IMPROVING THE DELAY STABILITY OF A TWO-WAY SATELLITE TIME AND FREQUENCY TRANSFER EARTH STATION

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Abstract

Two-Way Satellite Time and Frequency (TWSTFT) is increasingly used for the routine intercomparison of time scales at primary timing laboratories. The performance of a two-way time transfer link is, however, limited by delay instabilities in the earth station hardware. Several European laboratories have been operating near field satellite simulators to measure the delay instabilities of their TWSTFT earth stations. At the National Physical Laboratory (NPL) we have adopted a different characterization configuration, where two independent characterization loops are used to measure the TWSTFT earth station uplink and downlink delay instabilities separately. This allows an assessment of the performance of the difference loops in the measurement of the delay instabilities. The cables connecting the earth station hardware have also been investigated. Direct comparisons are made between PTFE coaxial cable propagating Ku-band and L-band signals. Furthermore, the performance of a higher chip rate code has been investigated. Finally, the results presented in this paper are used to discuss future improvements in TWSTFT at NPL.

1 INTRODUCTION

High precision time-transfer using the Two-Way Satellite Time and Frequency Transfer method involves an exchange of time-signals between two earth stations via a geostationary satellite [1]. The advantage of this method over a one-way method (such as GPS common-view) is that accurate determination of the satellite and earth station co-ordinates are not required. This is because the free space and atmospheric propagation delays of the signals travelling in opposite directions cancel out almost entirely. However, the present limitations of this method result from delay instabilities within the earth station hardware. These have to be taken into account and require calibration [2, 3]. Furthermore, it is important that hardware delays are stabilized as far as possible in order to reduce uncertainties after calibration.

This paper presents a series of tests that have been used to characterize NPL's

TWSTFT earth station to gain a better understanding of its delay instabilities. The performance of the earth station uplink and downlink characterisation tests is assessed and the origin of delay instabilities demonstrated. Tests have also been carried out on cables to investigate the variation of signal propagation delays with temperature. The earth station delay stability has also been investigated using a spread spectrum signal with a higher chip rate code than is used in the routine TWSTFT measurements.

2 EARTH STATION CHARACTERIZATION

(I) Downlink Tests

Downlink characterization tests were carried out using the configuration shown in Figure 1. The signals output by the Satre and Mitrex modems were input into one of two downlink characterization loops. The characterization test hardware in each loop consisted of the components between the output of each modem and the earth station feed. These included directional couplers, a switch box, Ku-band mixers, a 12.6 GHz phase-locked local oscillator, attenuators, cables, and horns. Apart from two cables and two horns, all of this hardware was located within a laboratory which is temperature-controlled to within 3°. In each loop the 70 MHz output signals from the two modems were combined using a directional coupler and mixed up to 12.67 GHz using a mixer and the 12.6 GHz local oscillator. The resulting signal was attenuated before being transmitted by a horn towards the earth station feed.

Measurements were taken using both the Satre and Mitrex modems for each loop. The switch box was used to switch between the two loops once per minute. The use of two loops allowed an independent check of the hardware. To allow for measurements to settle down after switching between the loops, measurements corresponding only to the final 30 s of each one minute interval were processed. A mean of these data was taken to provide a representative measurement of the loop delay. The resulting measurements of the Mitrex and Satre modems for each of the two loops (Loops 1 and 2) are presented in Figures 3 and 4 respectively. Indoor and outdoor temperature measurements are also shown for comparison. The tests demonstrate an inverse correlation between the loop delay and the outdoor temperature with a temperature coefficient of -0.1 ns/°C. Previous tests have shown that there can sometimes be a good direct correlation [4].

(II) Uplink Tests

Uplink characterization tests were carried out using the configuration presented in

Figure 2. The characterization test hardware in each loop consisted of the components between the Satre modem input and the earth station feed. These included a switch box, a directional coupler, Ku-band mixers, a 14.1 GHz phase-locked local oscillator, attenuators, cables, and horns. An uplink signal of frequency 14.03 GHz was generated by the earth station and transmitted into the horns of two sets of test hardware. The signals received by the two horns were mixed down to 70 MHz using a mixer in each loop and the 14.1 GHz local oscillator. The output from each mixer provided an input for the Satre modem via a switch box.

Measurements were taken for each loop using the Satre modem. The switch box was used to switch between the two loops once per minute. The use of two loops allowed an independent check of the hardware. To allow for measurements to settle down after switching between the loops, measurements corresponding only to the final 30 s of each one minute interval were processed. A mean of these data was taken to provide a representative measurement of the loop delay. The resulting measurements of the Satre modem for each of the two loops (Loops 1 and 2) are shown in Figure 6. The tests show a good correlation between the measurements of Loop 1 and the outdoor temperature with a temperature coefficient of 0.15 ns/°C. The measurements of Loop 2 show a similar but weaker correlation.

(III) Performance of Tests

It is not clear from the measurements for downlink and uplink tests, shown in Figures 3 and 6, what proportion of delay instabilities originate within the test hardware rather than within the earth station. Instabilities within the test hardware could limit the performance of the tests to characterize the earth station. These instabilities can be assessed by subtracting the measurements of one loop from the other. This allows the common contribution of the earth station delay to be removed in order to observe instabilities occurring only within the test hardware.

Figure 5 shows the differences between the two sets of loop measurements taken by the Satre modem in the downlink tests. Indoor and outdoor temperature data are also shown for comparison. It is found that the differences correlate inversely with outdoor temperature. Figure 7 shows the differences between the two sets of loop measurements taken by the Satre modem in the uplink tests. In this case it is found that there is a good direct correlation between the difference in loop measurements and outdoor temperature. These correlations with outdoor temperature indicate that the temperature coefficients of the test hardware in each of the two loops are different. Furthermore, they suggest that the origin of the instabilities are outdoor components. Apart from the horns, which are not expected to show a significant temperature coefficient, the only test hardware located outdoors are cables. We therefore conclude that the cables within the test hardware are the origin of a substantial proportion of the delay instabilities observed using such characterization tests.

3 CABLE CHARACTERIZATION TESTS

Several coaxial cables are used to transmit signals within the earth station, characterization test hardware, and associated time-transfer hardware within the laboratory. As discussed in Section 2, a significant proportion of delay instabilities are found to originate within such cables, particularly those exposed to the large outdoor temperature changes. Consequently, an investigation was carried out on the effect of environmental temperature changes on the signal delays in coaxial cables.

The delay variations within 50 Ω PTFE coaxial cables (Rhophase Microwave Ltd, part number SPS-1751-10000-SPS) have been investigated at Ku-band and L-band using the configurations shown in Figures 8 and 9 respectively. Two 10 m length cables were connected by an attenuator and placed outdoors in order to expose them to relatively large temperature changes. The first test involved propagating Ku-band signals through these cables. The resulting delay and outdoor temperature changes are shown in Figure 10. There is a strong inverse correlation observed between the delay measurements and outdoor temperature, demonstrating that there is a strong dependence of cable delays with temperature. The temperature coefficient is measured to be -0.15 ns/°C. A similar test was carried out by propagating L-band signals through the cables and the resulting measurements are shown in Figure 11. These data also demonstrate a dependence of cable delay with outdoor temperature and the measured temperature coefficient is -0.007 ns/°C.

4 TESTS USING DIFFERENT CODES

The present method of time-transfer employs 2.5 MChip rate coded signals which are available on both the Mitrex and Satre modems. However, a 20 MChip rate code is also available on the Satre modem. The higher bandwidth of this code may offer more stable hardware delays. A comparison has been carried out between the two codes by taking simultaneous measurements using the downlink test configuration shown in Figure 1. The Mitrex and Satre modems were used with 2.5 and 20 MChip rate codes respectively. The results shown in Figures 12 and 13 suggest that an improvement in delay stability is obtained using the 20 MChip rate code. The cause of the large difference in the loop delays (~ 60 ns) is not clear.

5 DISCUSSION

The tests presented in this paper and in previous papers [3, 4] were carried out to investigate the signal delay behaviors of the earth station and characterization hardware in order to realize methods for improving their performance. In Section 2 it was found that the downlink and uplink tests are affected by delay instabilities within the outdoor cables of the test hardware. This limits the performance of the characterization tests. To improve this it is necessary to reduce the instabilities within the cables.

Results presented in Section 3 demonstrate that PTFE coaxial cables show significant delay instabilities and that cables propagating Ku-band signals show much greater temperature coefficients (by a factor of 20) than cables propagating L-band signals. Cables within the downlink and uplink test hardware are used to transmit Ku-band signals to and from the horns located outdoors. It is clear that these cables could be the origin of the delay instabilities observed within the test hardware in Section 2. This is consistent with the conclusion drawn in Section 2. The instabilities would be greatest for these outdoor cables which are exposed to larger temperature changes.

It is proposed that the delay instabilities within the cables of the characterization hardware could be significantly reduced by transmitting through them at L-band, or possibly at 70 MHz, rather than at Ku-band. This would require a modified characterization configuration involving a Ku-band local oscillator or upconverter located at the antenna.

There are also cables that transmit Ku-band signals between the earth station hardware. These are expected to be the origin of significant delay instabilities within the earth station. By modifying the configuration of the earth station it would be possible to avoid transmitting Ku-band signals through long lengths of cable. The results from Section 3 suggest that the delay instabilities in such cables could be reduced by about an order of magnitude. This would lead to a significant improvement in the time-transfer performance of the earth station.

The increased stability of the 20 MChip rate coded signal described in Section 4 can be explained in terms of its much narrower correlation function. This results in any reflected signals within the earth station having a smaller perturbing effect due to less overlap of the correlation functions generated from the main and reflected signals. Consequently, any changes in the reflected signals will result in smaller changes in the earth station delay and lead to a greater stability.

6 CONCLUSIONS

The results presented in this paper lead us to the following conclusions.

- The delay instabilities of separate characterization loops as well as the differences between them are found to correlate with temperature. The performance of NPL's downlink and uplink characterization tests is presently limited by delay instabilities within the outdoor cables of the test hardware.

• Tests carried out on PTFE coaxial cables demonstrate that they can have significant temperature coefficients. The tests have also shown that PTFE coaxial cables propagating L-band signals have much lower temperature coefficients than cables propagating Ku-band signals.

• PTFE coaxial cables transmitting Ku-band signals between different hardware are the origin of delay instabilities within NPL's characterization and earth station hardware. It is proposed that the instabilities could be reduced by transmitting signals at L-band, or possibly at 70 MHz, through the cables.

• The use of 20 MChip rate coded signals lead to more stable earth station delay
• measurements than using 2.5 MChip rate coded signals.

7 REFERENCES

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[2] G. de Jong 1989, "Accurate delay calibration of satellite ground stations for two-way time transfer," Proceedings of the 3rd European Frequency and Time Forum (EFTF), 21-23 March 1989, pp. 198-203.

[3] J. A. Davis and P. R. Pearce, "Characterisation of the signal delays in a ground station designed for two-way time transfer," Proceedings of the 7th European Frequency and Time Forum (EFTF), 16-18 March 1993, pp. 113-118.

[4] J. A. Davis, J. M. Furlong and J. D. Clarke, "The performance and characteristics of a two-way time transfer earth station incorporating a new Satre modem," Proceedings of the 12th European Frequency and Time Forum (EFTF), 10-12 March 1998, pp. 169-174.

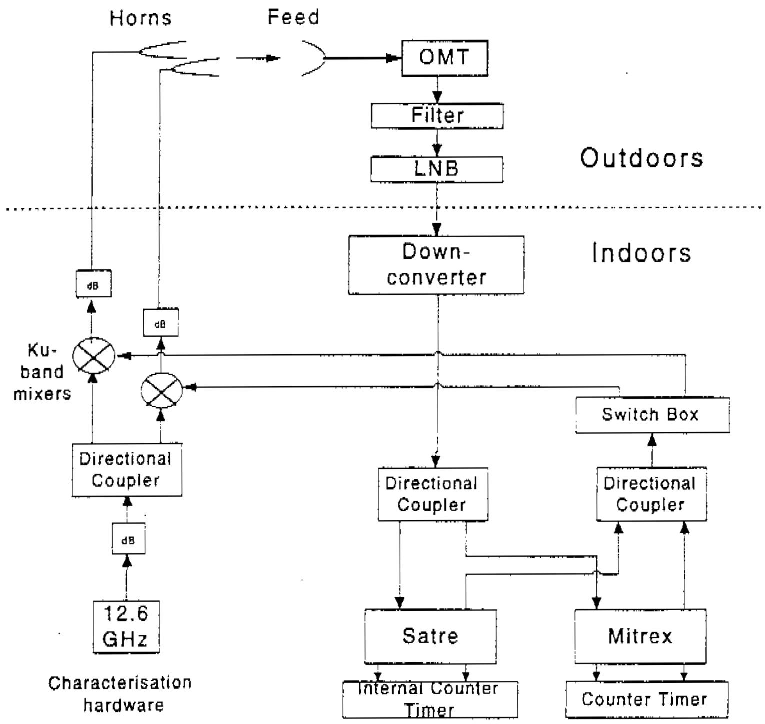

Figure 1. Downlink characterization test configuration.

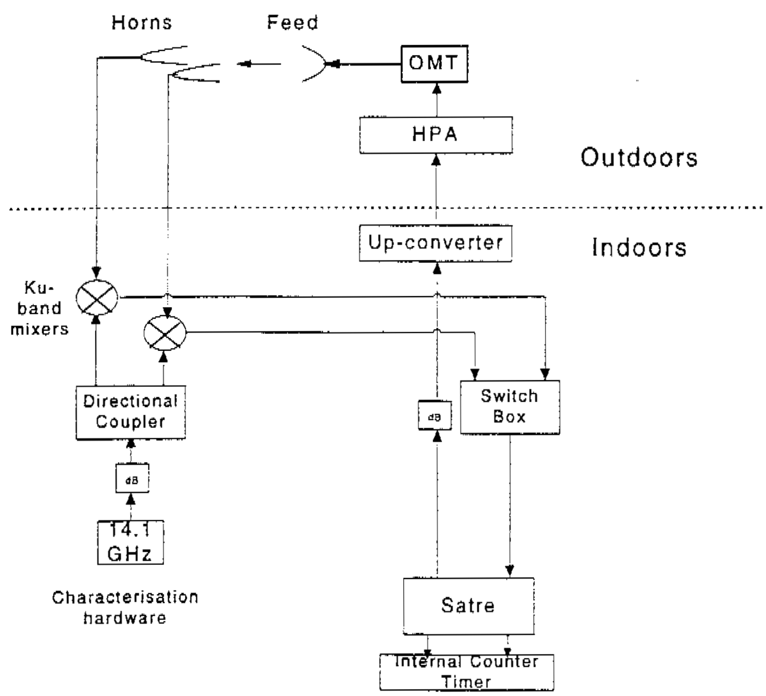

Figure 2. Uplink characterization test configuration.

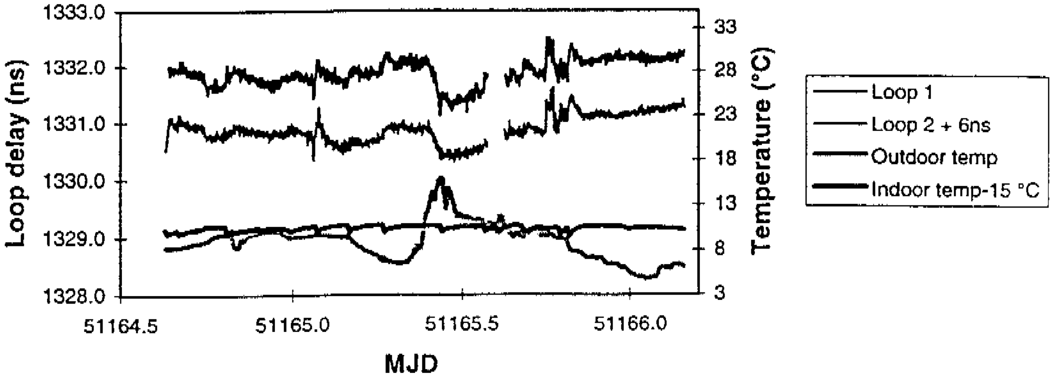

Figure 3. Measurements for two downlink characterization loops taken using the Mitrex modem. Indoor and outdoor remperature data are also shown.

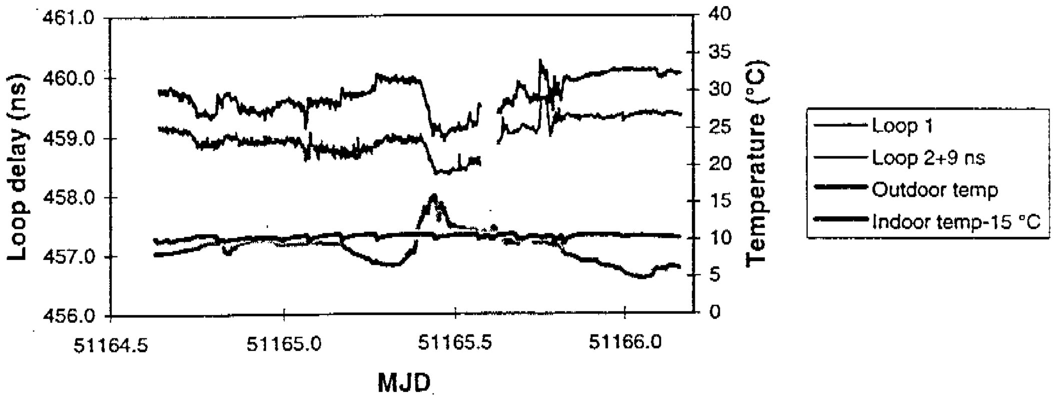

Figure 4. Measurements for two downlink characterization loops taken using the Satre modem. Indoor and outdoor temperature data are also shown.

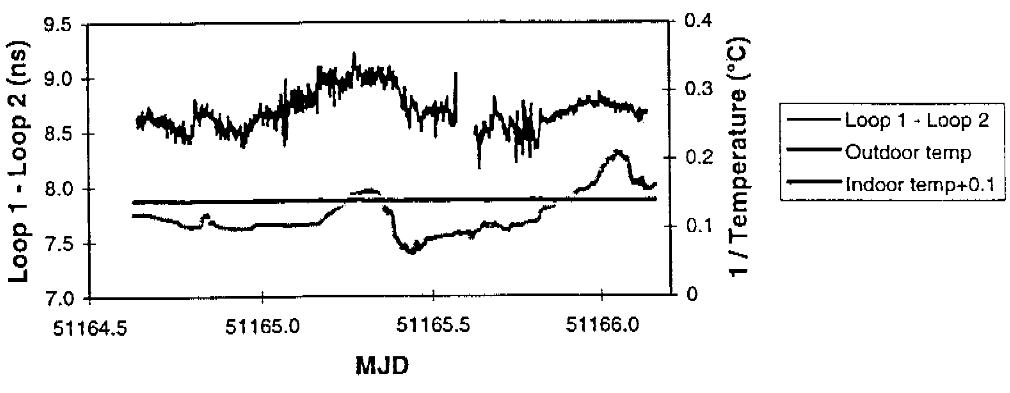

Figure 5. Difference between downlink characterization loop measurements of the Satre modem. Indoor and outdoor temperature data are also shown.

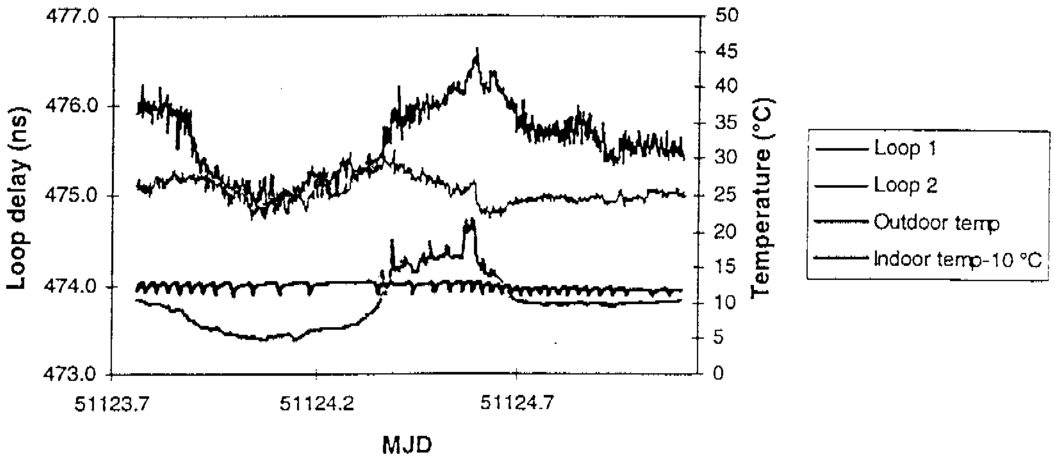

Figure 6. Measurements for two uplink characterization loops taken using the Satre modem. Indoor and outdoor temperature data are also shown.

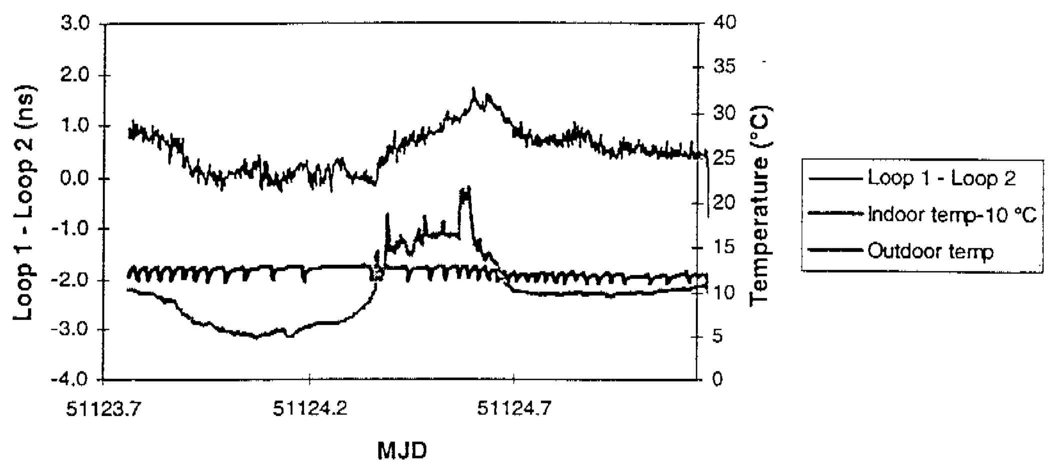

Figure 7. Difference between uplink characterization loop measurements of the Satre modem. Indoor and outdoor temperature data are also shown.

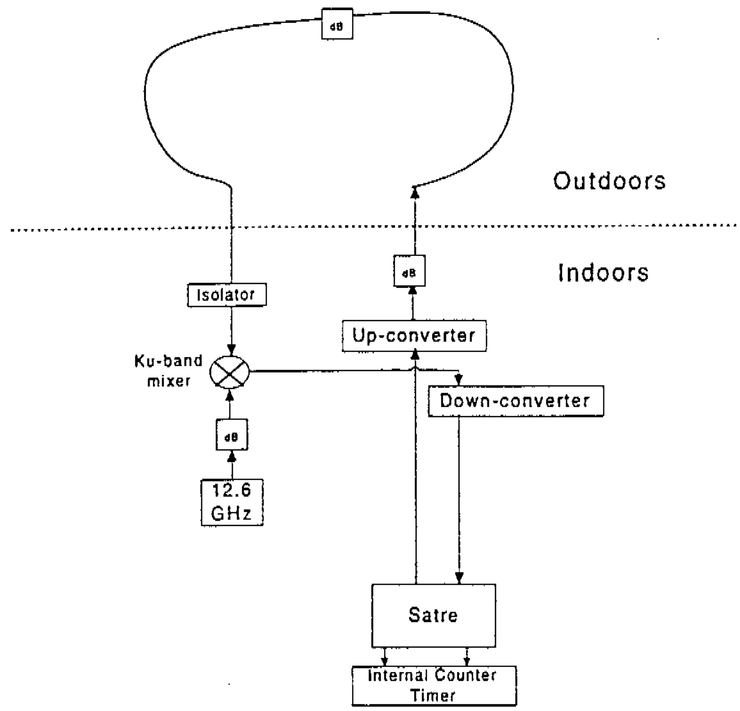

Figure 8. Configuration used to investigate Ku-band signal delay variations in PTFE cables.

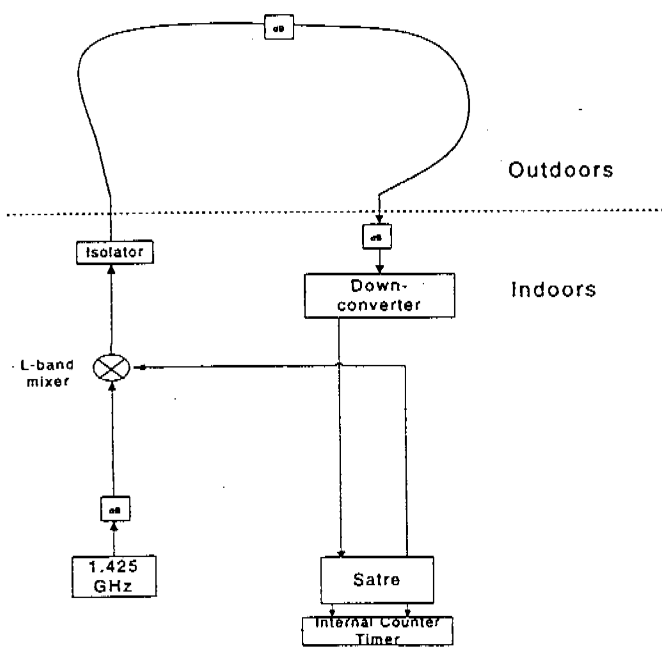

Figure 9. Configuration to investigate L-band signal delay variations in PTFE cable.

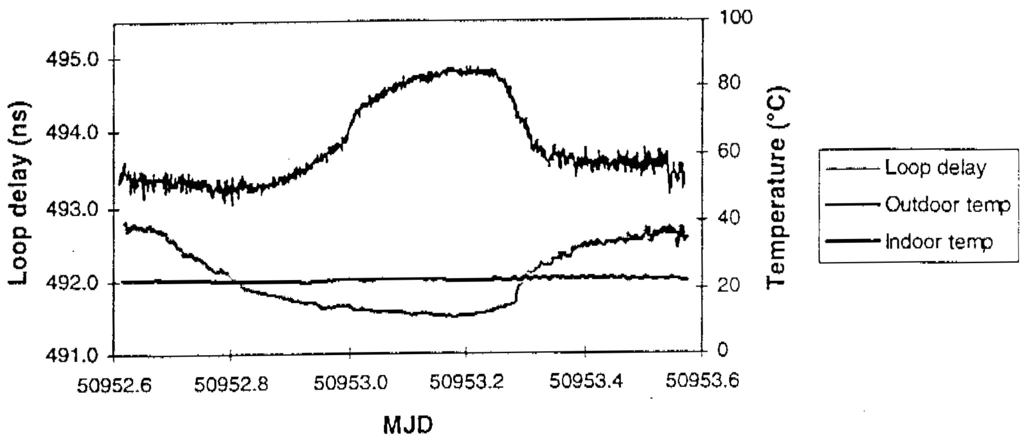

Figure 10. Measurements taken for Ku-band cable tests. Loop delay measurements have been taken with the Satre modem. Temperature data also shown.

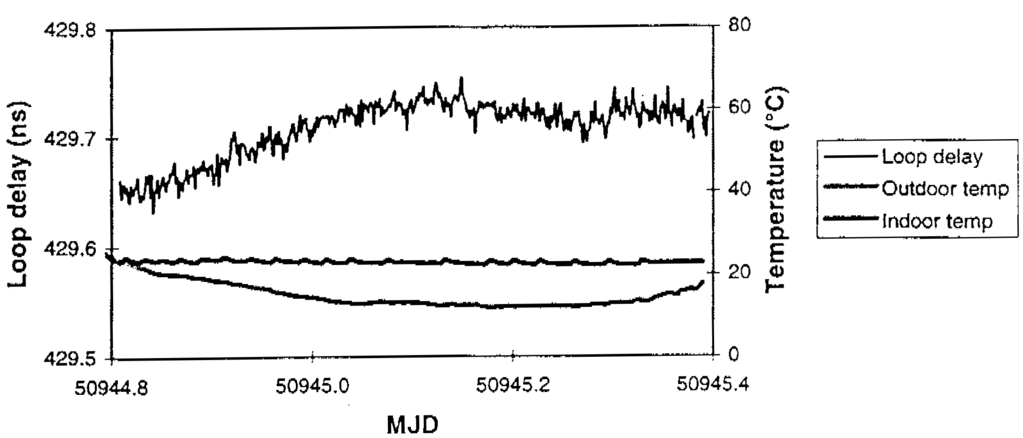

Figure 11. Measurements taken for L-band signal cable tests. Loop delay measurements have been taken with the Satre modem. Temperature data are also shown.

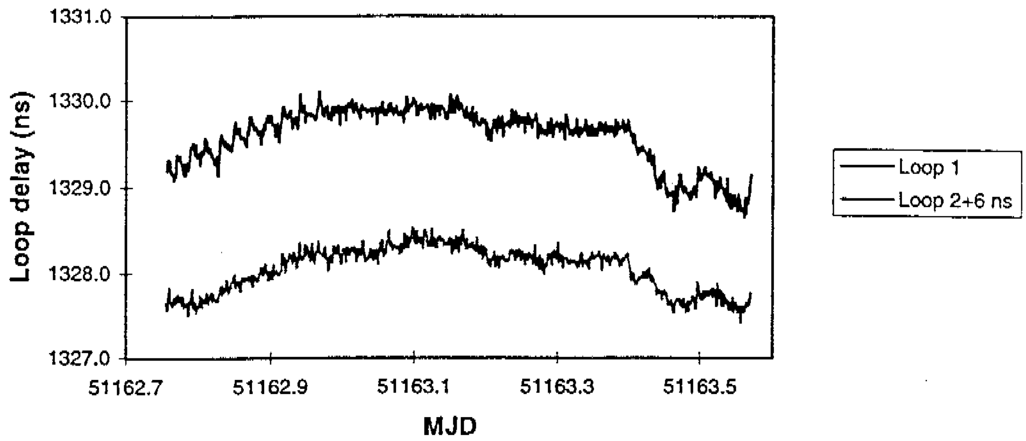

Figure 12. Measurements for two downlink characterization loops taken using the Mitrex modem.

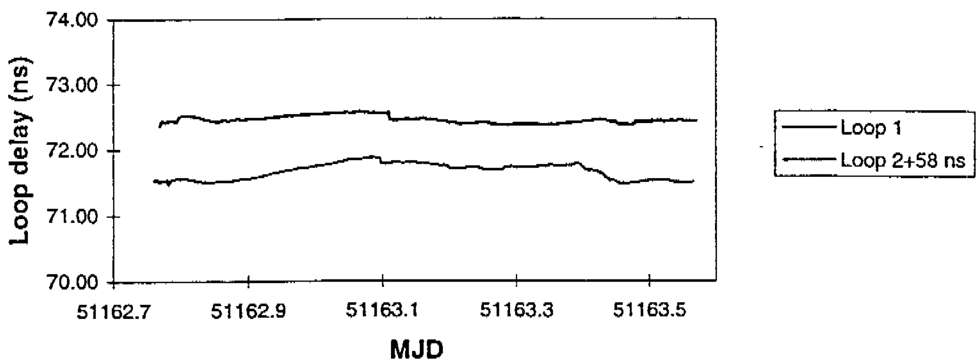

Figure 13. Measurements for two downlink characterization loops taken using the Satre modem.