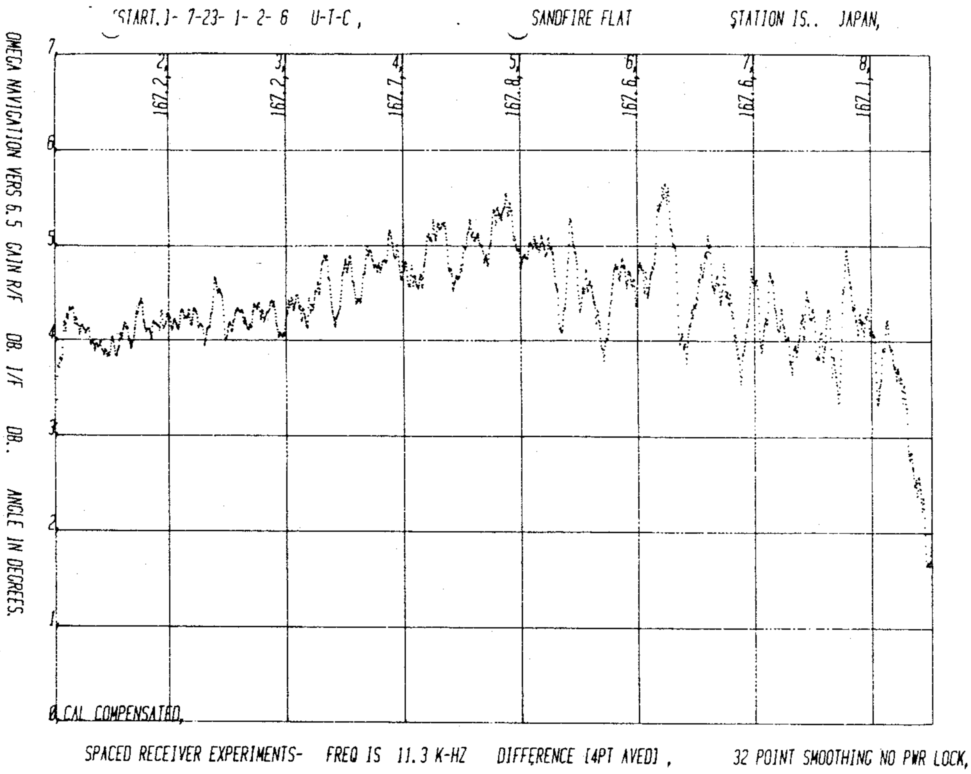


Figure 27. Sandfire Flat, Japan, 11-1/3 kHz

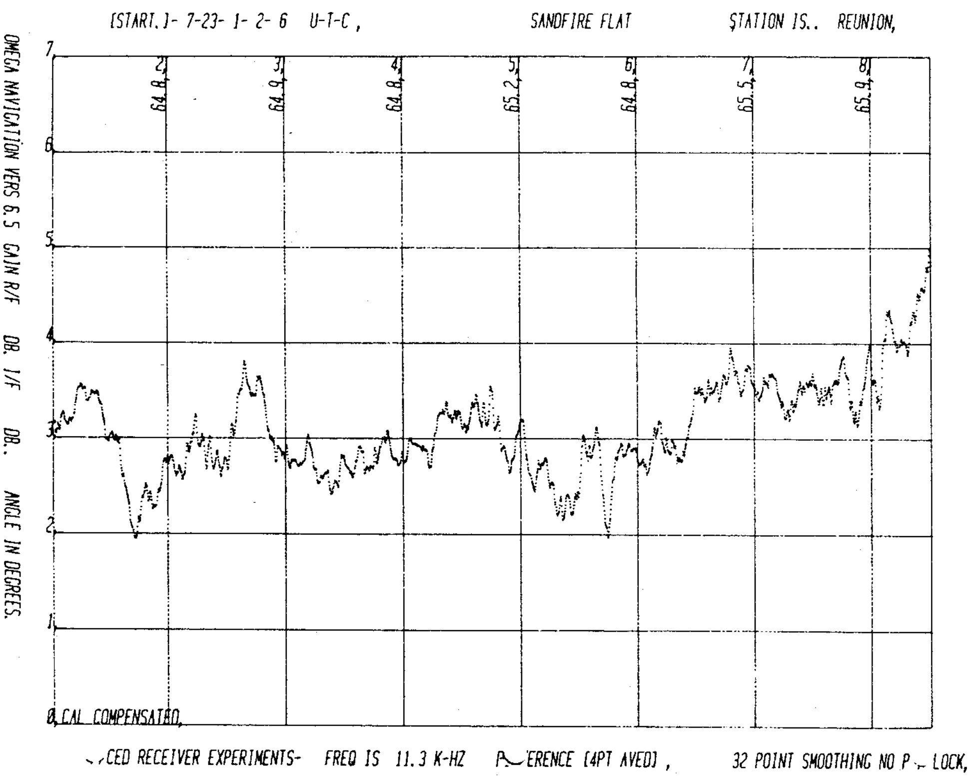


Figure 28. Sandfire Flat, Reunion, 11-1/3 kHz

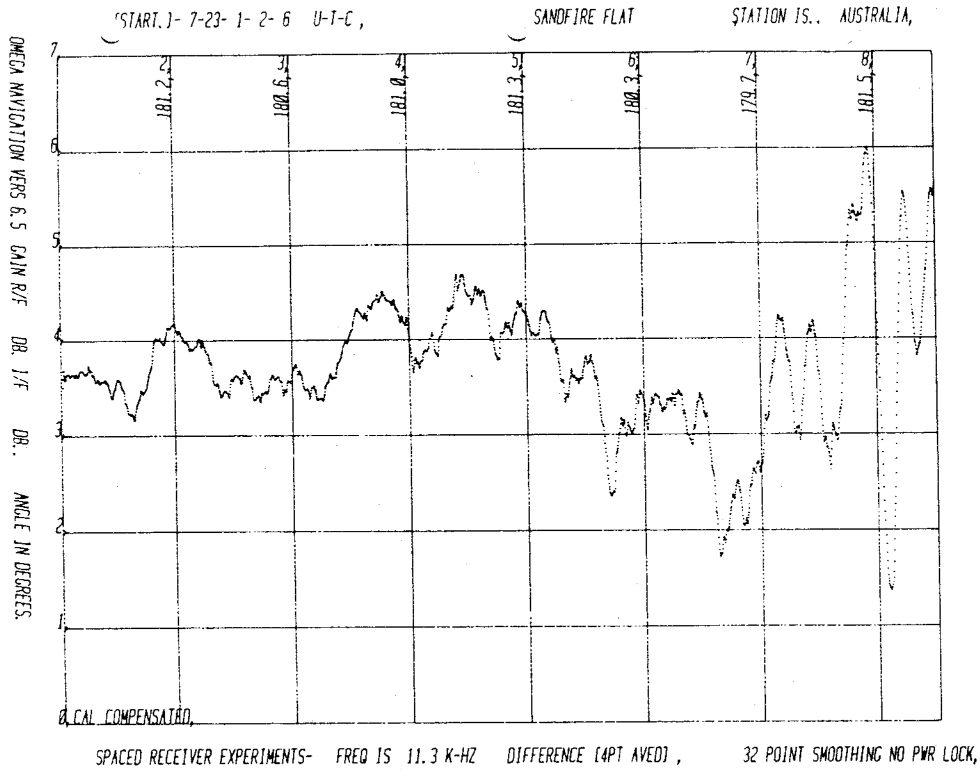


Figure 29. Sandfire Flat, Australia, 11-1/3 kHz

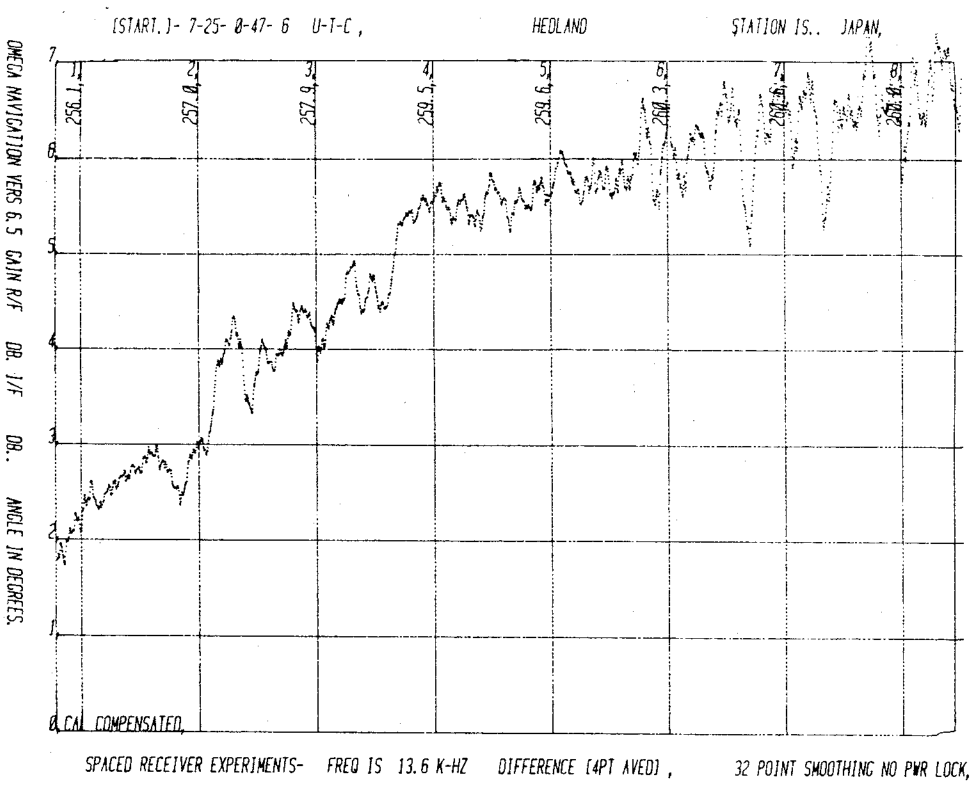


Figure 30. Pt Hedland, Japan, 13.6 kHz

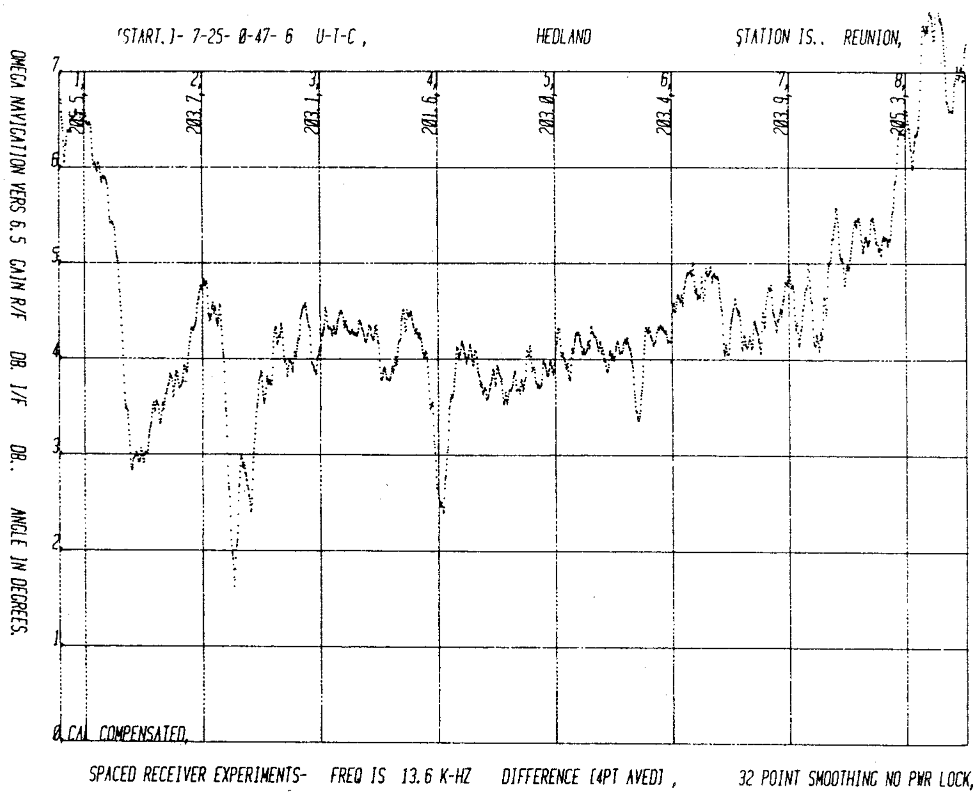


Figure 31. Pt Hedland, Reunion, 13.6 kHz

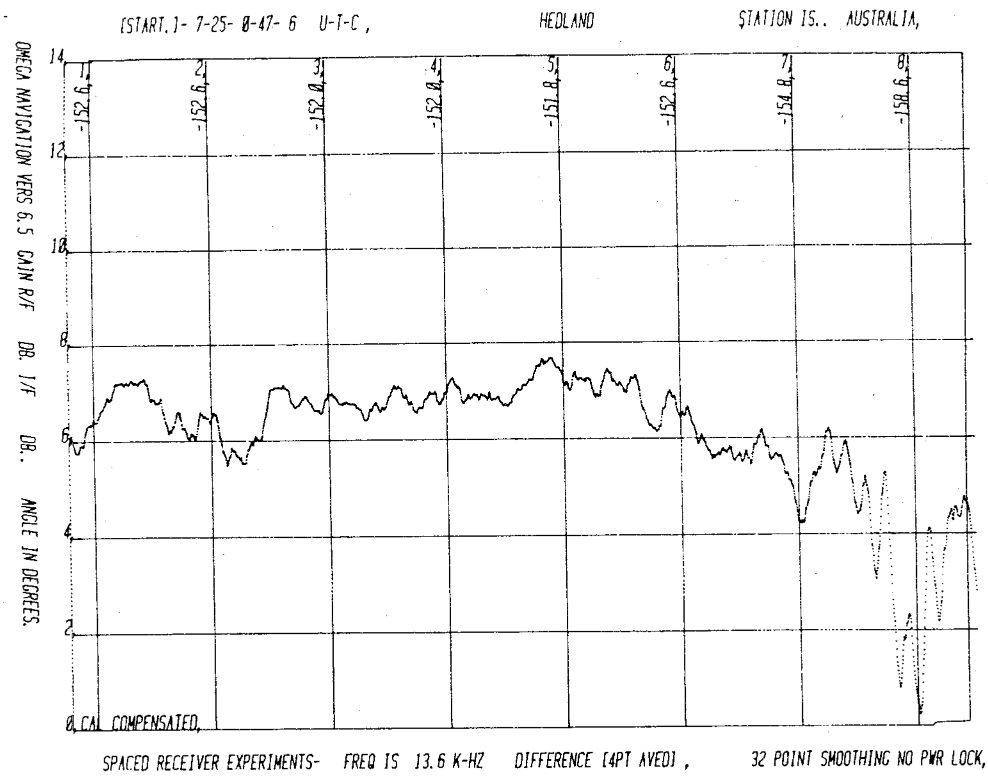


Figure 32. Pt Hedland, Australia, 13.6 kHz

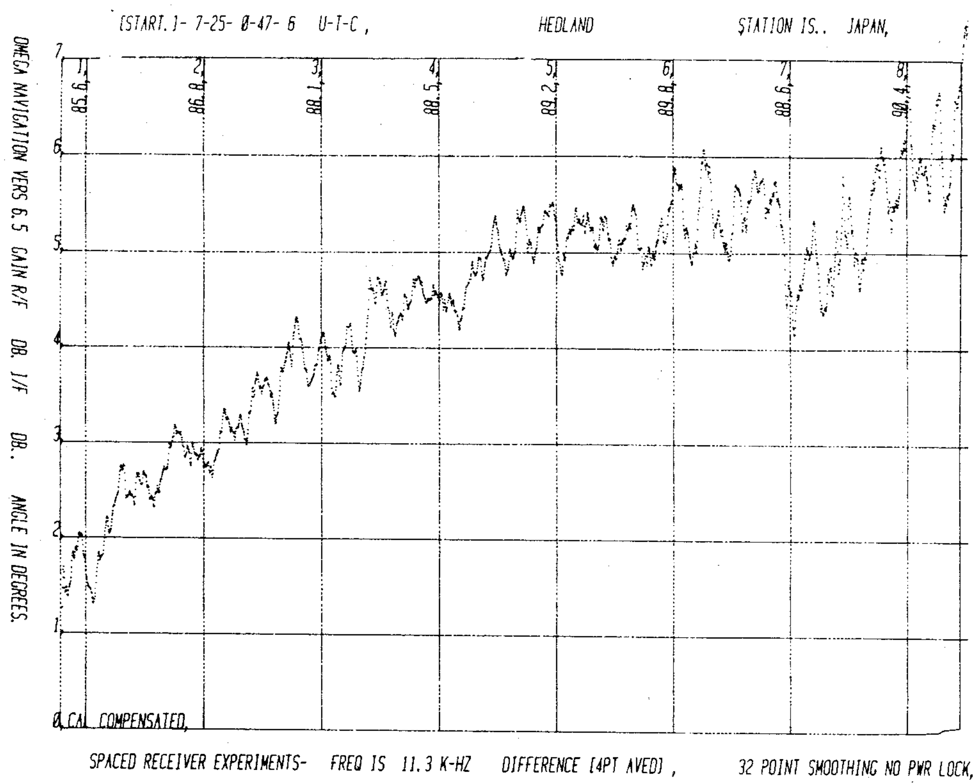


Figure 33. Pt Hedland, Japan, 11-1/3 kHz

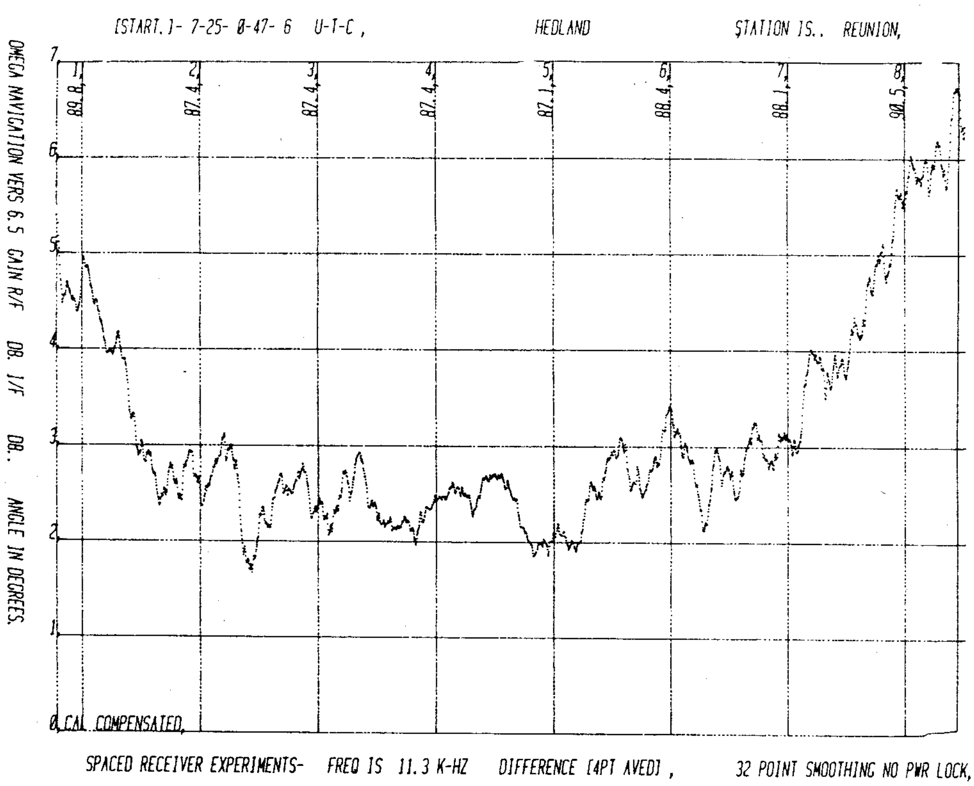


Figure 34. Pt Hedland, Reunion, 11-1/3 kHz

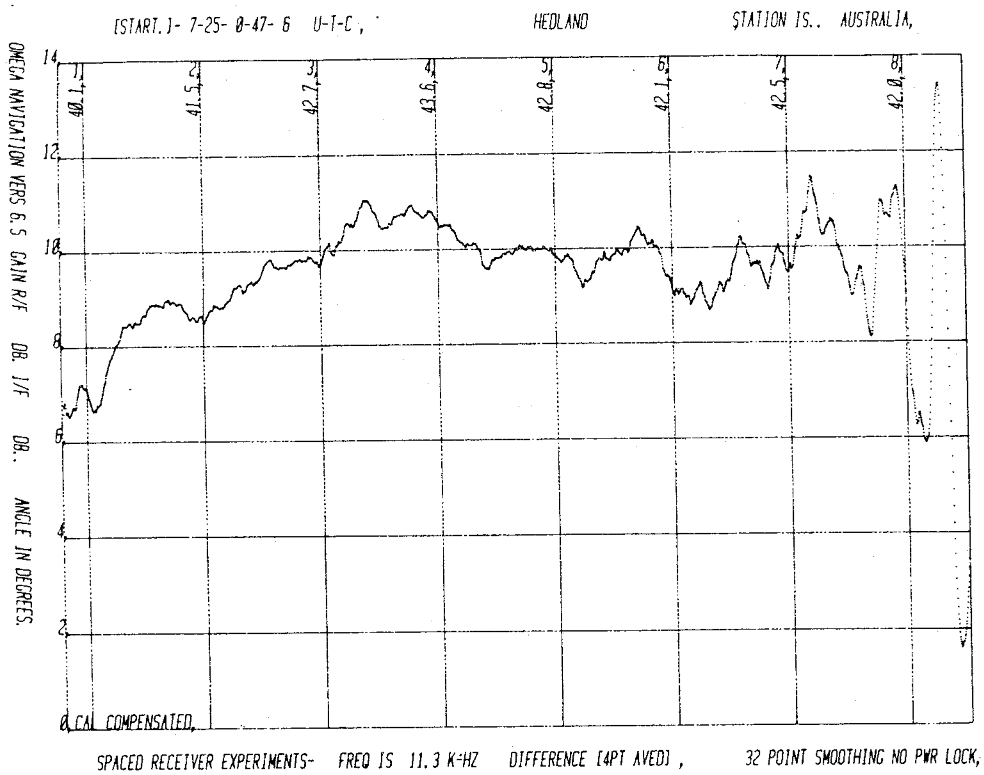


Figure 35. Pt Hedland, Australia, 11-1/3 kHz

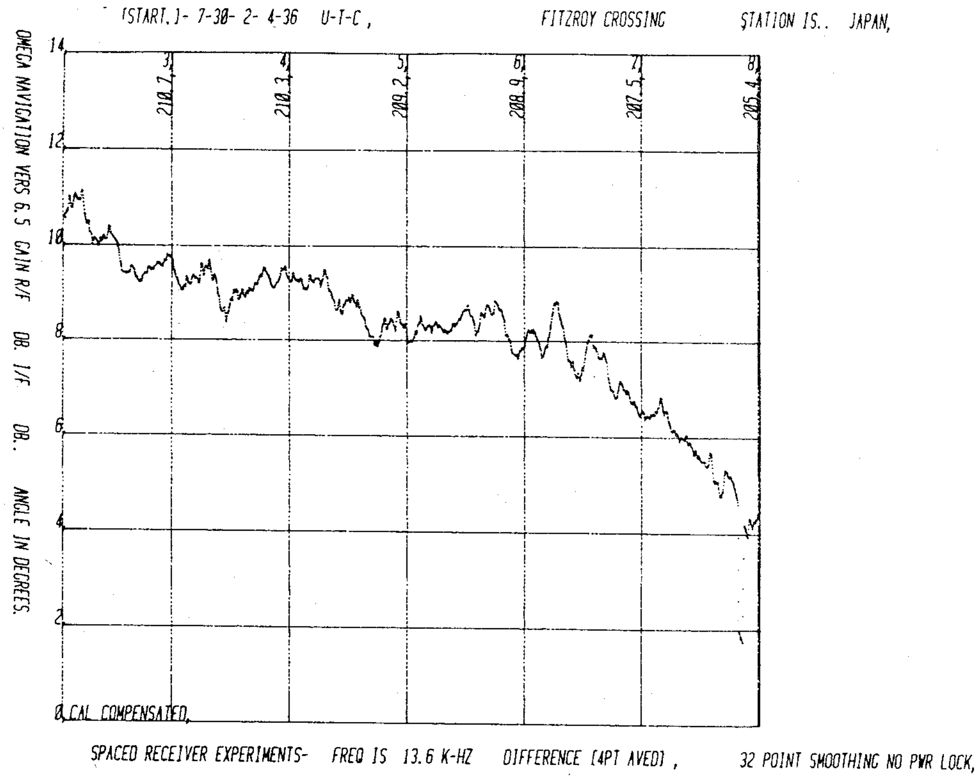


Figure 36. Fitzroy Crossing, Japan, 13.6 kHz

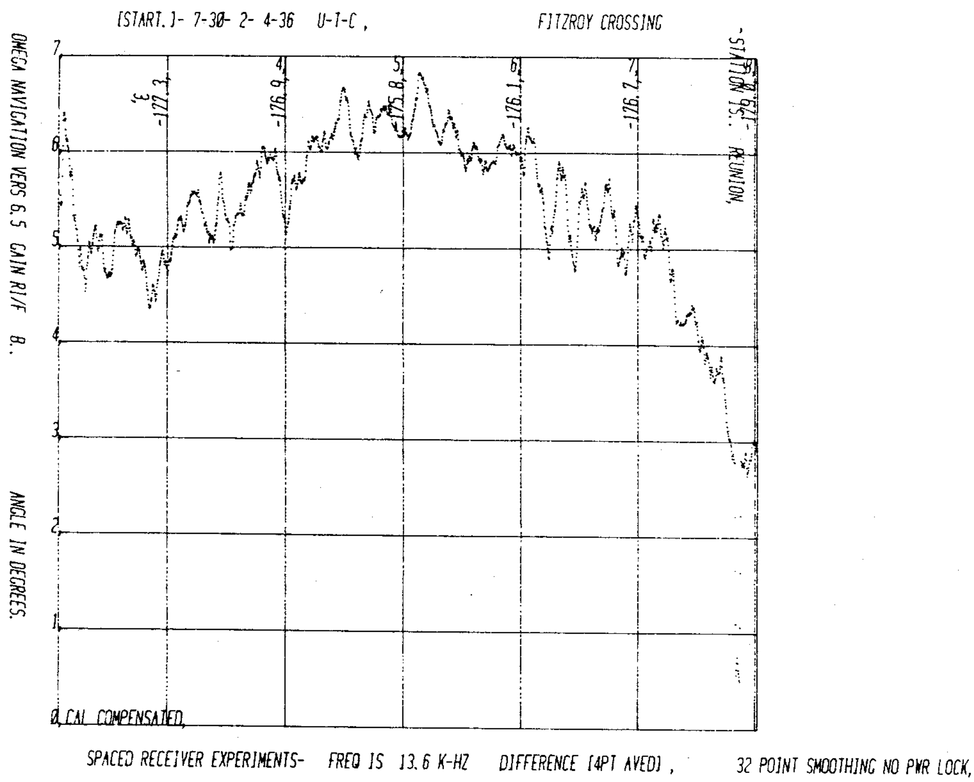


Figure 37. Fitzroy Crossing, Reunion, 13.6 kHz

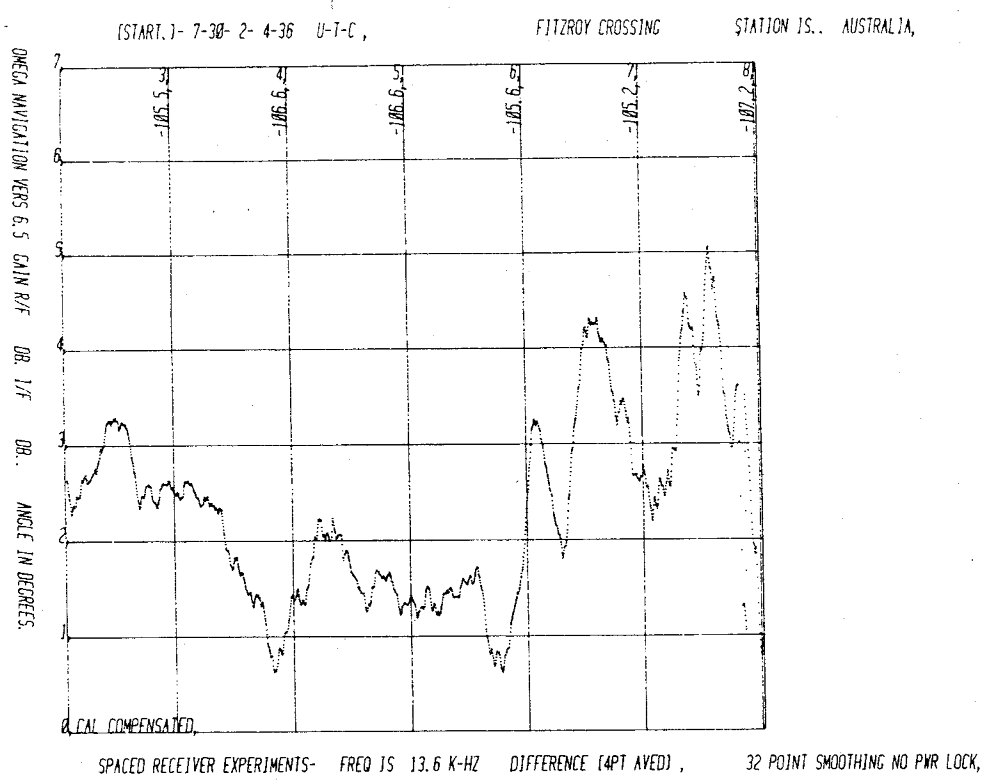


Figure 38. Fitzroy Crossing, Australia, 13.6 kHz

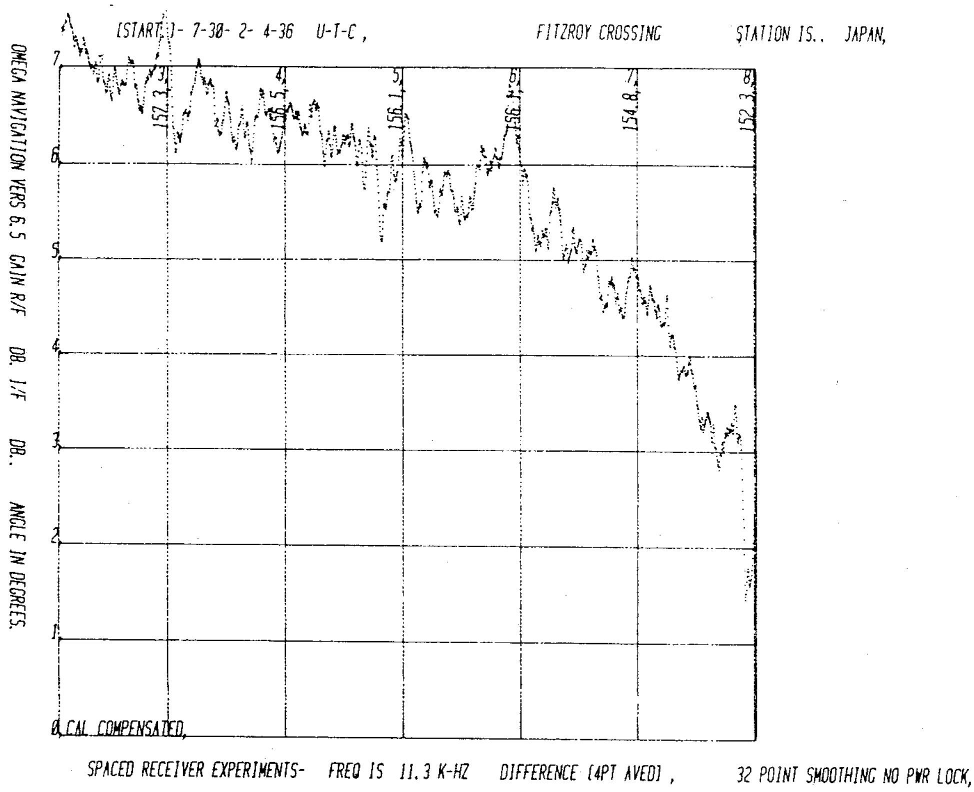


Figure 39. Fitzroy Crossing, Japan, 11-1/3 kHz

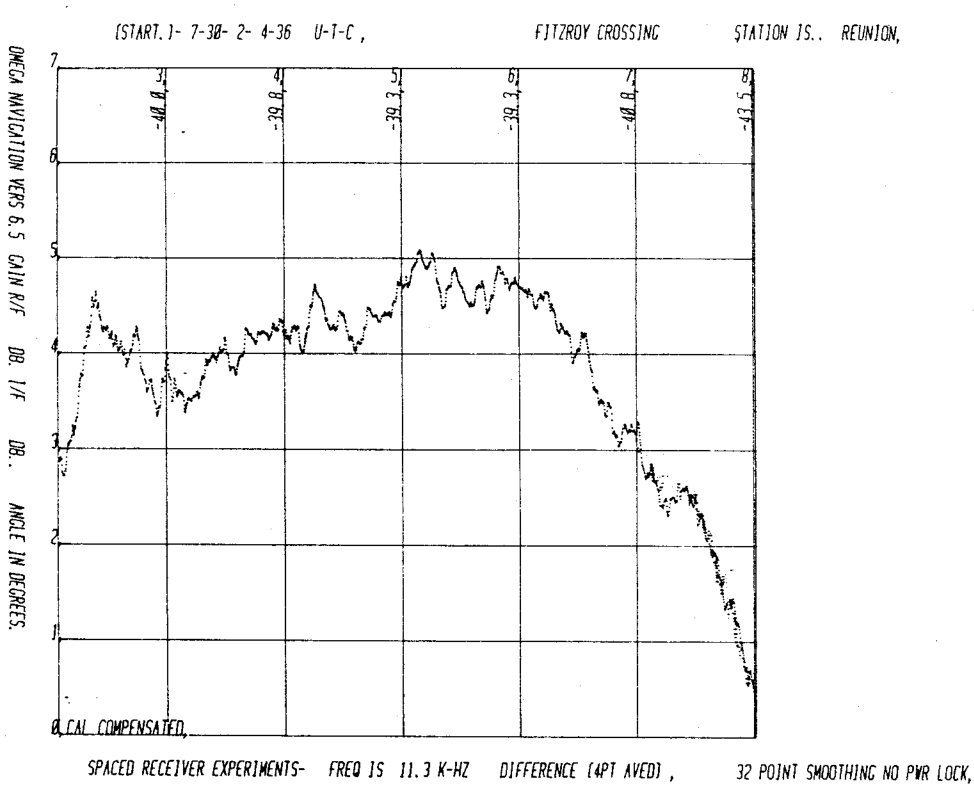


Figure 40. Fitzroy Crossing, Reunion, 11-1/3 kHz

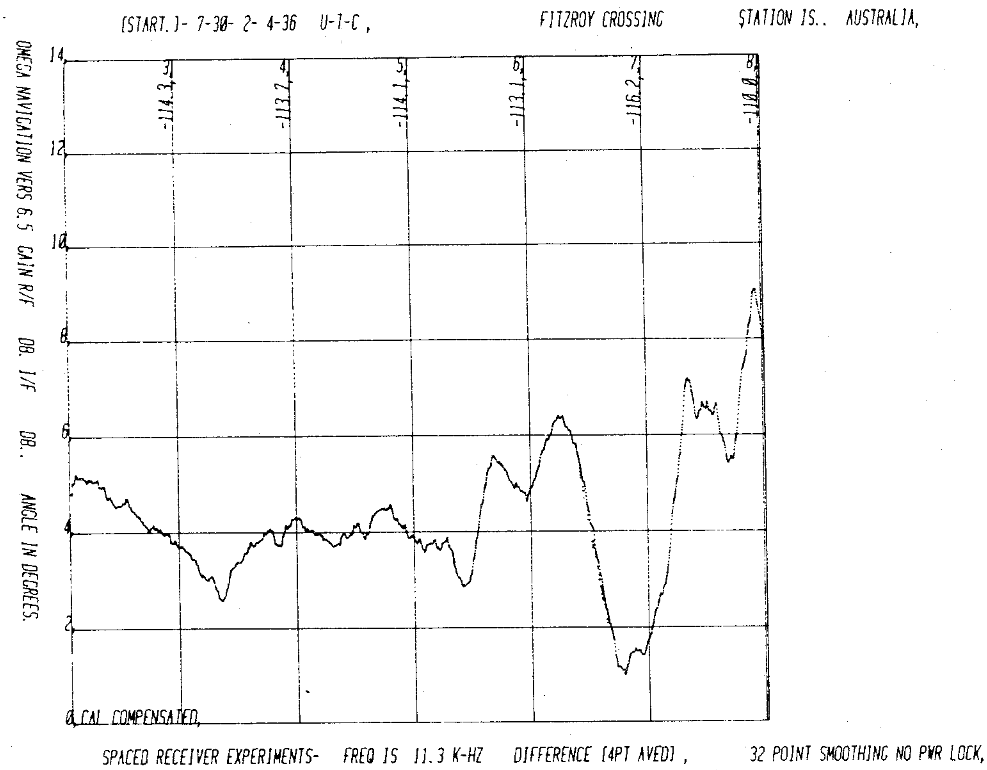


Figure 41. Fitzroy Crossing, Australia, 11-1/3 kHz

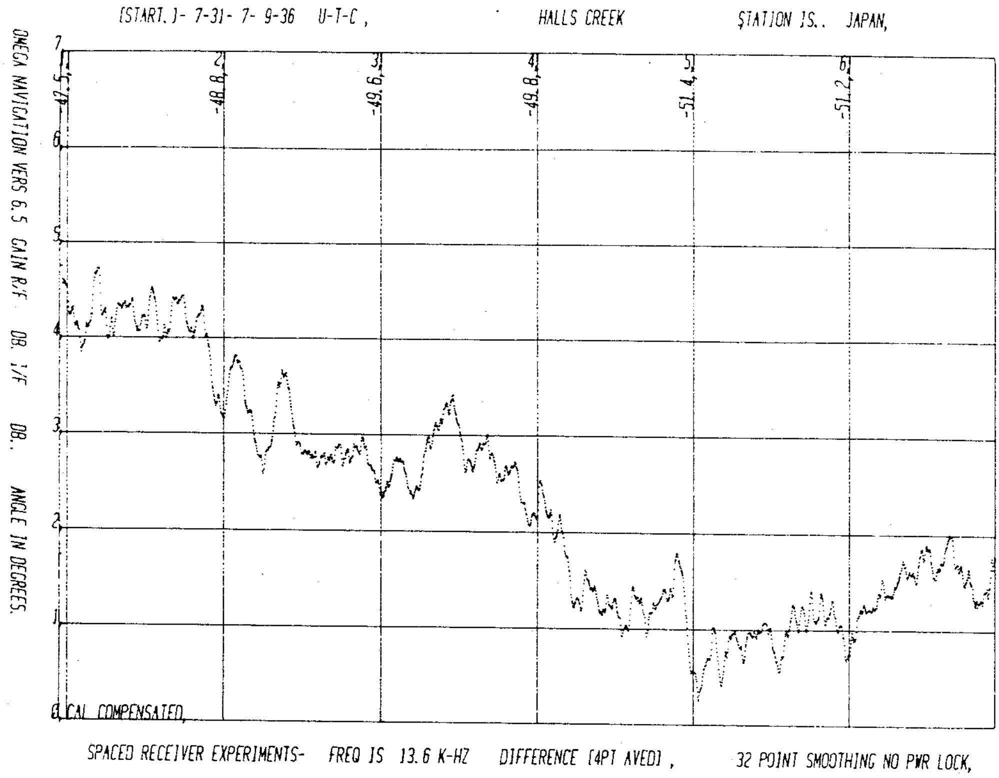


Figure 42. Halls Creek, Japan, 13.6 kHz

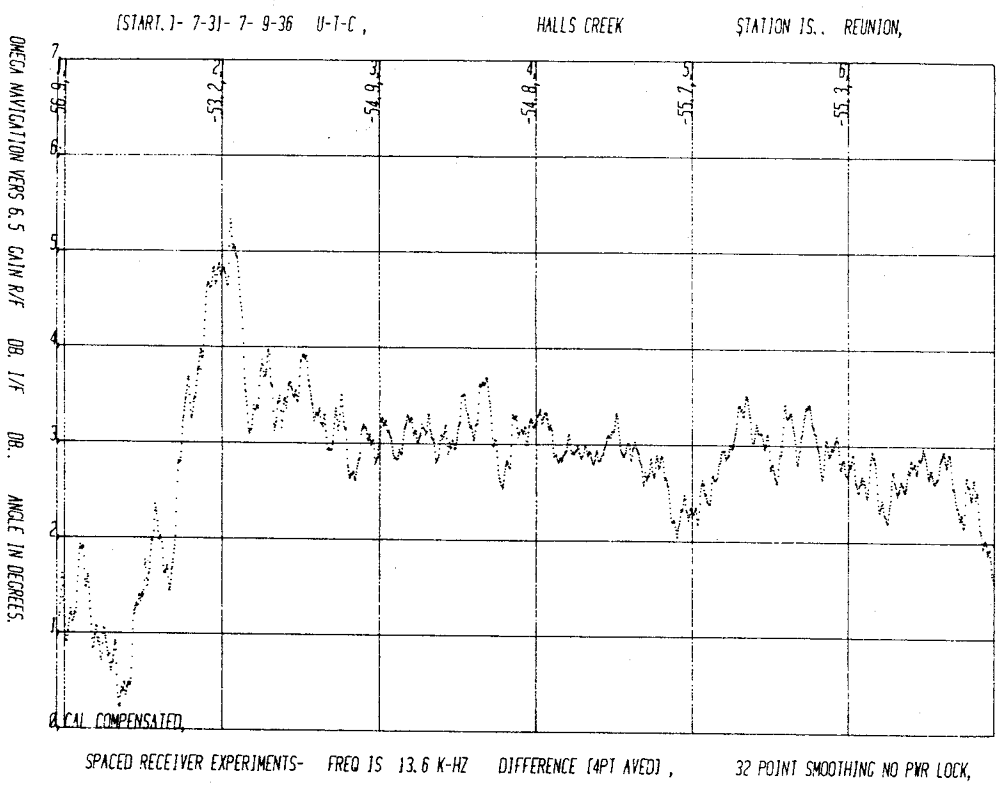


Figure 43. Halls Creek, Reunion, 13.6 kHz

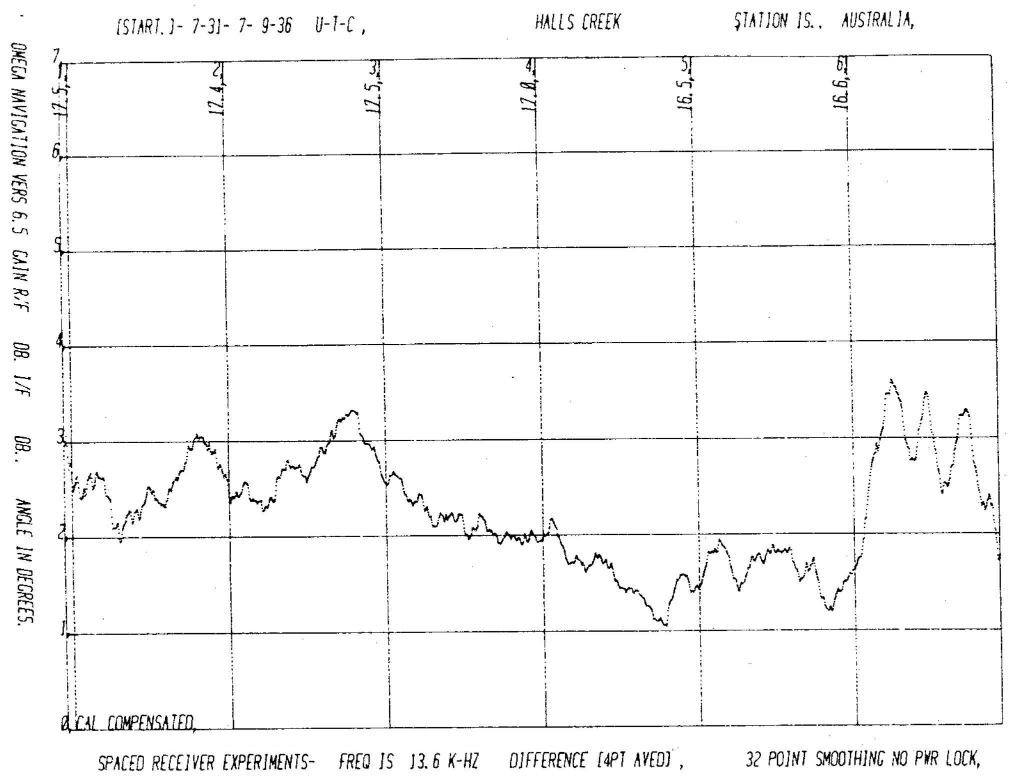


Figure 44. Halls Creek, Australia, 13.6 kHz

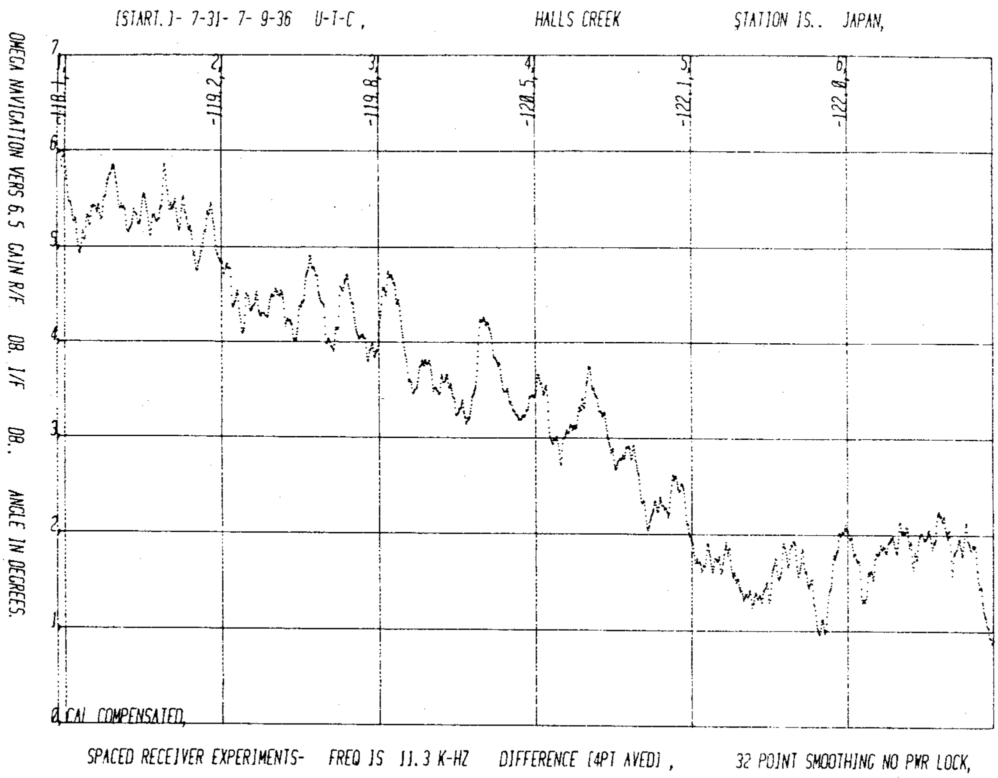


Figure 45. Halls Creek, Japan, 11-1/3 kHz

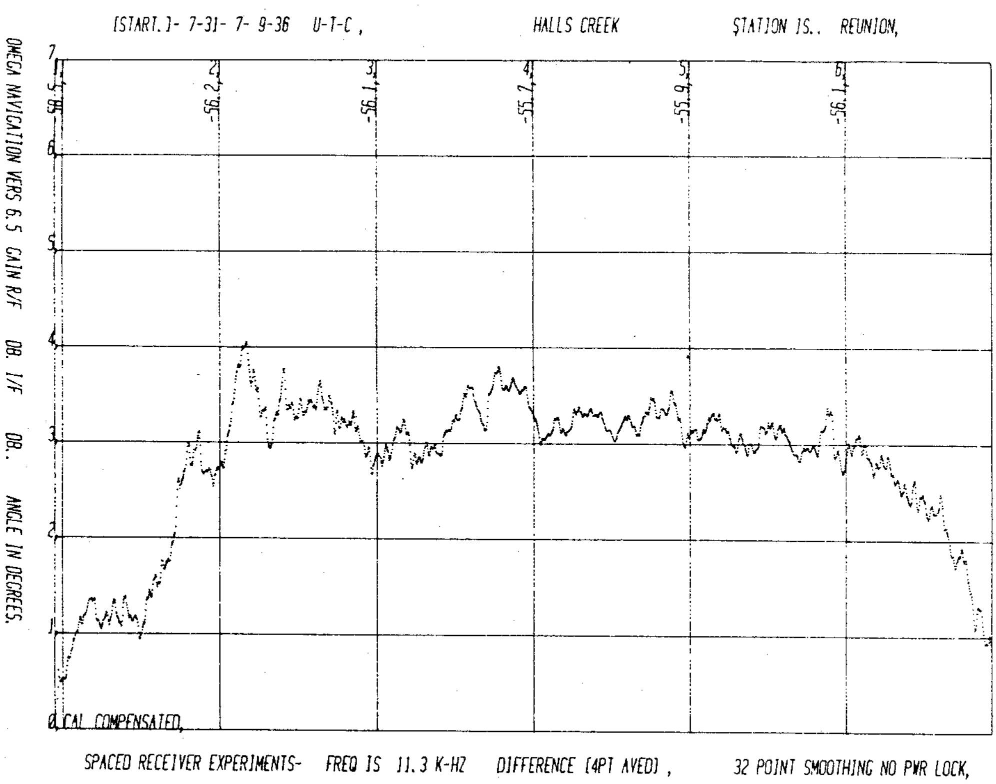


Figure 46. Halls Creek, Reunion, 11-1/3 kHz

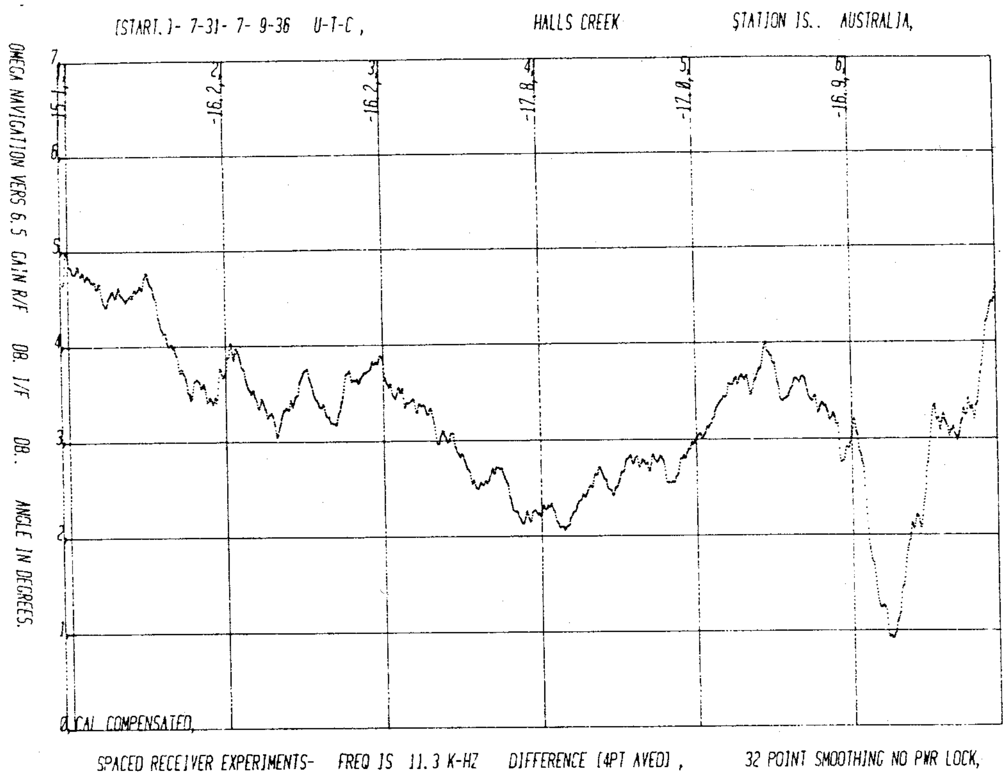


Figure 47. Halls Creek, Australia, 11-1/3 kHz

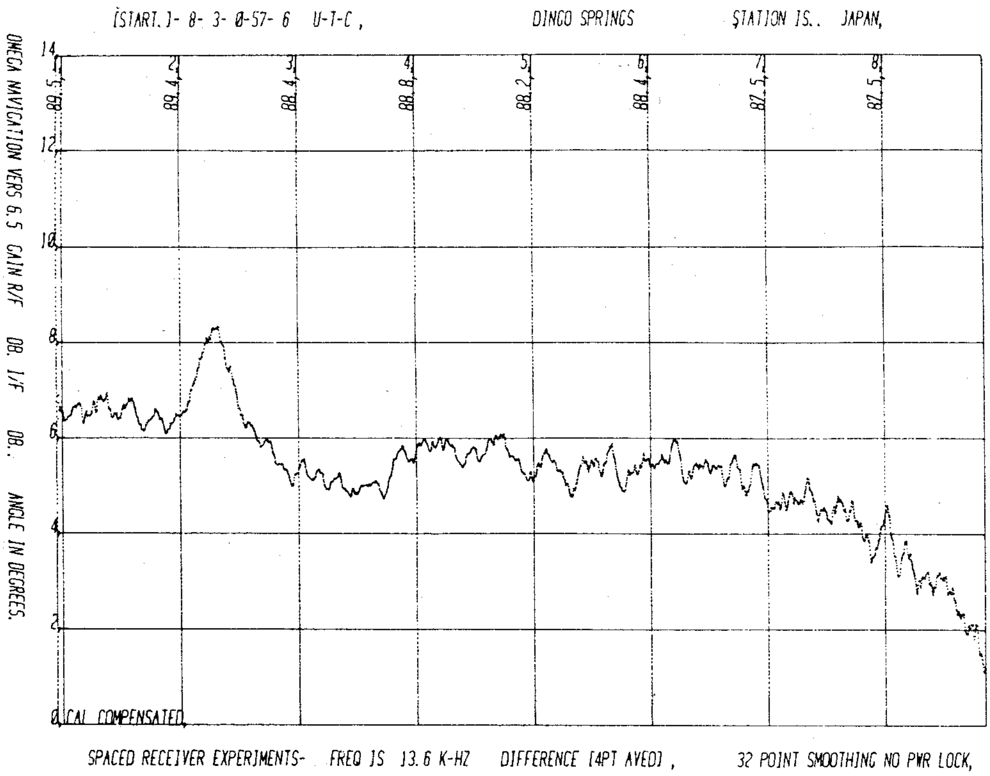


Figure 48. Dingo Springs, Japan, 13.6 kHz

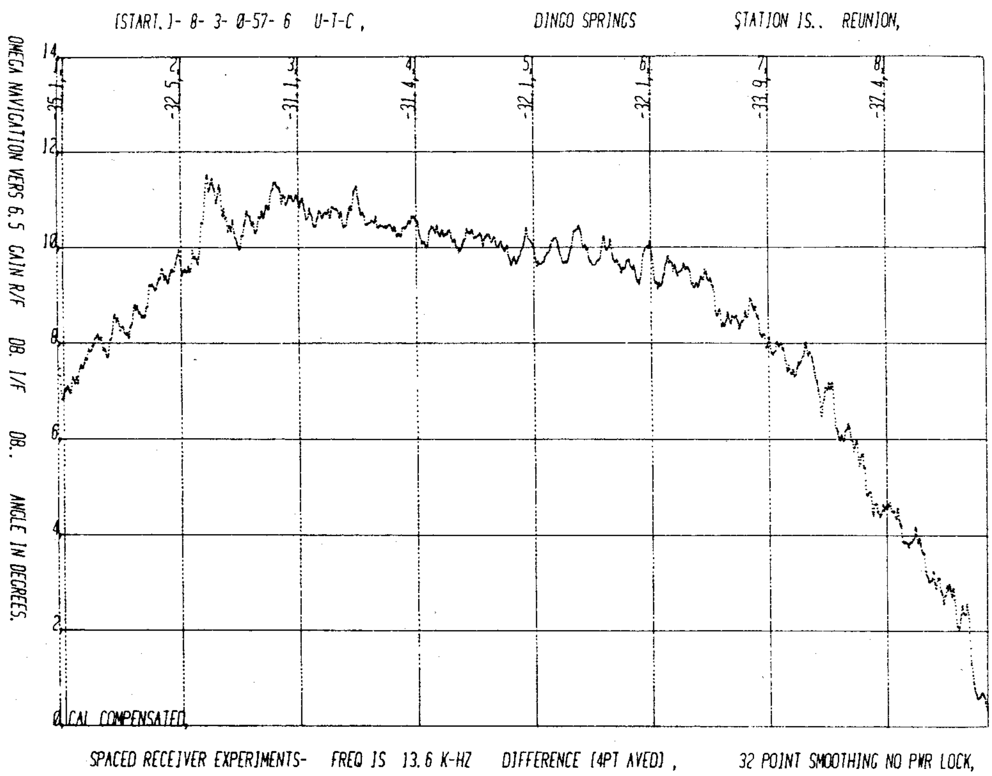


Figure 49. Dingo Springs, Reunion, 13.6 kHz

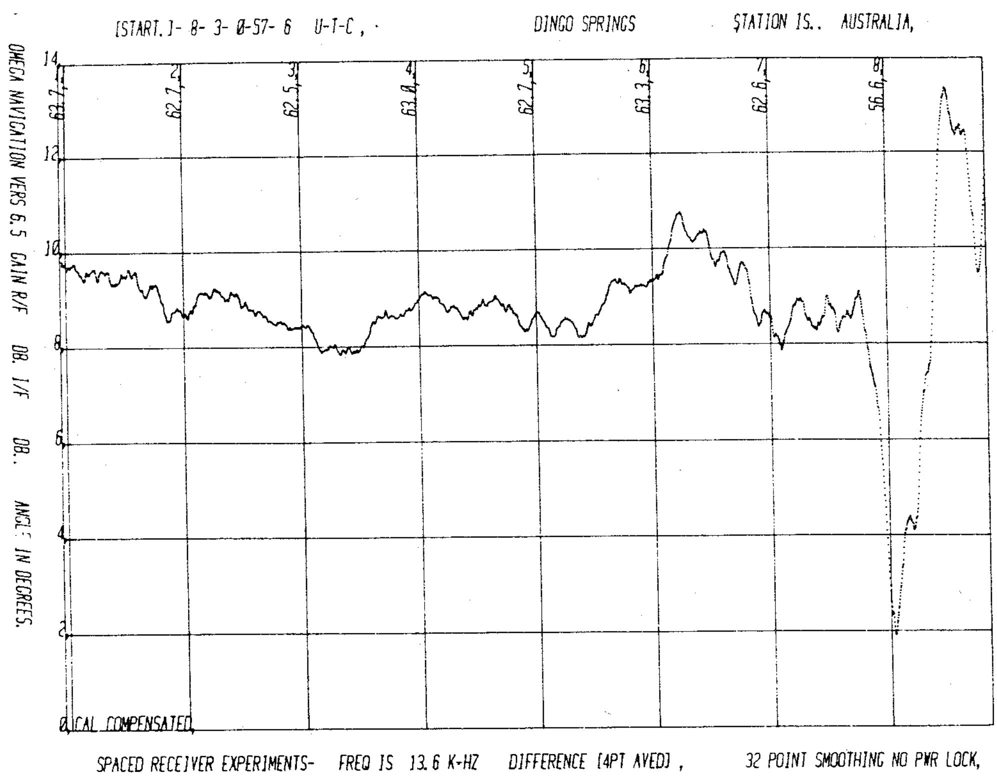


Figure 50. Dingo Springs, Australia, 13.6 kHz

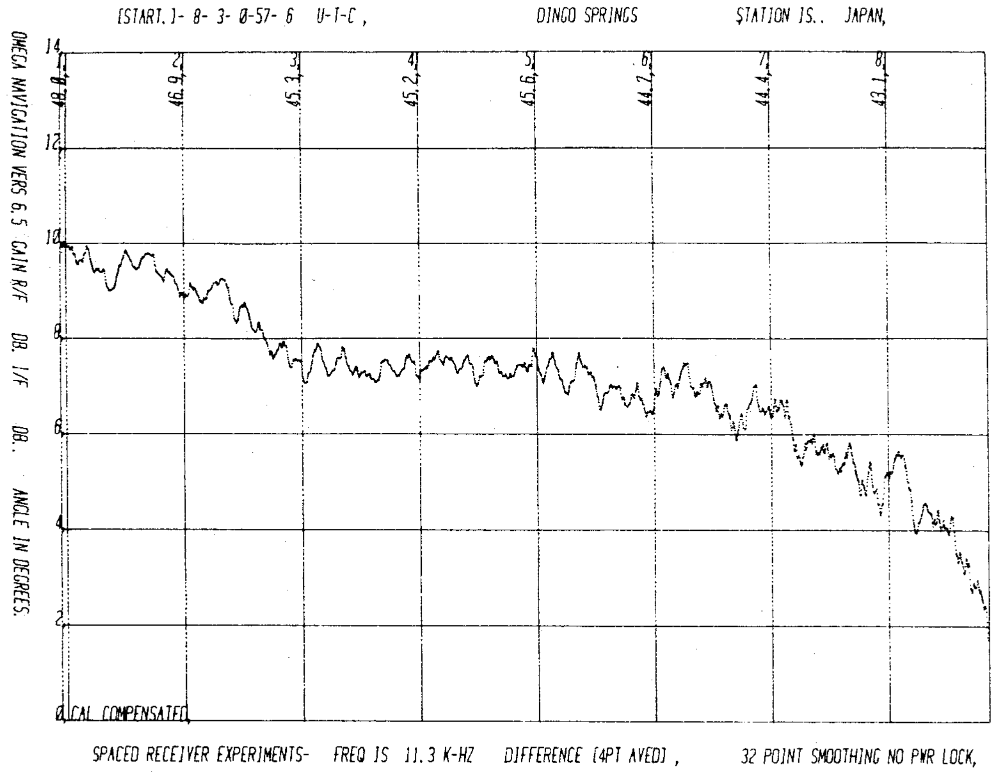
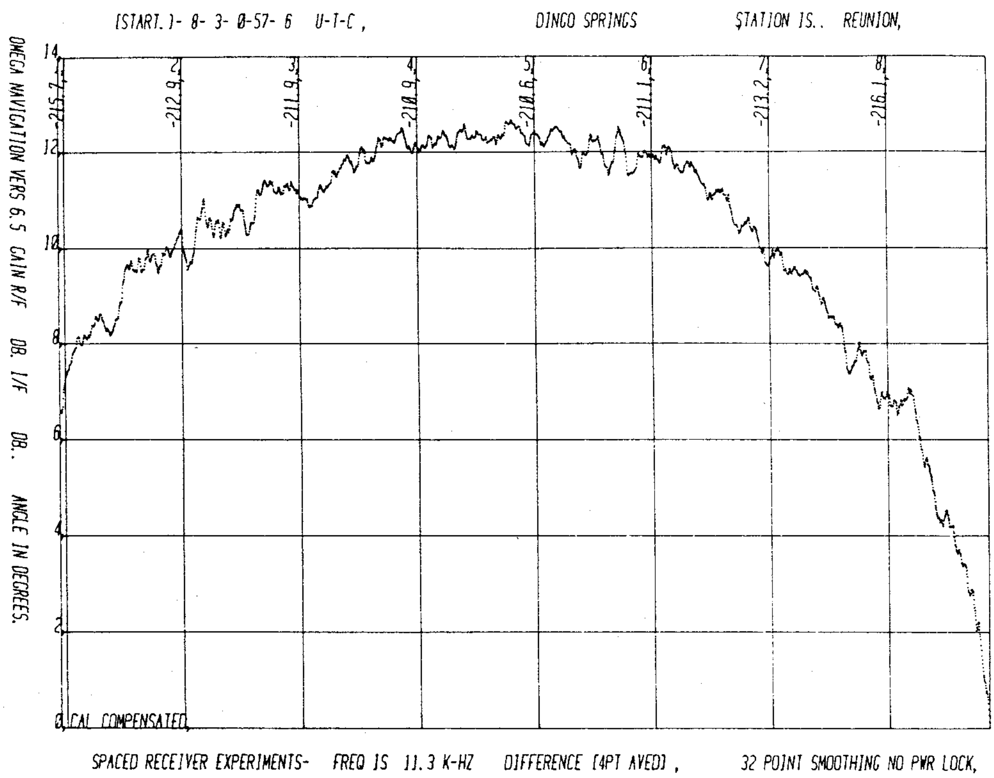


Figure 51. Dingo Springs, Japan, 11-1/3 kHz



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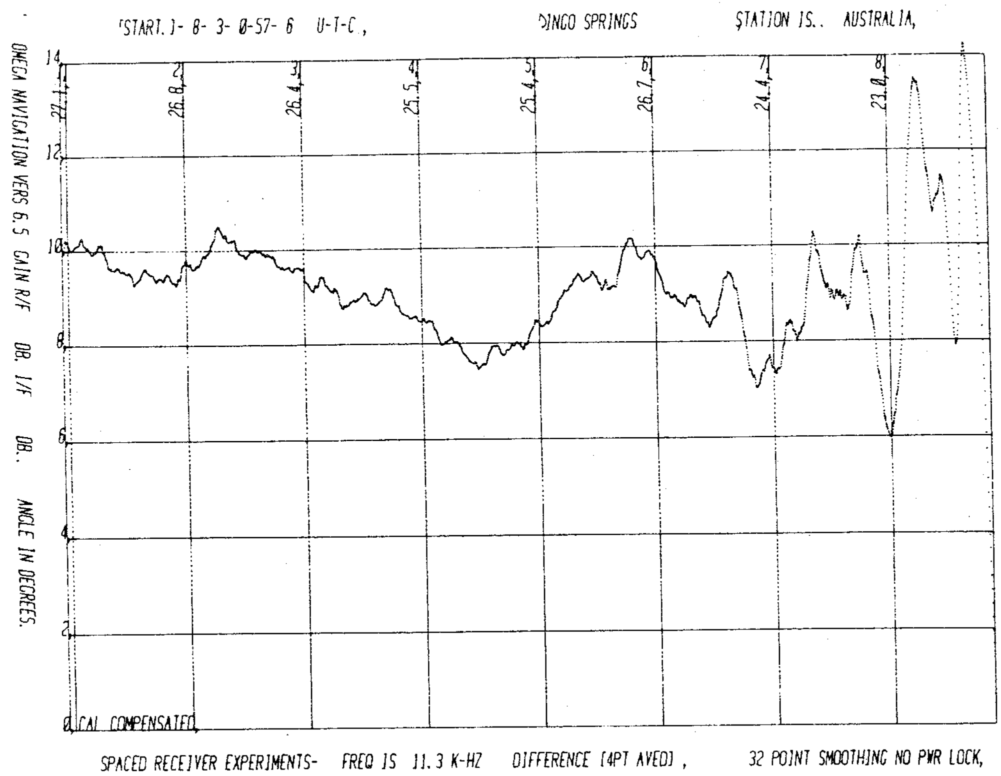


Figure 53. Dingo Springs, Australia, 11-1/3 kHz

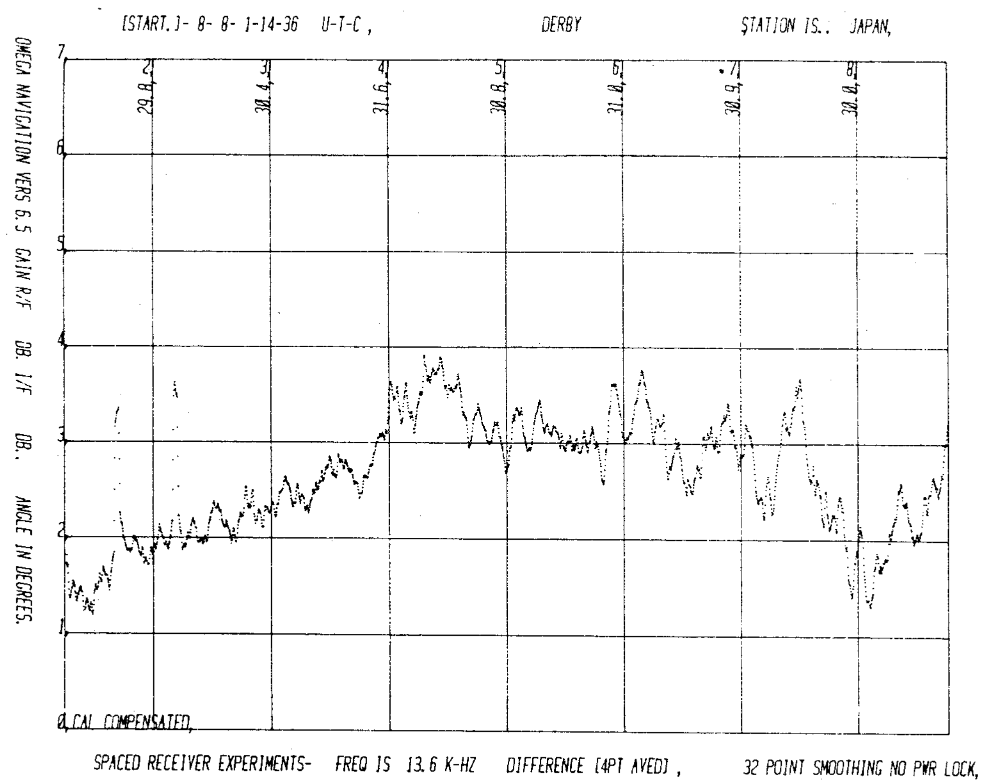


Figure 54. Derby, Japan, 13.6 kHz

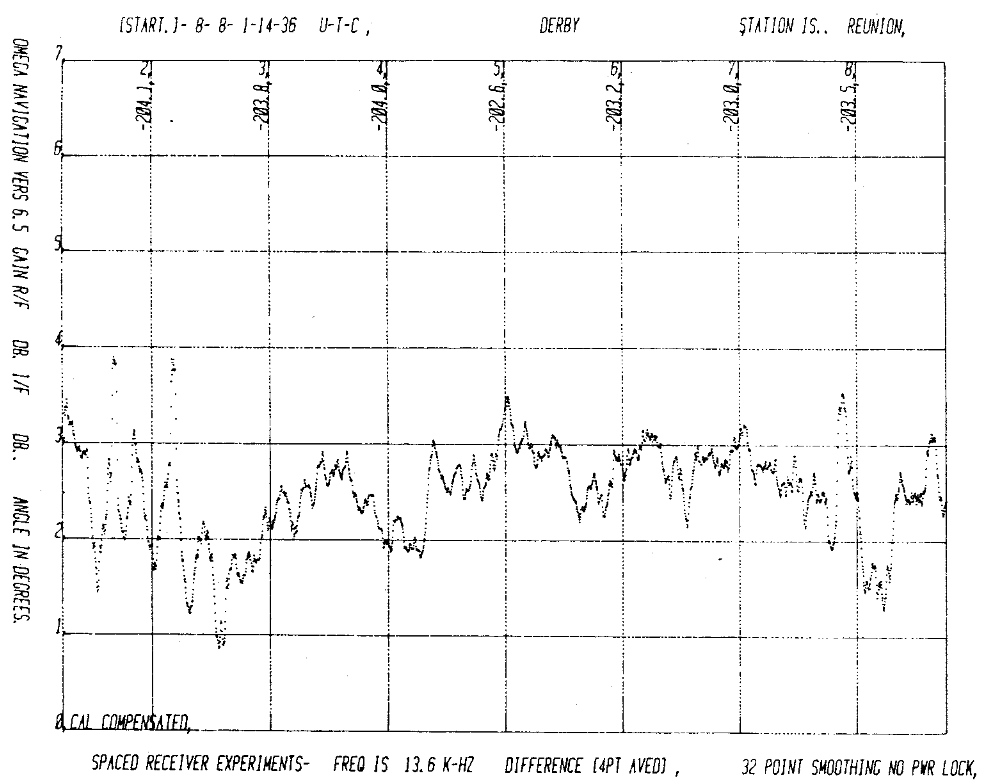
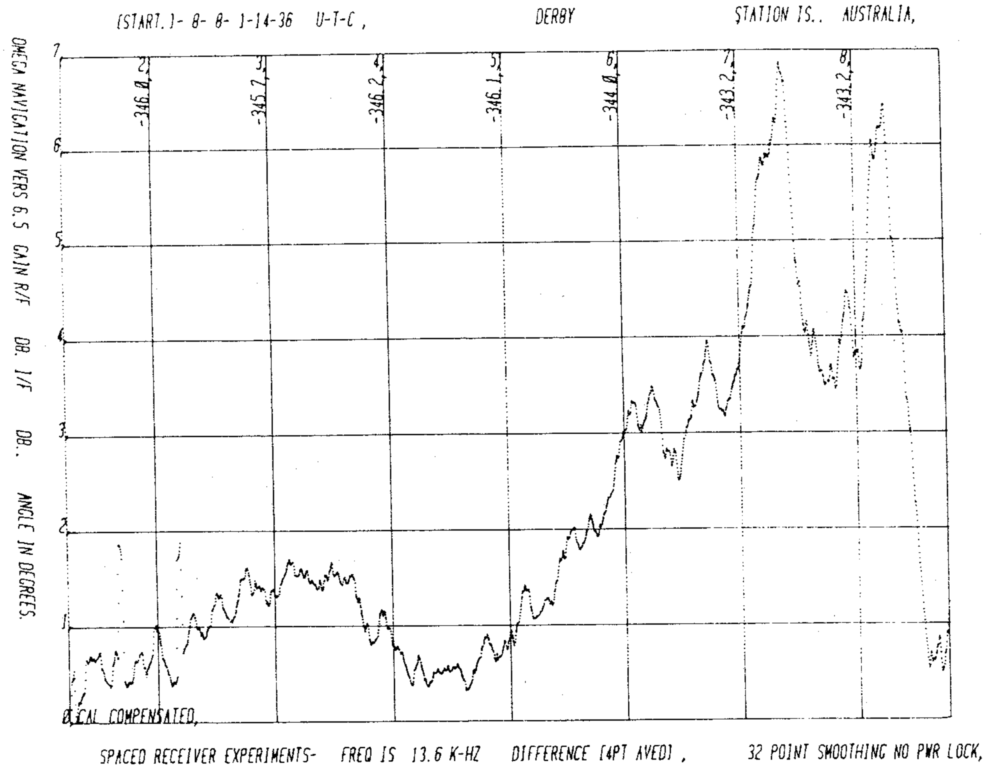


Figure 55. Derby, Reunion, 13.6 kHz



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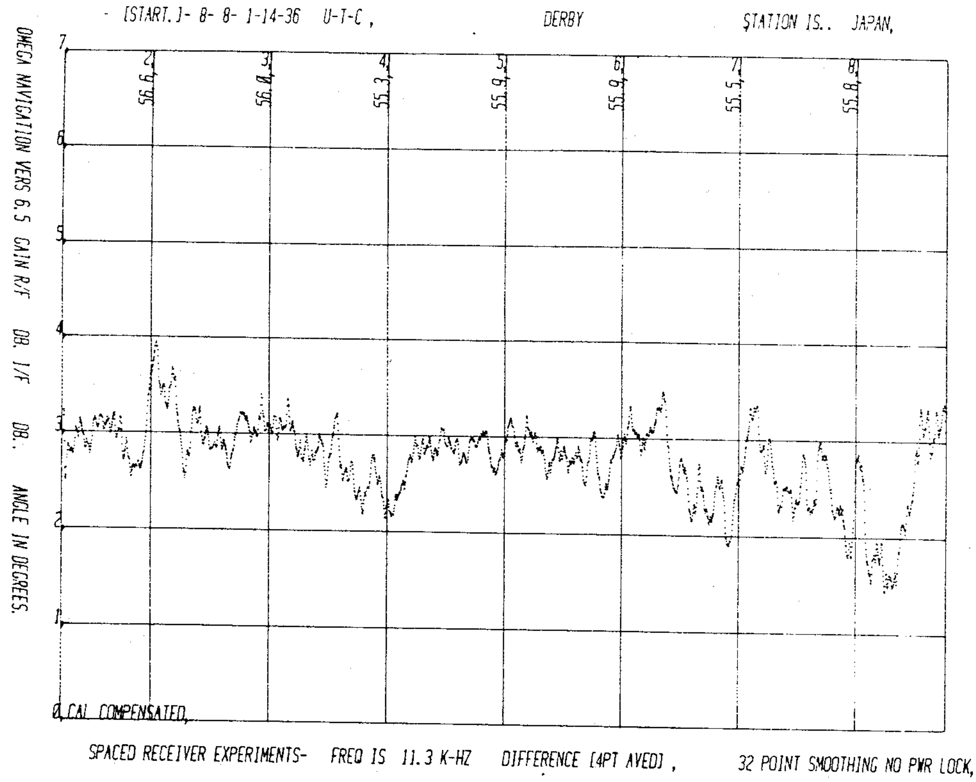

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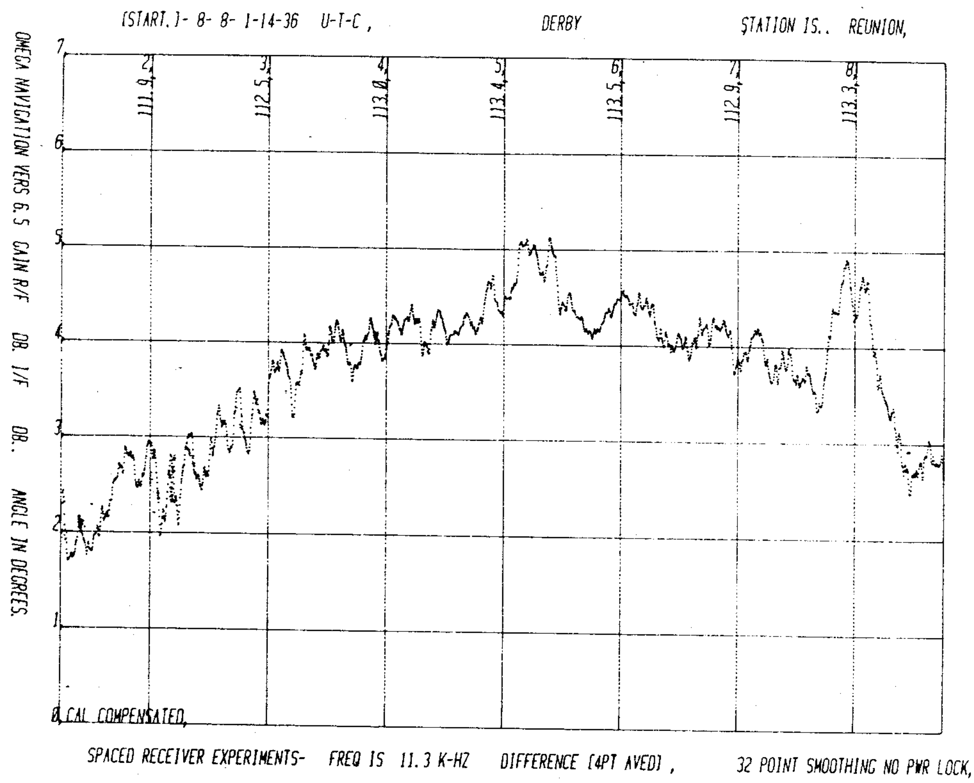
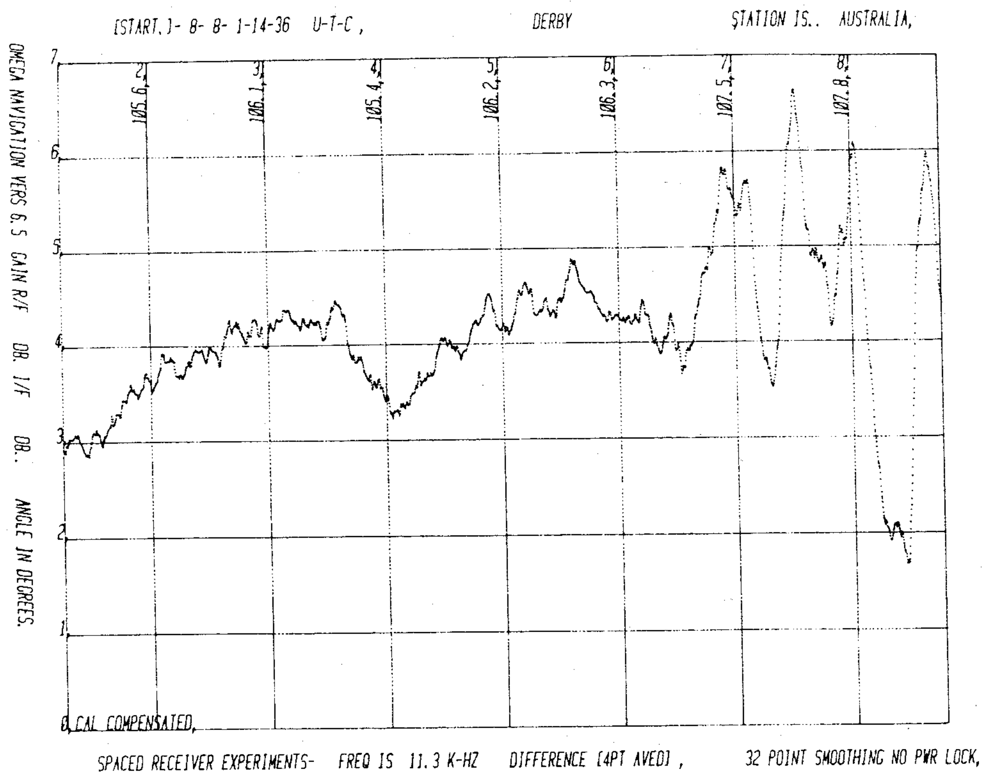


Figure 58. Derby, Reunion, 11-1/3 kHz



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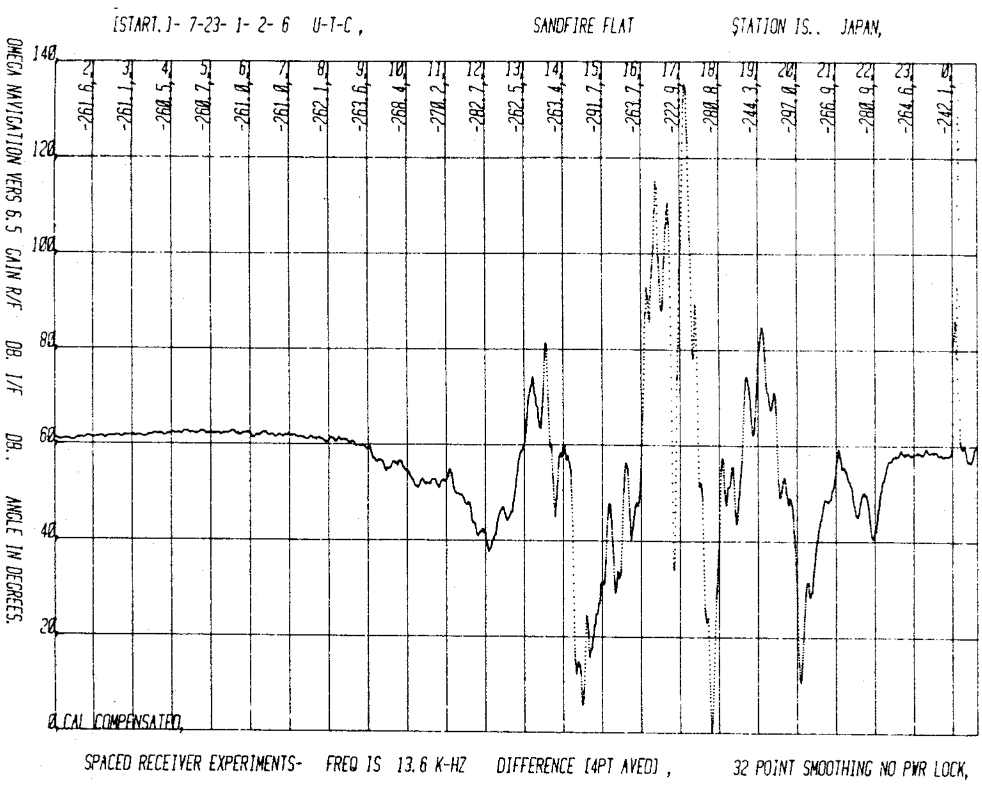

Figure 60. Sandfire Flat, Japan, 13.6 kHz

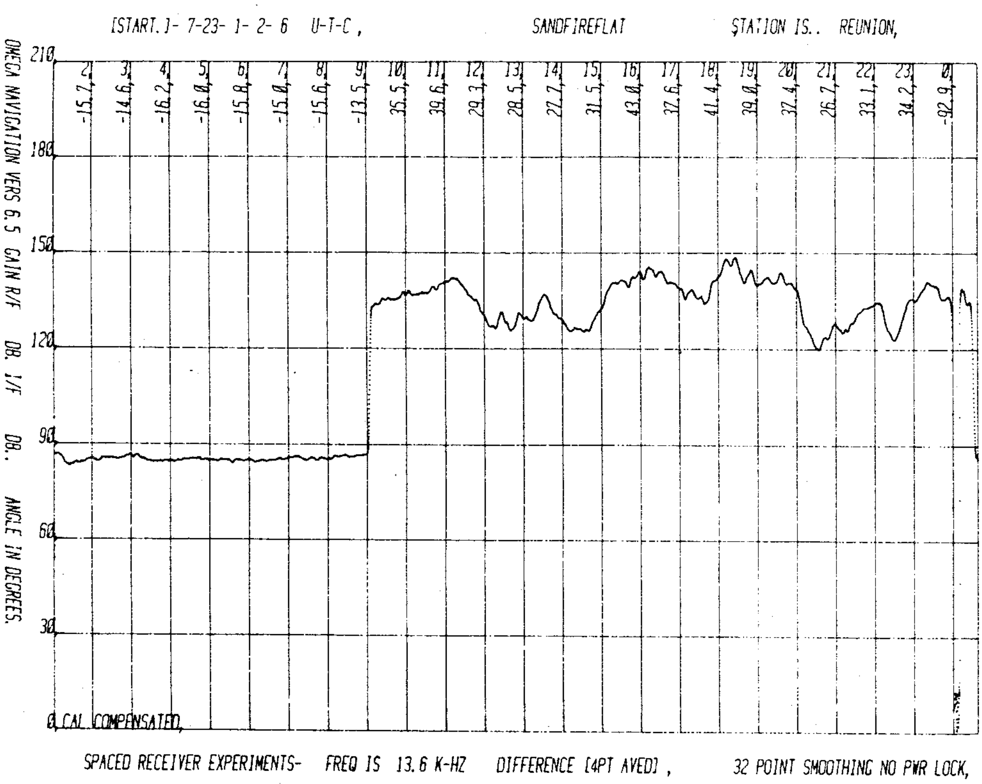

Figure 61. Sandfire Flat, Reunion, 13.6 kHz

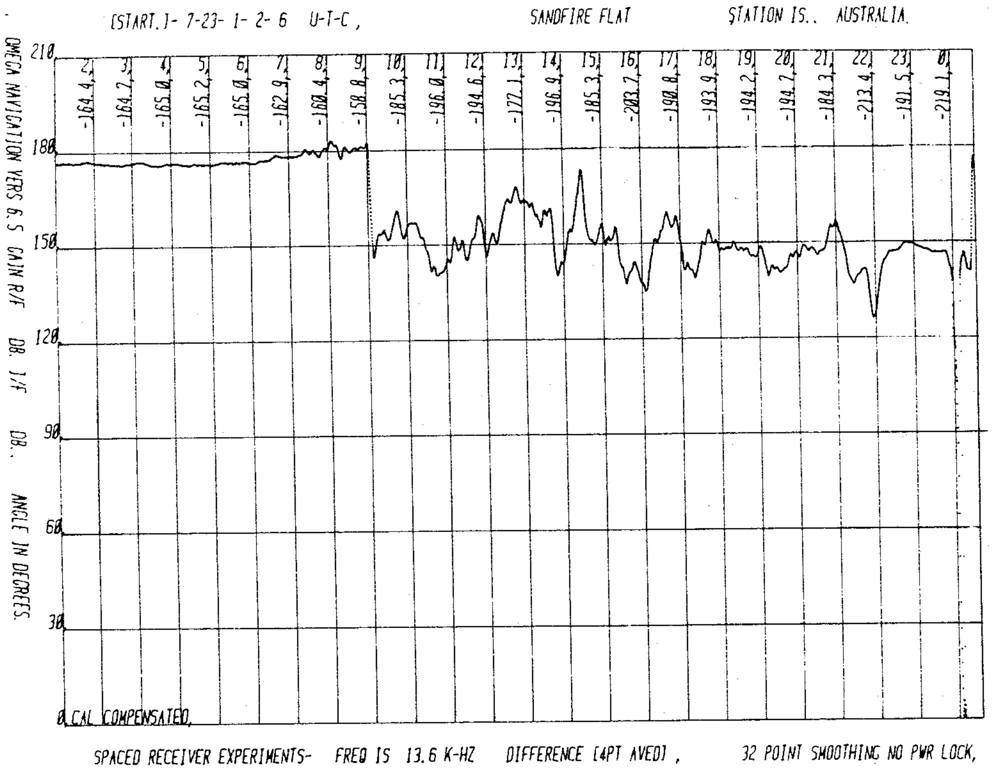

Figure 62. Sandfire Flat, Australia, 13.6 kHz

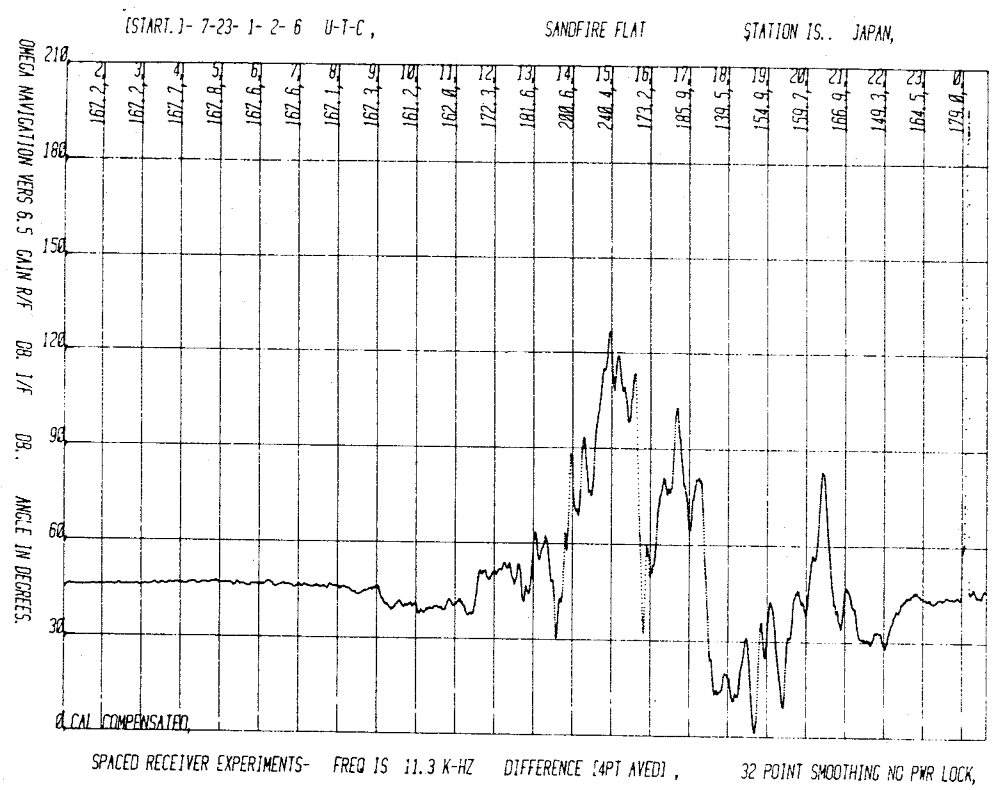

Figure 63. Sandfire Flat, Japan, 11-1/3 kHz

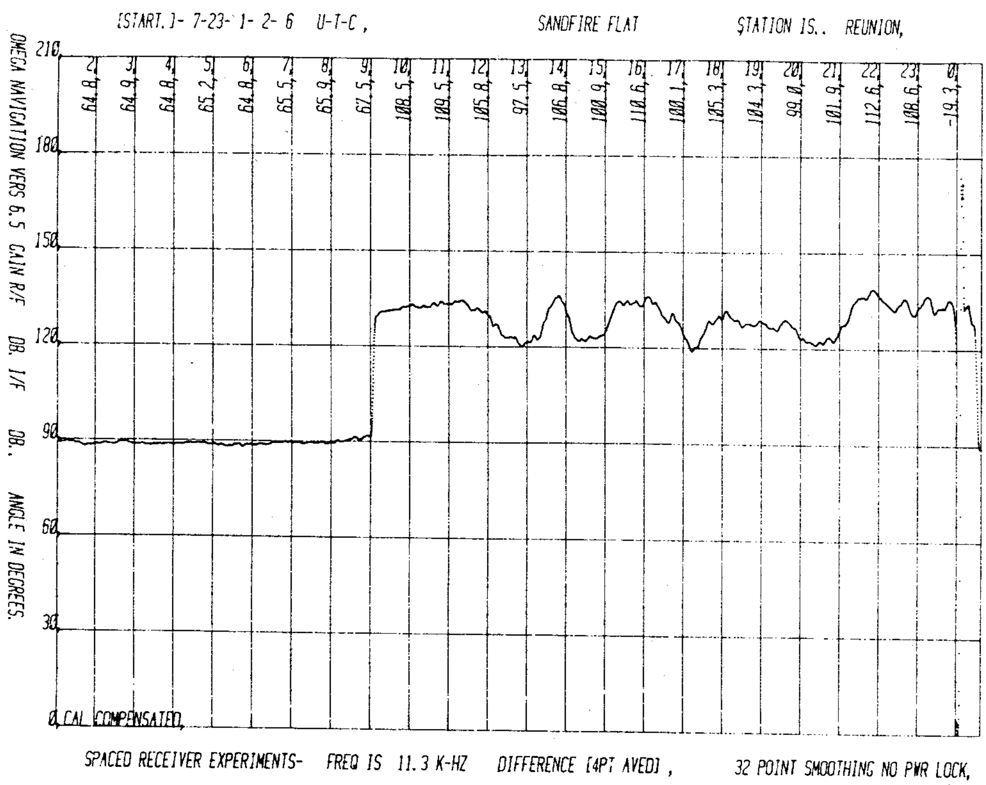

Figure 64. Sandfire Flat, Reunion, 11-1/3 kHz

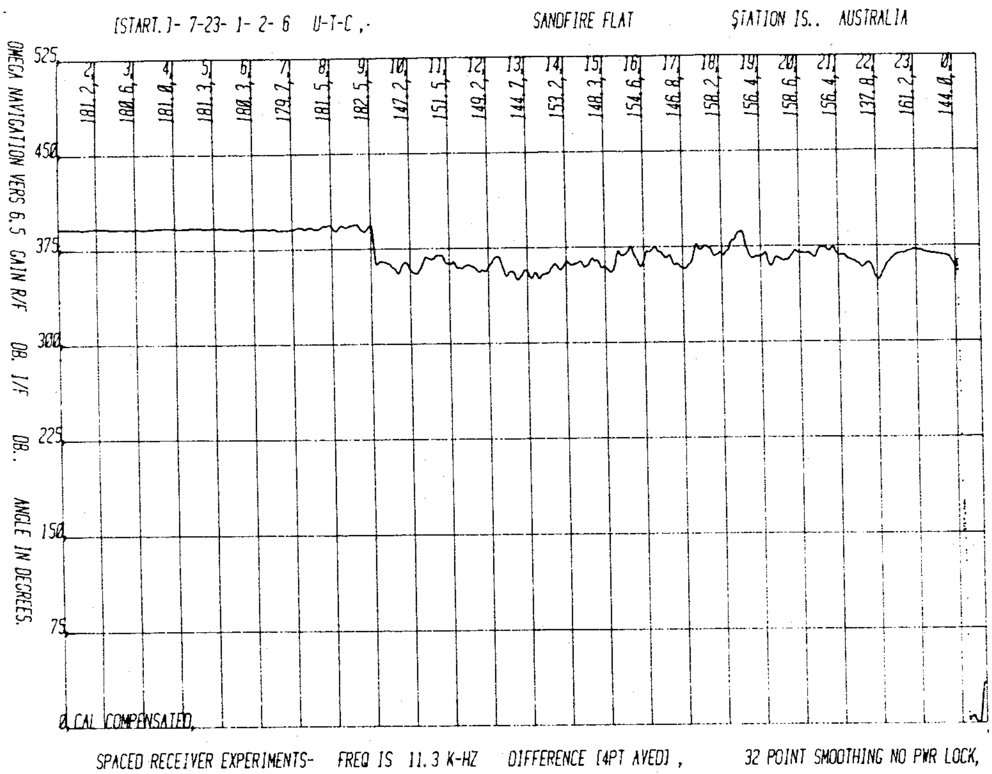

Figure 65. Sandfire Flat, Australia, 11-1/3 kHz

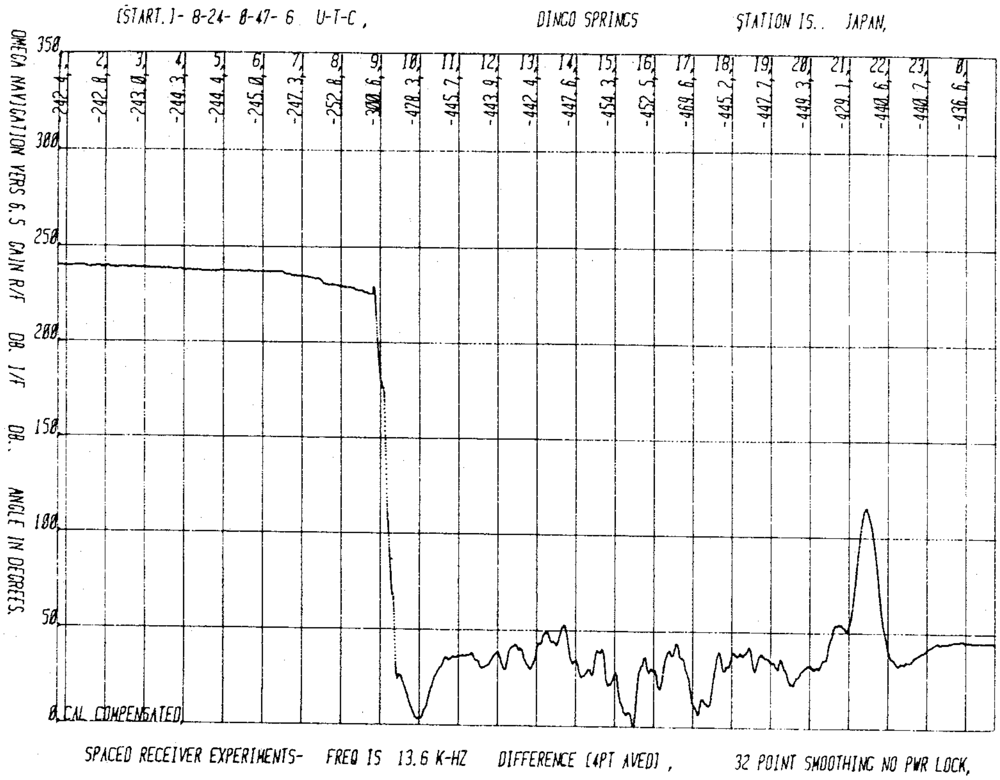

Figure 66. Dingo Springs, Japan, 13.6 kHz

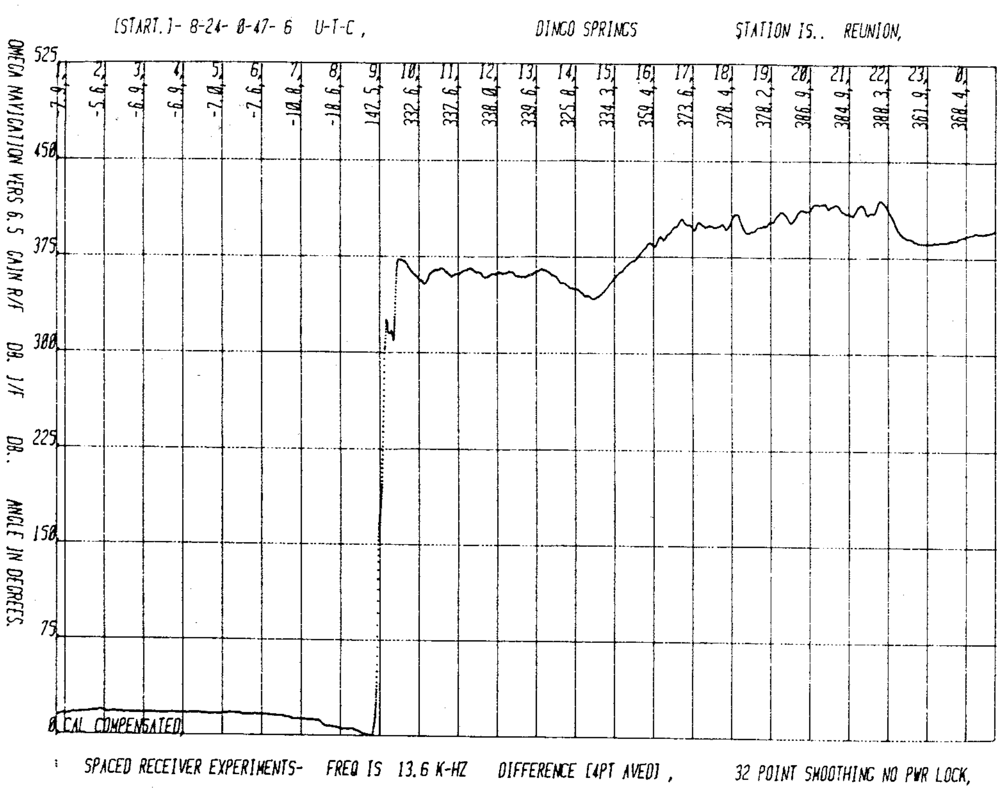

Figure 67. Dingo Springs, Reunion, 13.6 kHz

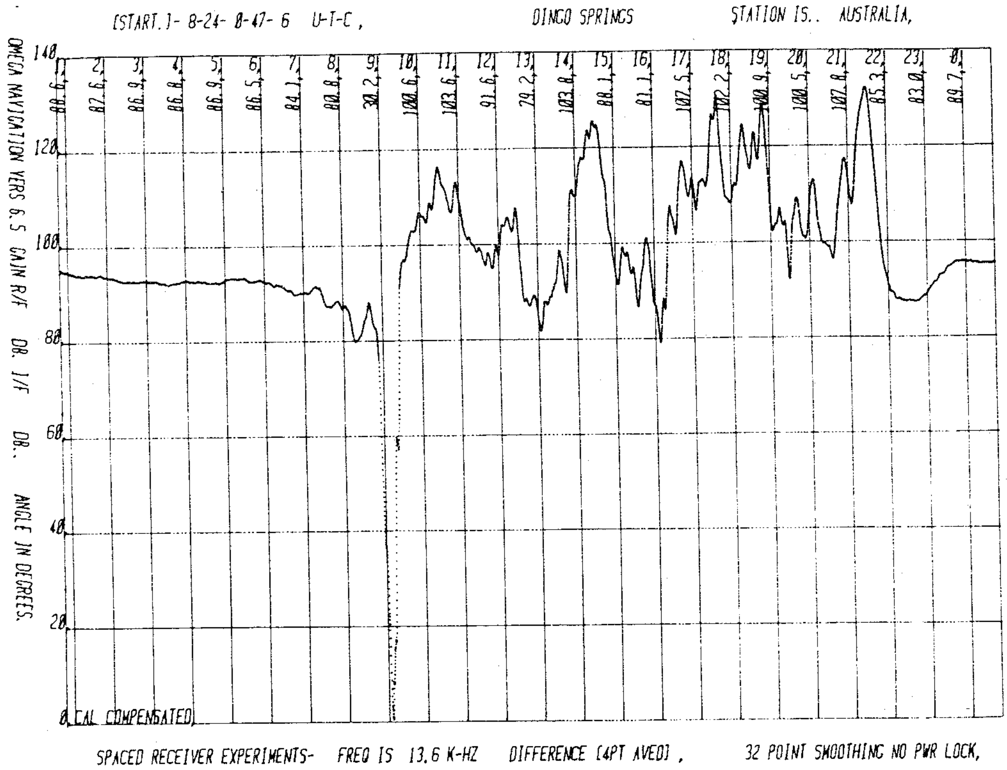

Figure 68. Dingo Springs, Australia, 13.6 kHz

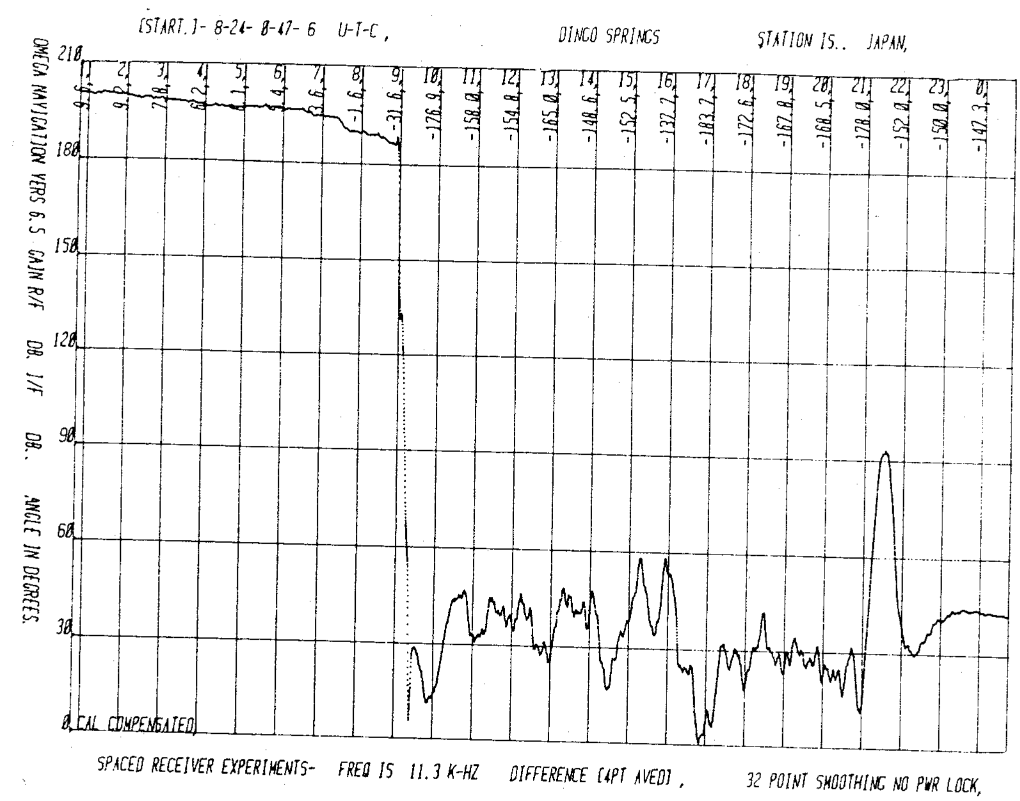

Figure 69. Dingo Springs, Japan, 11-1/3 kHz

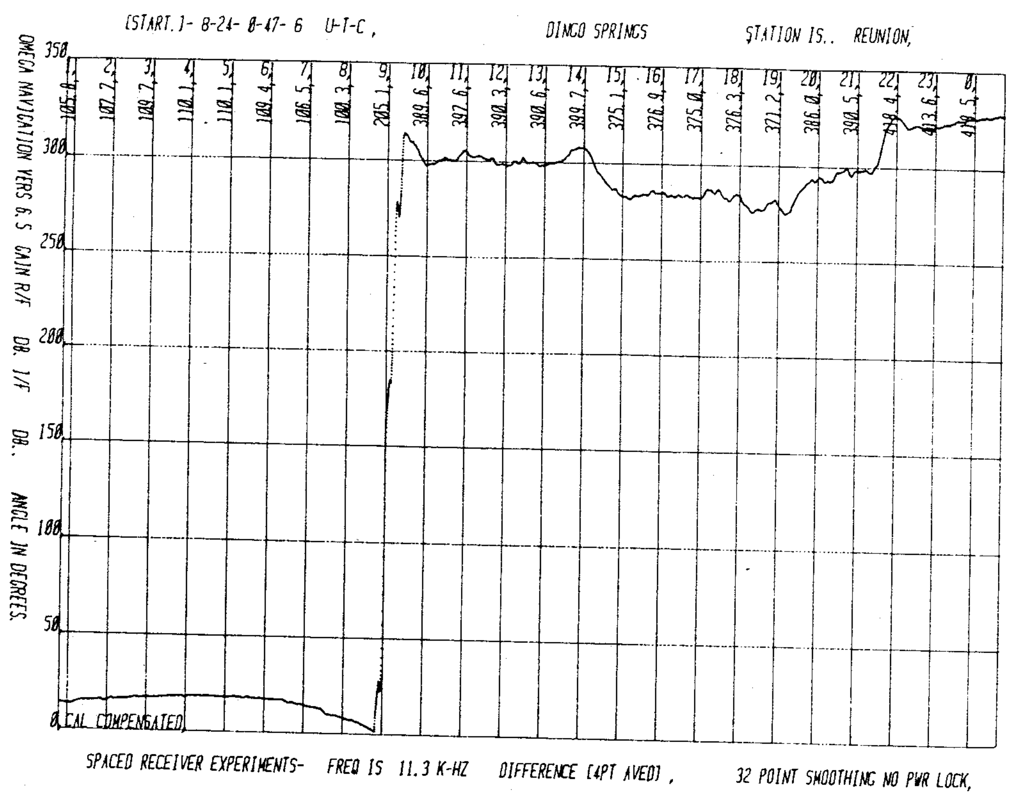

Figure 70. Dingo Springs, Reunion, 11-1/3 kHz

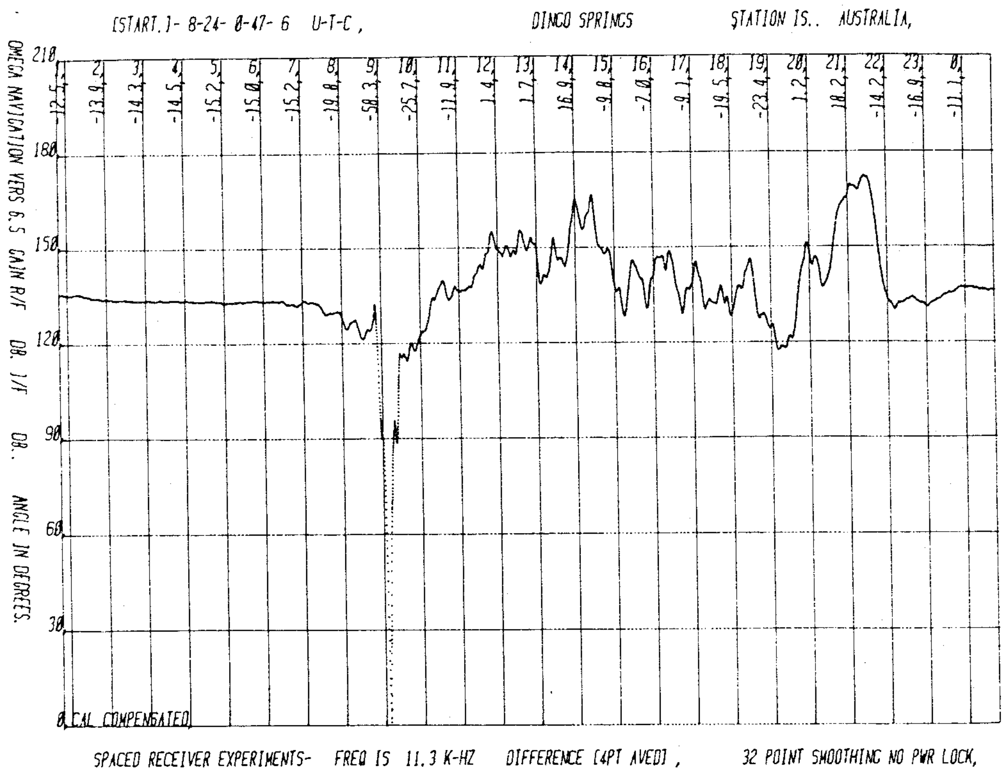

Figure 71. Dingo Springs, Australia, 11-1/3 kHz

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Field trials were carried out in July/August 1985 to test the efficacy of Differential Omega for land navigation in the East and West Kimberley regions of Western Australia. To this end a base station was set up in Broome and movements undertaken between a local survey mark and similar marks at ranges of up to 700 km. This Technical Memorandum describes the nature of the exercise and discusses the results obtained.

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