Centre for Radio Science

TESTING AND COMPLETION OF A MULTI-ELEMENT INTERFEROMETRIC MICROWAVE SYSTEM FOR THE ANALYSIS OF TERRESTRIAL MICROWAVE PROPAGATION

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Final Report

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Testing and Completion of a Multi-element Interferometric Microwave System for the Analysis of Terrestrial Microwave Propagation

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1. INTRODUCTION

The work described in this report is an extension of work performed under a previous contract (DSS #24SU.36001-3-1290). In that contract, an 8-element vertical array and associated receiving system, together with a simple CW transmitter, was developed; the system was designed to operate at a frequency of 16.65 GHz. The basic idea was to investigate the feasibility of developing a system to resolve accurately and simply the number of separate rays arriving at the receiver under multipath conditions.

As a result of encouraging results from that work, the object under this contract was to expand the array to 12-elements (to improve the resolution) and to deploy the system in the field to test the operation and to provide good experimental data. This was done in the late summer of 1984 with the transmitter mounted on an Ontario Hydro microwave tower at Uniondale and the receiving system, including the 12-element array, situated at the Centre for Radio Science.

2. THE SYSTEM

A detailed description of the basic principle and system was given in the previous report (see above); a brief summary is given below.

2.1 The Basic Principle of the System

Since changes in atmospheric refractivity occur as a function of height, the phenomenon of multi-path propagation essentially takes place in the vertical plane containing the line-of-sight between transmitter and receiver. Sampling of the complex amplitude across a wide vertical aperture at the receiver allows immediate access to the angle-of-arrival and amplitude of individual rays by way of the Fourier transform; this is illustrated in fig. 2.1.1. It will be noted that the effective beam-width, and hence the resolution, is inversely proportional to the total aperture (L_λ), while the unambiguous range in angle-of-arrival is inversely determined by the spacing (d_λ) between elements.

2.2 The Array

The design criteria used in building the array were that the range in angle-of-arrival covered be at least 1 deg. and the resolution be about 0.12 deg. Practical considerations relating to physical size dictated that a relatively high (16.65 GHz) frequency be used to reduce the physical dimensions (λ = 0.0180 m.).

At this wavelength, a 12-element array with 0.915 m (50.8λ) spacing results in a maximum (unweighted) resolution of 0.11 deg. and an overall range of 1.1 deg. in angle-of-arrival. Side-lobe suppression can be accomplished by suitable weighting of the amplitudes across the array at the expense of resolution; for example, a 30 dB Dolph-Tchebychev weighting results in a resolution of about 0.14 deg. and this was used in routine processing.

2.3 The Receiver

The basic receiving system is shown in fig. 2.3.1 in which two separate channels are provided. The reference channel uses a relatively high gain paraboloid to ensure a high s:n ratio (58 dB under normal circumstances) so that system lock is maintained even under extreme fading conditions. The signal channel uses lower gain simple horns which constitute the array; these (12) horns are sampled consecutively in a total time of about 40 ms and amplitude and phase (relative to the reference) recorded for each. A full sample repetition rate of up to $20s.^{-1}$ is achievable, although a rate of $1s.^{-1}$ was used routinely.

3. EXPERIMENTAL RESULTS

3.1 The Experimental Arrangement

The transmitter was mounted at the 50 m level on the Ontario Hydro microwave tower at Uniondale (43° 13'42"N, 81° 02'18"W). Transmitted power was + 15 dBm via a 37 dB gain antenna and the operating frequency, 16.650 GHz (C.W.). The receiving array (10 m length) was installed on the roof of the Centre for Radio Science (43° 00'25"N, 81° 16'28"W) centred approximately 30 m above local ground. The path length was 31.5 km and clearance in excess of 1 Fresnel zone maintained along the entire path under normal propagation conditions.

3.2 Experimental Data Base

Full operation of the 12-element array started on September 20 and continued until November 14, 1984. Thereafter, the reference channel was maintained as a check on the long-term stability of the microwave frequencies and phase locking arrangement until April 12, 1985. At this point, a major fire in the Centre destroyed the receiver and computer facilities so that planned further observations in the Spring of 1985 were not possible.

By this time, data from the month of October had been condensed into about 315 hours of good data including a total of 5 hours exhibiting severe fading. Some of these data and virtually all of the original raw data were lost in the fire. Nevertheless, sufficient remains to allow significant conclusions to be reached.

3.3 Experimental Observations

Fig. 3.3.1 shows a selection of experimental results under quiet and multi-path conditions together with an example using synthesized data (i.e, weighted amplitude and phase data inserted into the computer routine). In these and all AOA results presented, a 30 dB Dolph-Tchebyschev weight was used and a 64-point Fourier transform applied (zeros added). It will be noted that the peak widths are modulated slightly by the close proximity of another peak, but a resolution of better than 0.15 deg. is achieved. Paths closer together than about 0.1 deg. will not be resolved although their presence is often clear from the width and/or shape of the resultant peak.

Fig. 3.3.2 shows the development of multi-path in the evening of 22 Oct. 1984; the amplitude is that of the reference channel and the angle-of-arrival is generated by a routine which looks for distinct peaks in each record (1 sec. intervals) with the line thickness being representative of the amplitude. In this latter, all peaks exceeding 10% (-20 dB) of the maximum for that record are presented so that occasionally a small genuine peak may be missed or, conversely, a combined side-lobe detected; additionally, inflection points associated with very close rays are not extracted. Nevertheless, the appearance of multiple rays, predominantly 3, during the active fading period is clearly seen. The system is calibrated, here, so that the AOA of the single-path at about 20.30 E.D.T. appears at 0 deg. (there is circumstantial evidence that this ray in fact was elevated by about 0.2 deg. over the normal value).

There appears to be considerable fine structure in the behaviour of the component AOAs in fig. 3.2.2, and some of these are examined in the following.

Splitting and recombination of rays occurs in several places, the first occurring at about 22.05 E.D.T. in which a second ray appears below the first. Starting at about 22.15, basically 3 rays are in evidence with some indication of oscillation in AOA. This is shown in expanded form in fig. 3.3.3 which indicates some correlation between these oscillations and the occurrence of deep fades. This would seem to be reasonable since such changes in AOA might be expected to be accompanied by commensurate small changes in the delays between components. Considerable movement in AOA of the components is evident at about 22.28 to 22.30 in which the lowest ray moves up and is replaced in its original position by a further ray. This occurs twice in this period and the effect is shown to better advantage in fig. 3.3.4(a); this figure presents amplitude versus AOA versus time together with a mirror image so that the rays may be viewed from top and bottom. For most of the time in this figure, 3 rays are resolved but 4 rays are clearly resolved at 22.30. Fig. 3.3.4(b) shows a similar split in the bottom ray at around 22.54.

A further example of multiple rays with suggestions of splitting and oscillation is shown in fig. 3.3.5 for the next morning (23 Oct. 1984). Again 3 rays appear to be resolved for much of the time.

4. DISCUSSION

From the above. it seems quite clear that in many, if not most, instances when multi-path propagation occurs, several paths are involved. This has important implications from the point of view of the modelling of the transmission channel in communications systems. While the data base is somewhat limited the following seems to be indicated and relevant.

(a) On many occasions, three distinct paths occur with the occasional appearance of more; rarely, if ever, are only two paths generated.

(b) The amplitudes of the individual components, especially the stronger ones, exhibit considerable fluctuation; these variations have typical time-constants of a few seconds.

(c) The separation in angle-of-arrival between components is somewhat variable but tends to settle down at about 0.2 deg once the structure is fully developed; this is quite consistent with the predictions arising from ray-tracing exercises.*

(d) Considerable fine structure is seen in the behaviour of AOA of individual components with some evidence of oscillatory variations; these variations appear to play a role in the generation of deep fades.

*See Webster, A.R., IEEE Trans.Ant.Propagat., AP-31, 12-17, 1983

5. CONCLUSIONS AND RECOMMENDATIONS

The results presented above confirm that the system performed much as expected. Phase-lock was maintained continuously over a period of several months, which is testimony to the stability of the microwave oscillator frequencies; the difference between the two (at 16.5 GHz) never exceeded + 25 kHz.

The resolution of separate rays in a multipath situation, the main objective, is better than 0.14 deg. (amplitudes weighted) and this allows considerable insight into the structure of multipath to be gained. On the question of time resolution, the acquisition of data every 1 second during fading appears to have caught the variations in amplitude and AOA which seem to vary significantly over a period of a few seconds at the fastest.

To consolidate the findings presented here, the following is suggested.

(i) Expand the array to 16 elements in order to improve further the resolution; this is a natural extension given the waveguide feed arrangement at the receiving end.

(ii) Modify the waveguide feed to allow pressurisation of the waveguide: some difficulties were experienced with moisture in the waveguide during inclement weather.

(iii) Mount the system on an established communications link for a full fading season in order to accumulate sufficient data to allow statistical information to be generated; a link employing digital radio would be desirable in order to assess the impact of multi-path.

(iv) Some very high speed samples (perhaps $10s^{-1}$) should be obtained in order to confirm the maximum rate of change of the ray parameters.

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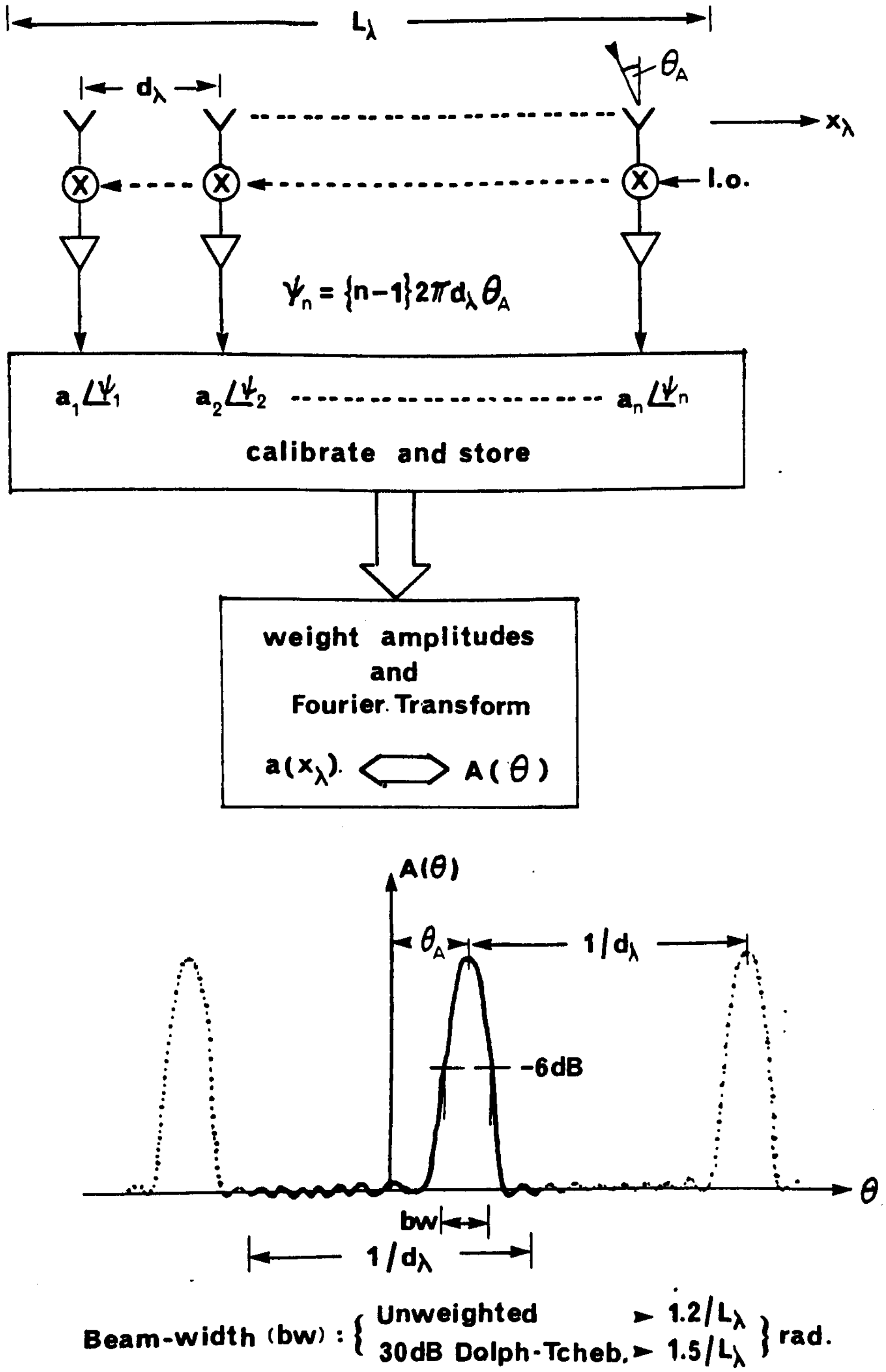

Fig. 2.1.1 Angle-of-arrival derived from a wide-aperture array.

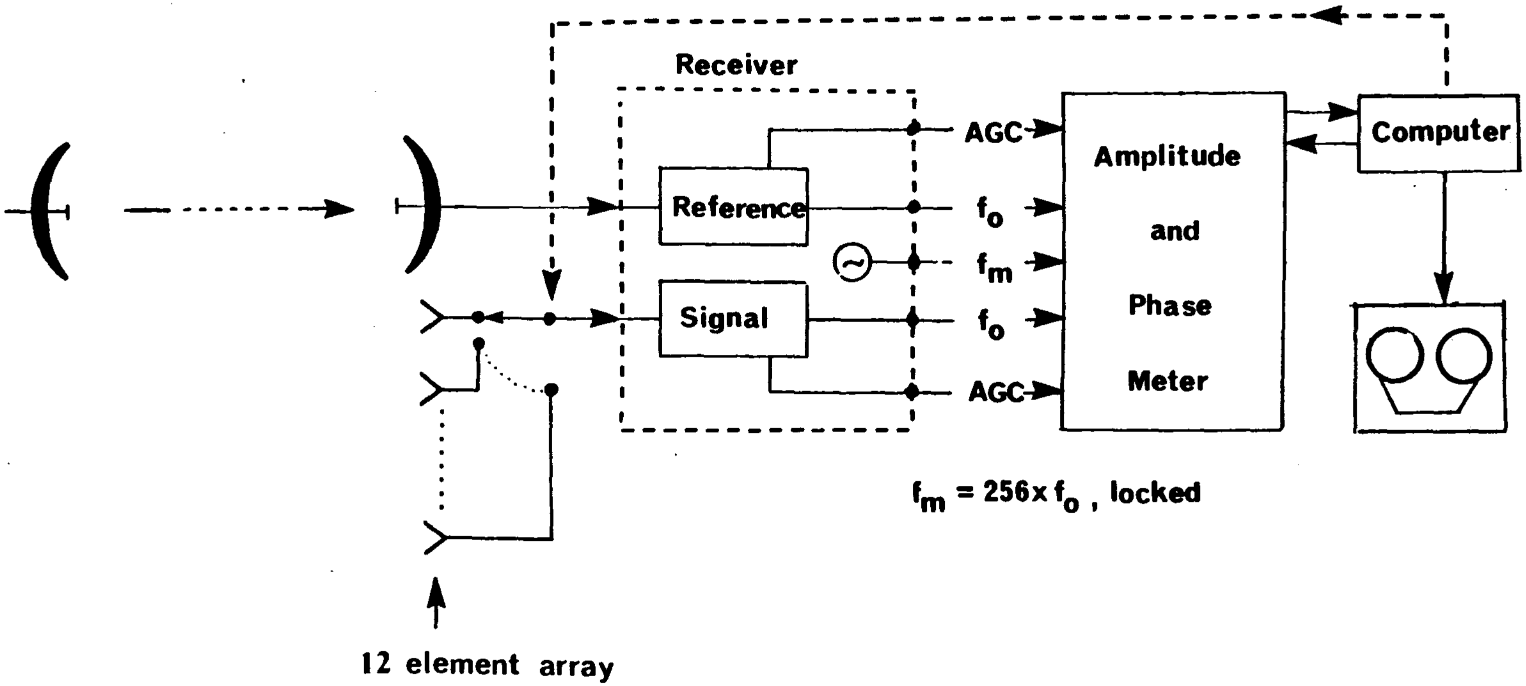

Fig. 2.3.1 The basic system.

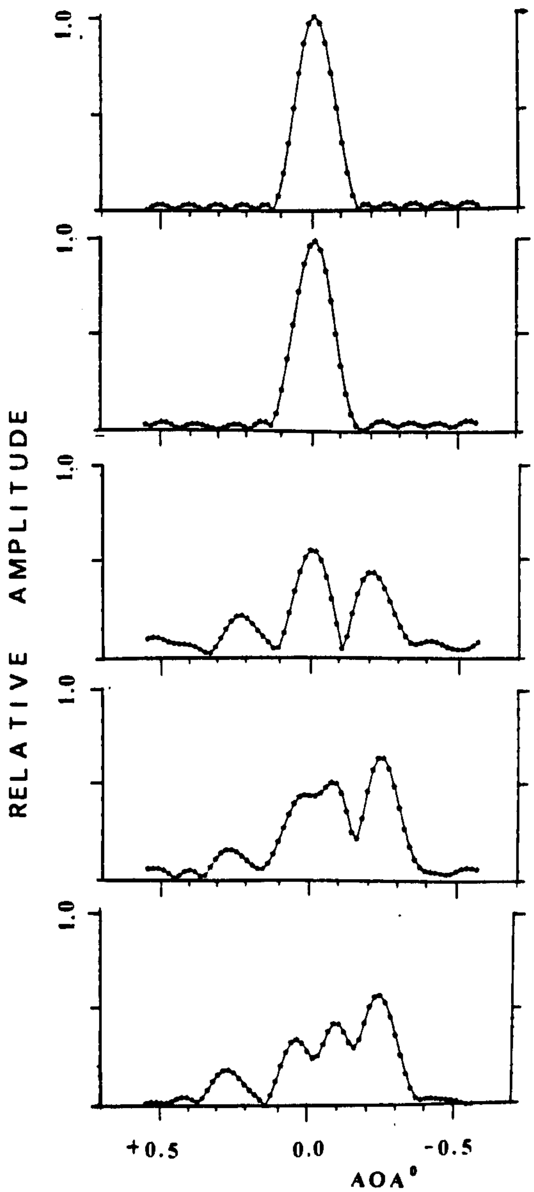

Fig. 3.3.1 Examples of individual records; the top one uses synthesized data, the rest are experimental records.

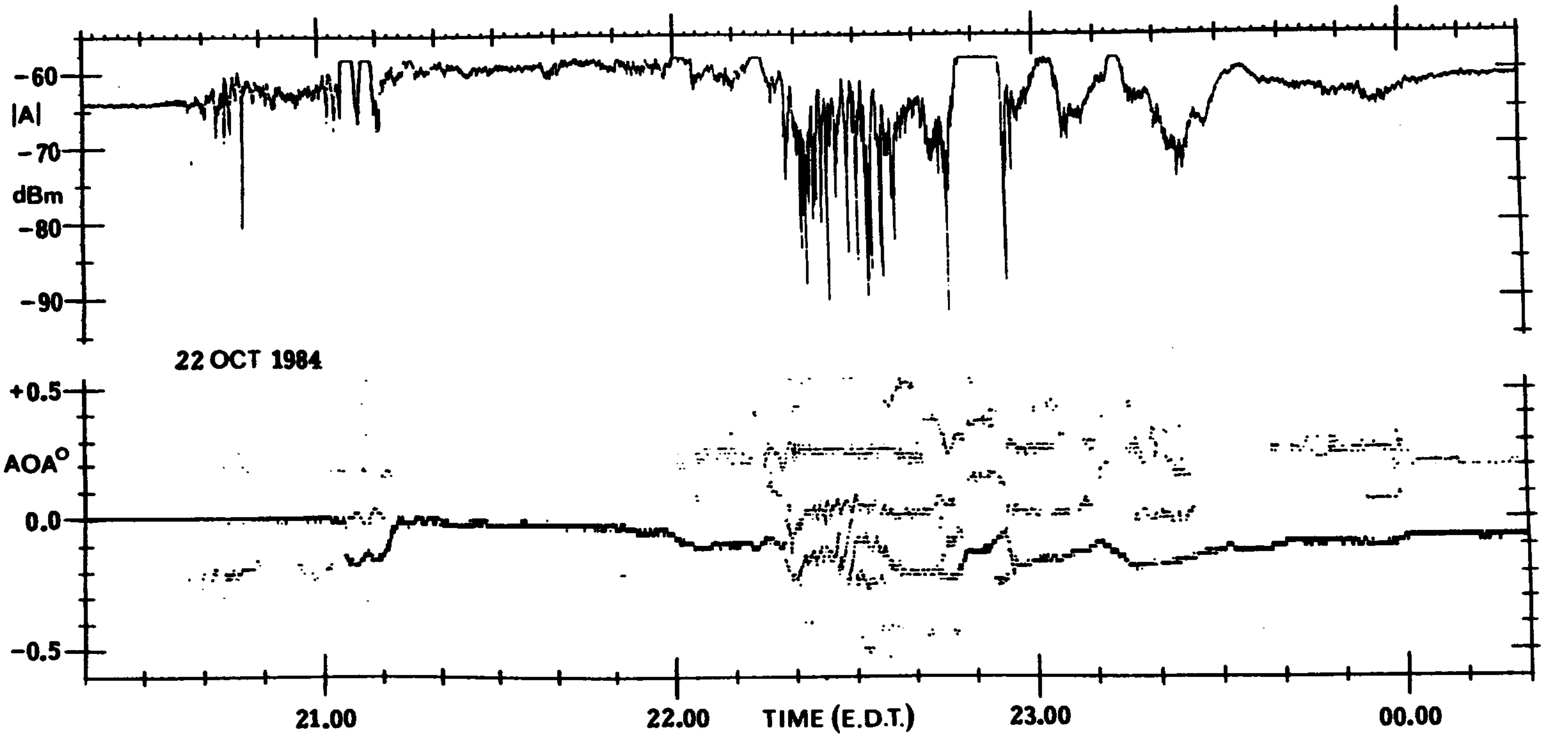

Fig. 3.3.2 The development of multi-path fading on 22 Oct. 1984; |A| is the amplitude of the reference channel.

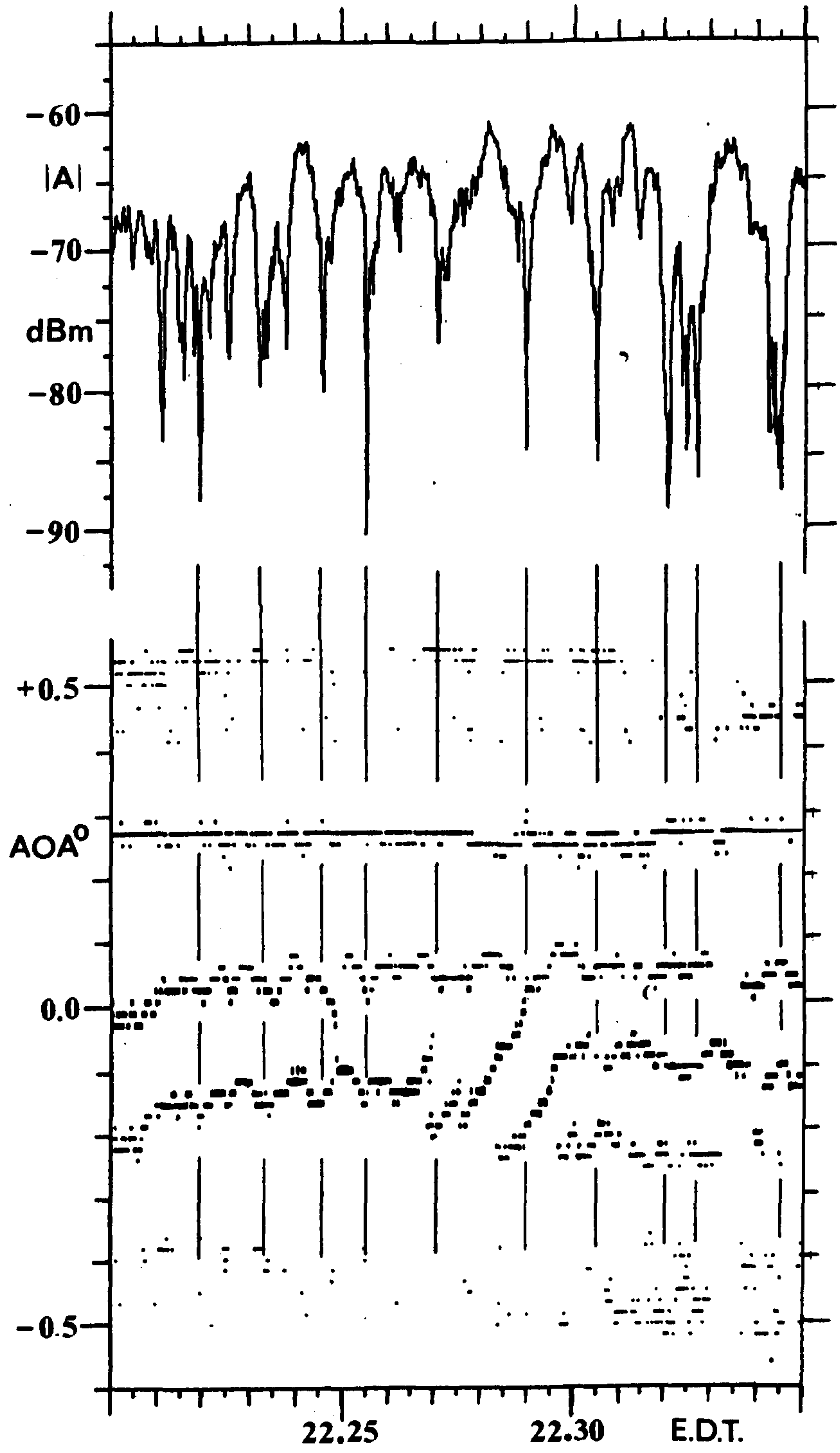

Fig. 3.3.3 An expanded view of activity around 22.30 E.D.T., 22 Oct. 1984; the vertical lines represent the time of major fades on the reference channel.

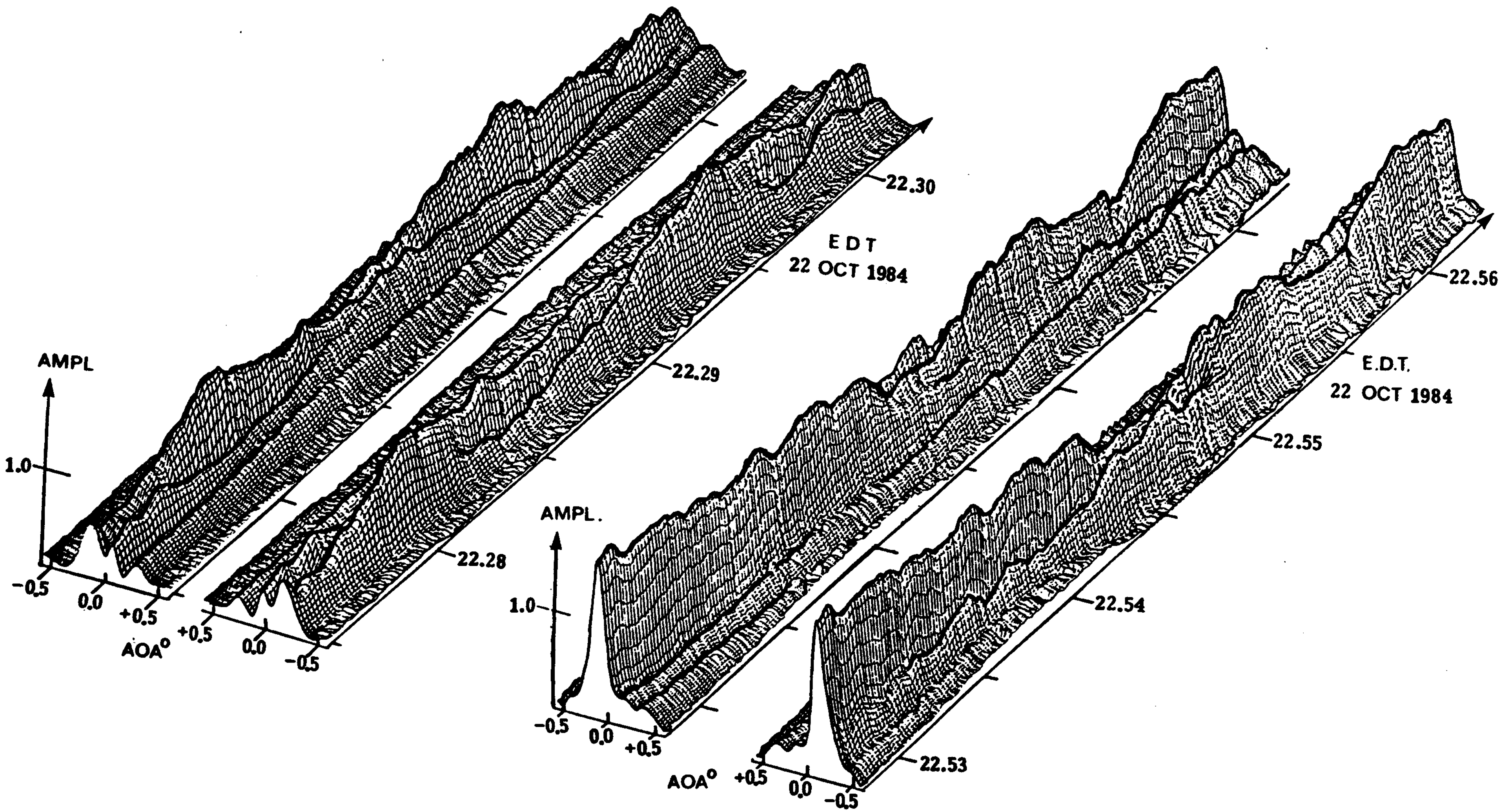

Fig. 3.3.4 Three-dimensional (amplitude vs AOA vs time) plots at two different times on 22 Oct. 1984; mirror-image pairs are presented to provide a view from both above and below.

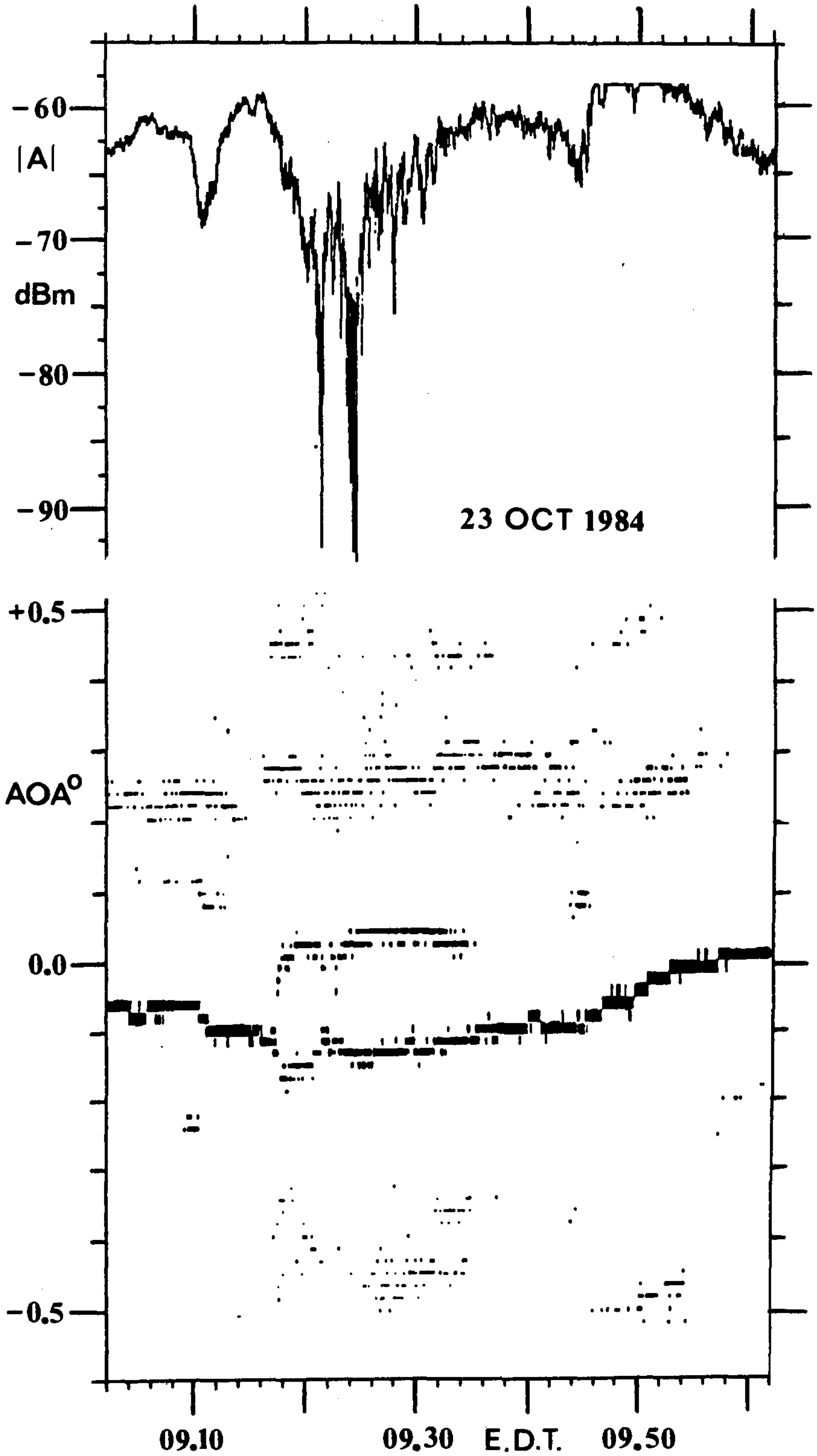

Fig. 3.3.5 A further example of fading and occurrence of multiple paths.

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