'UP-LINK DEPOLARISATION PRE-COMPENSATION EXPERIMENT'

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1. INTRODUCTION

Rain and snow on earth-satellite links at C-Band can be a particular problem when frequency re-use by dual-polarisation working is operated. The problem may be serious in those parts of the world which experience heavy rainfall and/or where low-elevation angle working is necessary since depolarisation is proportional to the amount of rain along the path. On a down-link the depolarisation only causes cross-channel interference at the receive earth station concerned and it is generally straightforward to compensate by means of a closed-loop type of correction system. The up-link effects however are somewhat more serious not only because, at the higher frequency, degradation in isolation is greater but also because interference is caused at the satellite to other links operating on the opposite polarisation of the up-path.

In 1981, BTI were awarded a contract by INTELSAT (Intel-156), the aims of which were to investigate active depolarisation correction by the use of phase-shifters (rotating polarisers) in both up- and down-paths of a large 32 metre antenna.

The antenna chosen for the experiment was the third Standard A antenna built at Madley Earth Station in the West of England. This was chosen because phase shifters were already part of the feed assembly and also because of the low elevation angle (6^o) to the ISVF5 satellite located at 63^o East. Additionally it operates on the edge of the satellite beam and is a worst case from the point of view of satellite axial ratio. A typical year's cross-polar discrimination statistics (uncorrected) for the antenna are shown in Figure 1.

2 SYSTEM PLANNING

One of the main considerations was to avoid disruption to services carried by the antenna and this formed a substantial part of the initial planning. The system was to be implemented on an operational antenna without prior simulation or a full operational check. This led to close co-operation with operational staff and the inclusion of continuous self-check routines and 'fail-safe' devices particularly as the work was largely based on theory but with some practical work done previously (e.g. Reference 1).

The method of correcting the degradation in XPD was by means of rotatable phase-shift elements (polarisers) in the feed of Madley 3. A 90^o polariser tracks the tilt angle (major axis) of the elliptically-polarised wave but the actual correction to the magnitude of cross-polar discrimination is performed by moving a 180^o polariser to introduce sufficient differential phase-shift to just cancel that caused by the atmospheric perturbation. It also has to compensate for the differential phase-shift caused by the rotation of the 90^o polariser.

The overall system as designed is shown in Figure 2. An unmodulated carrier is radiated LHCP which on the down-link (satellite configured West Hemi/West Hemi LHCP up/RHCP Down) is separated into RHCP (co-pol) and LHCP (x-pol) components. The theoretical study had shown that a good down-link (closed-loop) correction method was to separate the down-link cross-pol signal into in-phase and quadrature-phase components and minimise these signals by respectively driving the 180^o and 90^o polarisers.

A second carrier was radiated RHCP and the satellite was configured

LHCP up/RHCP down (West Hemi/West Hemi) so that only the cross-polar component of this signal goes through the satellite. It thus provides a measure of the up-link depolarisation occurring and shows the success or otherwise of the pre-compensation. Relations between up- and down-link XPD are well established at C-Band (Ref 2) so applying the differential phase-shift correction at 6 GHz is a straightforward part of the algorithm.

A microprocessor-based system was used to continually check the positions of the polarisers and ensure that a potential hazard to traffic would be avoided. Pascal coding was used here to enable easy software changes as experience of the control system developed.

The conventional monopulse tracking used by this antenna could not be used when rotating the polarisers because their rotation caused erroneous tracking errors. To overcome this problem, a new sophisticated step-track system was employed, this so-called 'Smoothed Step-Track' has since been developed further and is now used on most BTI antennas (Reference 3). This proved to be far cheaper and easier in the timescale than installing a compensation circuit to offset the phase-shift through the polarisers.

3 RESULTS

The down-link closed-loop method performed exceptionally well for all events which occurred September-December 1983. X-polar degradations down to about 18 dB were corrected to better than 40 dB. Unfortunately the 3 month period did not coincide with the rainy summer season at Madley (due to operational constraints) - though this had been the original plan. Figure 3 shows the distribution of XPD both corrected (measured) and predicted uncorrected (calculated from the polariser positions).

The up-link pre-correction technique did not prove to be so successful due to poor correlation between the up- and down-path axial ratios in clear weather which in turn was no doubt caused by the use of separate antennas at the satellite. It was originally thought that static cancellation would take care of this problem but in the event was found to compound it unless, as discovered later, the correction was done between the polarisers and the feed horn. Under perfect conditions, ie where the earth station and satellite axial ratios are very good, it can be assumed that in the degeneration of the wave from circular to elliptical polarisation, both the ellipticity and the tilt angle of the wave are determined solely by the mechanism of the rain. Under these circumstances the receive and transmit 90° polarisers would be expected to adopt the same angle; differences in the up- and down-link differential phase-shift attributable to the rain are then allowed for by offsetting the 180° polariser in the correct proportions. In practice of course perfect conditions do not exist and in the Madley 3 case the up- and down-path static corrections which were implemented between the feed and the polarisers only served to make matters worse. Once this was realised it prompted a detailed investigation into the role of the static cancellation network using a computer simulation technique.

Four cases were investigated,

a) A pure circularly-polarised wave incident on a perfect antenna.
b) An incident elliptically-polarised wave caused by imperfect satellite/earth station axial ratios.
c) As (b) but with static cancellation incorporated in the feed between the horn and the polarisers.
d) As (b) but with static cancellation incorporated outside the OMT ports of the feed by cross-coupling a portion of the RHCP (co-pol) signal into the LHCP path.

The program computed the polariser solutions for varying amounts of depolarisation due to rain in the atmosphere for each of the cases above. Polarisers and the static cancellation networks were simulated in this test. The quarter-wave polariser results in Table 1 show that, for case (a) and (c), the tilt angle of the elliptically-polarised wave is independent of the magnitude of depolarisation. For case (b) and (d) however the movement of the tilt angle is not just a function of canting angle changes but is dependent on the amount of depolarisation (ie differential phase-shift) occurring.

We can therefore say that, when a satellite with below-average XPI is worked and/or the earth station is around the mandatory limits then the optimum method is to statically cancel the clear-sky XPD between the feed horn and the polarisers. Cancellation after the polarisers is suitable for a clear-sky static cancellation but merely complicates the pre-correction required if adaptive cancellation is to take place. Without any clear-sky cancellation the down-link/up-link algorithm becomes unduly complicated and would require considerable expertise and measurements when satellite roles were switched or beams changed.

The compensation system described here would be able to cope with whichever option was chosen. For cases (a) and (c) it would work as it stands. For the other two cases (which were the only two which we could study here), further work is necessary to develop the more complex algorithm. The most straightforward way of doing this would be to have a closed-loop type of experiment on the down-link and interpret the parameters necessary to drive the up-link polarisers to a calculated position.

4 CONCLUSIONS

These conclusions are based on findings using the configuration described in this paper which is a specific antenna with motor-driven polarisers and a particular control philosophy designed to protect traffic under all situations. Other types of antenna systems may demand a different approach, but in general the following principal conclusions should apply to all:

1 A reliable receive correction system is possible without hazarding traffic.
2 Up-link pre-correction of rain depolarisation was unsuccessful due to satellite cross-polar isolations but should be possible if pre-correction is carried out between polarisers and feed horn or satellite axial ratios better than 0.1 dB can be guaranteed. Otherwise the algorithms would become extremely complex and require calibrating for each link.
3. The preclusion of monopulse tracking because of the phase changes due to polariser rotation has led to a sophisticated step-tracking system, unaffected by such variations, being used on the antenna for the duration of the experiment.

5 REFERENCES

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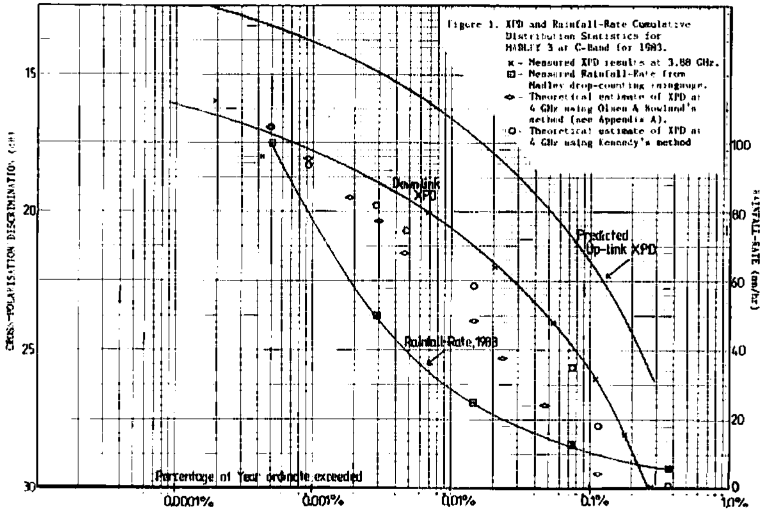

Figure 1. XPD and Rainfall-Rate Cumulative Distribution Statistics for HADLEY 3 at C-Band for 1983.

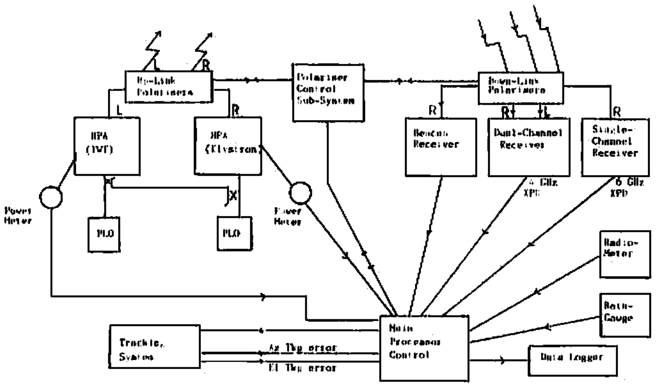

Figure 2. Block Diagram of Intel-15B Overall System.

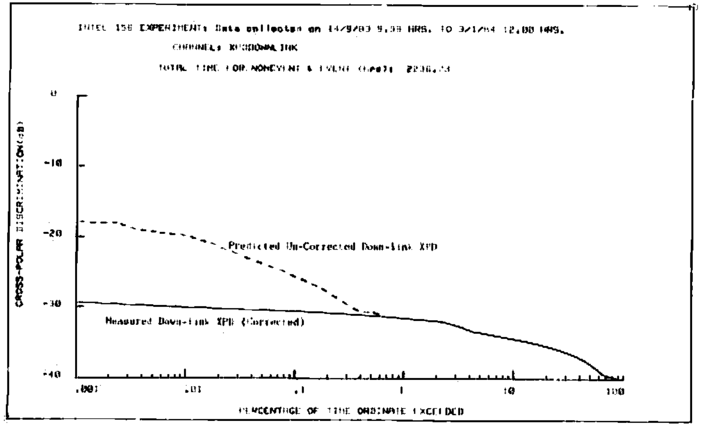

FIGURE 3. Down-Link Cross Polarisation Discrimination for Three Month's Measurements.

	Canting Angle	ATMOSPHERIC DIFFERENTIAL PHASE SHIFT				
		0°	5°	10°	15°	20°
1. Perfect Satellite $E_y=0+j$ $E_x=1+0j$	70°	$\alpha_q=315°$ $\alpha_h=0°$ $\}$ $\Delta\rho=0°$ *	$\alpha_q=334.9°$ $\alpha_h=0.72°$ $\}$ $\Delta\rho=4.42°$	$\alpha_q=334.9°$ $\alpha_h=7.3°$ $\}$ $\Delta\rho=8.0°$	$\alpha_q=334.96°$ $\alpha_h=4.21°$ $\}$ $\Delta\rho=14.0°$	$\alpha_q=334.90°$ $\alpha_h=5.11°$ $\}$ $\Delta\rho=19.92°$
	65°	$\alpha_q=315°$ $\alpha_h=0°$ $\}$ $\Delta\rho=0°$ *	$\alpha_q=290.9°$ $\alpha_h=340.8°$ $\}$ $\Delta\rho=5°$	$\alpha_q=289.96°$ $\alpha_h=349.9°$ $\}$ $\Delta\rho=9.9°$	$\alpha_q=289.96°$ $\alpha_h=351.22°$ $\}$ $\Delta\rho=14.96°$	$\alpha_q=289.97°$ $\alpha_h=352.47°$ $\}$ $\Delta\rho=19.94°$
2. Satellite Ellipse- No Correction $\tau=209.0°$ $\epsilon=41.1°$ $E_y=0+0.9j$ $E_x=0.916+0.001j$	70°	$\alpha_q=289.70°$ $\alpha_h=349.31°$ $\}$ $\Delta\rho=7.60°$	$\alpha_q=279.6°$ $\alpha_h=341.6°$ $\}$ $\Delta\rho=9.2°$	$\alpha_q=354.01°$ $\alpha_h=16.35°$ $\}$ $\Delta\rho=12.62°$	$\alpha_q=340.07°$ $\alpha_h=12.75°$ $\}$ $\Delta\rho=16.0°$	$\alpha_q=345.88°$ $\alpha_h=16.1°$ $\}$ $\Delta\rho=21.4°$
	65°	$\alpha_q=289.70°$ $\alpha_h=349.31°$ $\}$ $\Delta\rho=7.60°$	$\alpha_q=289.02°$ $\alpha_h=350.39°$ $\}$ $\Delta\rho=12.73°$	$\alpha_q=289.00°$ $\alpha_h=351.07°$ $\}$ $\Delta\rho=17.22°$	$\alpha_q=289.09°$ $\alpha_h=351.15°$ $\}$ $\Delta\rho=21.7°$	$\alpha_q=289.91°$ $\alpha_h=354.4°$ $\}$ $\Delta\rho=27.1°$
3. As (2) but with pre-cancellation (before pole.)	70°	$\alpha_q=315.3°$ $\alpha_h=0.02°$ $\}$ $\Delta\rho=0°$ *	$\alpha_q=335.65°$ $\alpha_h=9.15°$ $\}$ $\Delta\rho=4.70°$	$\alpha_q=336.9°$ $\alpha_h=8.6°$ $\}$ $\Delta\rho=9.2°$	$\alpha_q=337.4°$ $\alpha_h=7.80°$ $\}$ $\Delta\rho=13.6°$	$\alpha_q=337.65°$ $\alpha_h=6.01°$ $\}$ $\Delta\rho=18.1°$
	65°	$\alpha_q=315.26°$ $\alpha_h=0.02°$ $\}$ $\Delta\rho=0°$ *	$\alpha_q=290.35°$ $\alpha_h=348.6°$ $\}$ $\Delta\rho=4.1°$	$\alpha_q=291.4°$ $\alpha_h=350.4°$ $\}$ $\Delta\rho=8.8°$	$\alpha_q=291.8°$ $\alpha_h=351.7°$ $\}$ $\Delta\rho=13.2°$	$\alpha_q=291.9°$ $\alpha_h=352.9°$ $\}$ $\Delta\rho=18°$
4. As (2) but with post-cancellation (after pole.)	70°	$\alpha_q=315°$ $\alpha_h=0°$ $\}$ $\Delta\rho=0°$	$\alpha_q=293.9°$ $\alpha_h=349.9°$ $\}$ $\Delta\rho=5.90°$	$\alpha_q=339.8°$ $\alpha_h=0.90°$ $\}$ $\Delta\rho=16.1°$	$\alpha_q=330.5°$ $\alpha_h=4.40°$ $\}$ $\Delta\rho=20.7°$	$\alpha_q=337.99°$ $\alpha_h=4.09°$ $\}$ $\Delta\rho=25.4°$
	65°	$\alpha_q=315°$ $\alpha_h=0°$ $\}$ $\Delta\rho=0°$	$\alpha_q=301.9°$ $\alpha_h=356.05°$ $\}$ $\Delta\rho=6.3°$	$\alpha_q=299.9°$ $\alpha_h=355.6°$ $\}$ $\Delta\rho=11.8°$	$\alpha_q=297.75°$ $\alpha_h=354.64°$ $\}$ $\Delta\rho=17.1°$	$\alpha_q=296.4°$ $\alpha_h=354.27°$ $\}$ $\Delta\rho=22.5°$

* Minimum exists at any 2:1 position relative to nominal angles, $\alpha_q=315$, $\alpha_h=0°$

TABLE 1. Receive Polariser Solutions for Four Different Situations, with and without cancellation. Each example is for five different differential phase shifts and two canting angles. α_q is the quarter-wave polariser angle; α_h is the half-wave polariser angle; $\Delta\rho$ is the predicted atmospheric differential phase-shift calculated from $\Delta\rho=4\alpha_h-2(\alpha_q-315)$