Submillimeter Array Technical Memorandum

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From: Colin Masson, J. D. Williams, Dan Oberlander & Jim Hermstein

The SAO Phase Monitor

Summary

The SAO has recently installed a radio phase monitor to study the atmospheric stability (radio 'seeing') near the summit of Mauna Kea. The instrument employs two small antennas, separated by approximately 100 m, receiving a beacon signal from a geosynchronous satellite. The phases of the two signals are compared to give an instantaneous measurement of the fluctuations in path length to the two antennas. The atmospheric changes occur predominantly on short time scales, typically -1 minute, and can therefore be separated from slower drifts in the instrument.

The instrument will remain in place for a period of l-2 years, and the measurements will be correlated with other data, such as wind speed and atmospheric opacity. Preliminary results show that the magnitude of the phase fluctuations varies by a factor of 30 during a day, with the largest variations being found during the middle of the day.

1 Introduction

The submillimeter array (SMA) is to be a high-frequency (230 - 900 GHz) interferometer array operating at high angular resolution (< 1"). As well as choosing a site with low opacity (low precipitable water vapor) for this instrument, it is also important to verify that the atmosphere is stable enough to permit high-resolution imaging. We have therefore constructed a device which will monitor the stability of the atmosphere at potential sites. A similar device has been used at Nobeyama in Japan (Ishiguro, Kanzawa, and Kasuga 1989).

This device, the Phase Monitor, consists of a pair of 1.8 m antennas which receive a beacon tone at 11.712 GHz from a geosynchronous satellite. The satellite used is GStar A2, which is operated by GTE Spacenet and which has a Ku band transponder with a beam covering all 50 states. The antennas are separated by 100 m, comparable with the size of the planned submm interferometer, and the orientation of the baseline is orthogonal to the line-of-sight to the satellite so that there is no fore-shortening. The signal is received by each antenna, and converted to a 21.4 MHz IF, where it is filtered to separate out the beacon tone. The difference in phase betweeen the tones from the two dishes is measured by a vector voltmeter and recorded continuously by a small computer. Any variations in path length, due to atmospheric water vapor, will perturb the phase of the signal. At 11.712 GHz, 1° of phase corresponds to a path difference of $71\mu m$. At our 100 m baseline, this corresponds to an apparent shift of the satellite position by 0.15".

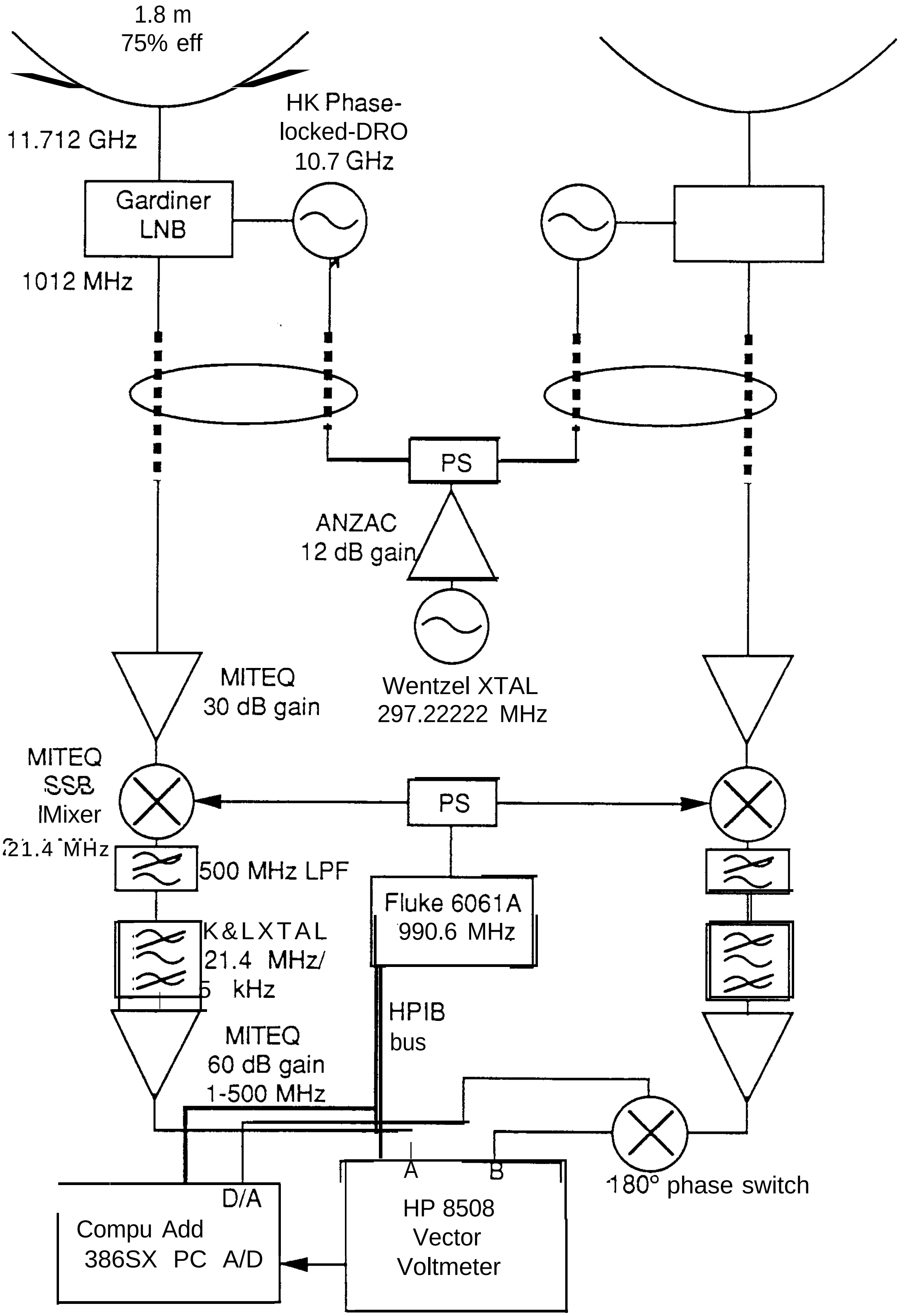

Figure 1. Block diagram of the Phase Monitor.

Although the operating frequency of the phase monitor is much less than that of the SMA itself, **the** atmosphere is nearly non-dispersive at frequencies where it is not opaque, so the phase is simply proportional to frequency. The principal difficulty in making the measurement is that the path length stability of the monitor must be as good as that of the SMA, i.e. better than 30 μm rms, which corresponds to 0.42’ of phase at 11.712 GHz. While this goal is difficult, it is not impossible, particularly when it is realised that the atmospheric fluctuations occur on a time scale, of 1 minute or less, as described below in Section 3. This implies that the Phase Monitor will be sufficiently stable if it has low drift over a period of 30 minutes, even if the longer-term drift is larger.

2 Technical Description.

A diagram of the Phase Monitor is shown in Figure 1. The beacon tone from the satellite GS tar A2 is at a frequency of 11712 MHz, and is transmitted with less than 1% of the power of a transponder. The signal is received by 1.8 m antennas, which are offset-fed to maximize efficiency and minimize standing waves, which could perturb the phase. The antennas are mounted on steel posts, which are held in place by earth-anchors. The receivers employ commercial HEMT LNBs with noise temperature of ~ 100 K at 12 GHz.

The two first local oscillators are phase-locked DROs at 10.7 GHz, with a common crystal reference at 297.222 MHz. This crystal is stable to 0.1 ppm, to ensure that the IF signal does not drift out of the band of the 5 kHz filters. The phase stability of the first local oscillators is of paramount importance. Several precautions are taken to minimize drift, such as using a relatively high frequency for the crystal reference, to minimize the multiplication of any phase drift. The LOs were found to have drifts of about 10°/°C of ambient temperature, and 1°/mV of supply voltage. The temperatures are therefore regulated to 2 °C p-p, and the supply is regulated to 1 mV p-p.

The cables to the antennas have electrical lengths of approximately 10^6 ° at 117 12 MHz. Andrews Heliax FSJ l-50 cables were used, with temperature coefficients ~ 1 ppm/°C over the range from -10 °C to 20 °C, to minimize drifts. To simplify the design, no active compensation of cable length was used, but the cables are wrapped in insulating foam and housed in white PVC pipes to slow down any temperature changes.

In the IF section, the most important precaution is to avoid filters, which can have very large phase drifts. The second conversion therefore uses a single-sideband mixer to reject the lower sideband and there is only a single filter with a modest selectivity ($f/\partial f$ ~ 4000) in the signal path for each channel. This is a crystal filter which is specified to have a low temperature coefficient. The output signals at 21.4 MHz are fed to a Hewlett Packard Vector Voltmeter, and the resulting phases are averaged and recorded once per second by a 386SX computer, which also controls the instrument and monitors a number of temperatures and other parameters. The final noise level is better than 0. 1° (7 urn) rms, in 1 second of integration.

3122000 **SITE-TESTING DATA** Phase

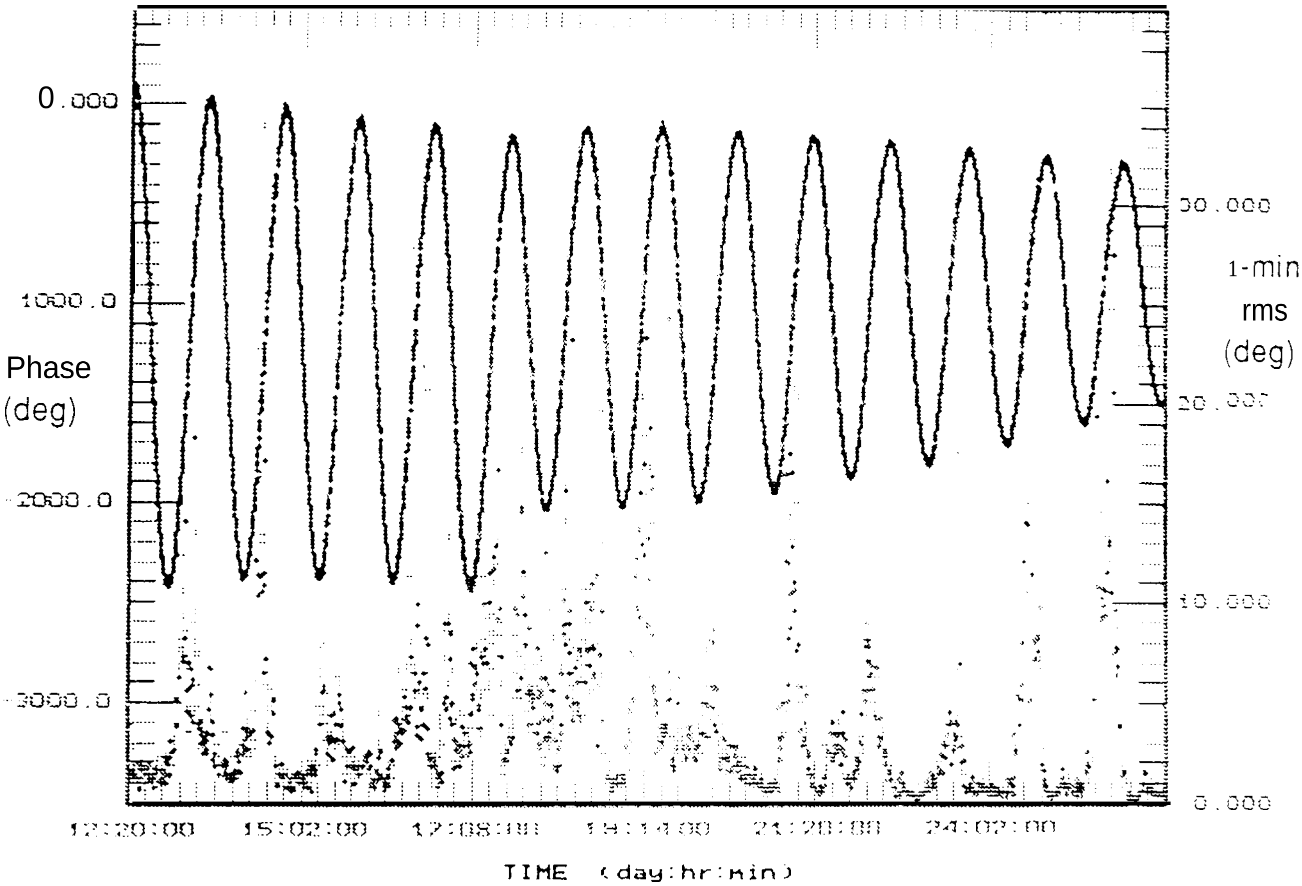

Figure 2. Phase and rms over 13.5 days

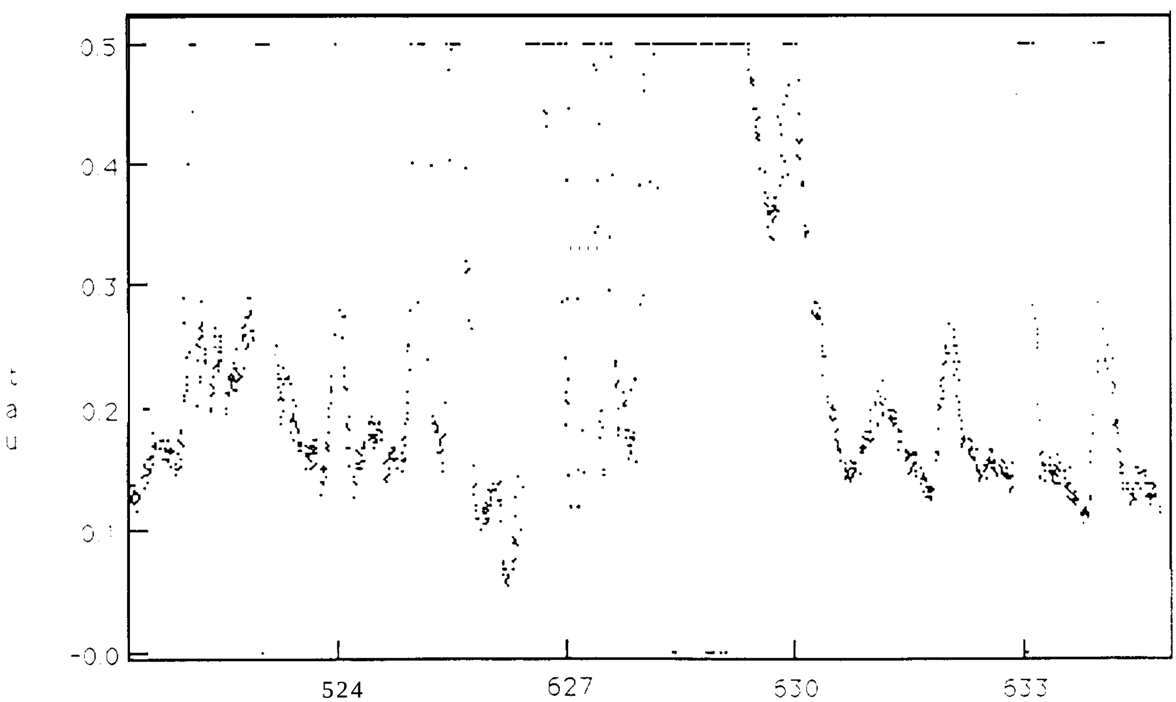

Figure 3. 225 GHz Opacity

The Phase Monitor is installed in millimeter valley on Mauna Kea, Hawaii near the James Clerk Maxwell Telescope (JCMT). The IF section and computer are housed in the non-rotating basement of the JCMT carousel. The phase measurements are recorded in binary form and passed over to the MWTCON Vax at JCMT for transmission to Massachusetts. An ASCII text summary file is also written to the Vax.

3 Initial Results

The Phase Monitor appears to be very stable in practice. The p-p diurnal phase variation of the instrument is about 30°, and most of this occurs smoothly enough that it has no effect on the measurement of the atmospheric fluctuations. The upper curve in figure 2 shows a plot of the recorded phase over 13.5 days from September 12, 1990 to September 26, 1990. The large sinusoidal signal in the upper curve is due to the -50 km periodic motion of the satellite about its mean position. This motion varies due to gravitational effects and station-keeping maneuvers (e.g. Sep 18). The lower curve is a plot of the rms values which are calculated for each 1 minute section of data in real-time. Because of the short period over which these rms values are calculated, these understate the true rms by a factor of about 5, but they clearly show that there are large variations in atmospheric stability from one time to another. As a comparison, the 225 GHz opacity during this time is plotted in figure 3. The opacities are quite high, showing that the observing conditions were worse than average during this time.

The phase of a single day is shown in figure 4, after removal of a 24 hr and 12 hr sinusoidal component, along with curves showing the cable temperatures. An expanded plot of a good period is shown in Figure 5a, with its frequency spectrum shown in Fig 5b. This is the best 1 hour section recorded in the first 2 weeks of operation. Figure 6 shows a typical bad period from the same day (September 25). One important feature in these plots is the flattening in the spectra below about 0.01 Hz. This shows that most of the atmospheric fluctuations occur quite fast. It is easy to understand why this should be, since the Phase Monitor is most sensitive to scales in the atmosphere which are comparable with the separation of its antennas. To a good approximation the atmosphere blows past the Monitor as a fixed screen at a velocity of a few m/s, giving a characteristic timescale of about 1 minute for our 100 m baseline. This is the justification for building a Phase Monitor with only modest long-term stability. It also indicates that there will be difficulty in obtaining enough signal/noise ratio for removal of these rapid atmospheric effects by self-calibration at the short baselines used in millimeter and submillimeter interferometers.

The l-minute rms values are expected to be highly correlated with JCMT pointing variations (‘anomalous refraction’), and are therefore provided in the monitor files on MWTCON in near-real time (twice per hour) to aid in the monitoring of observing conditions. The format of the monitor file is described in Appendix A. As a rough guess, the 1 minute rms values in degrees should be comparable with JCMT pointing fluctuations in arcseconds, but it would be useful to collect information to determine this relation.

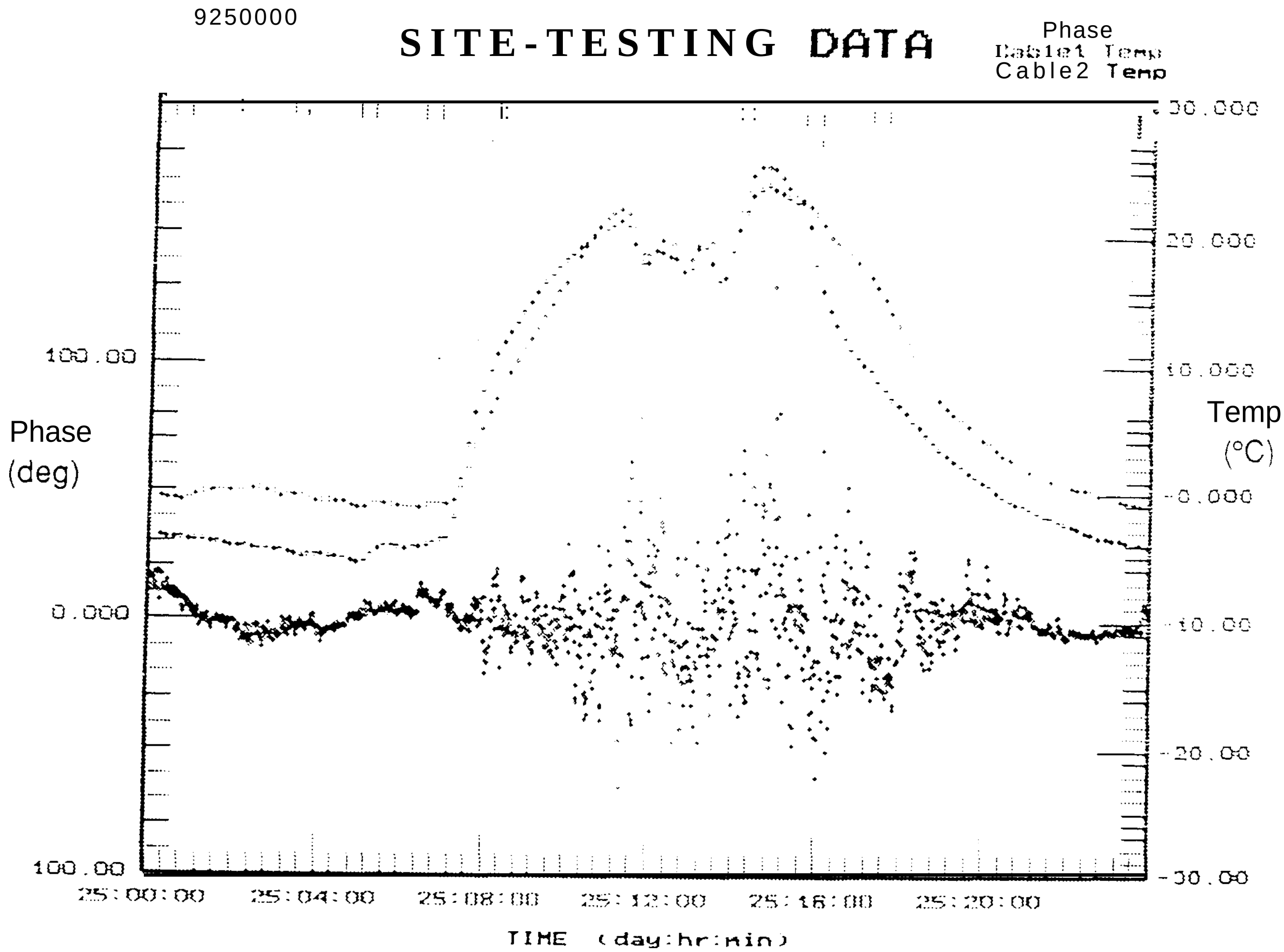

Figure 4. Phase and Cable temperatures on September 25.

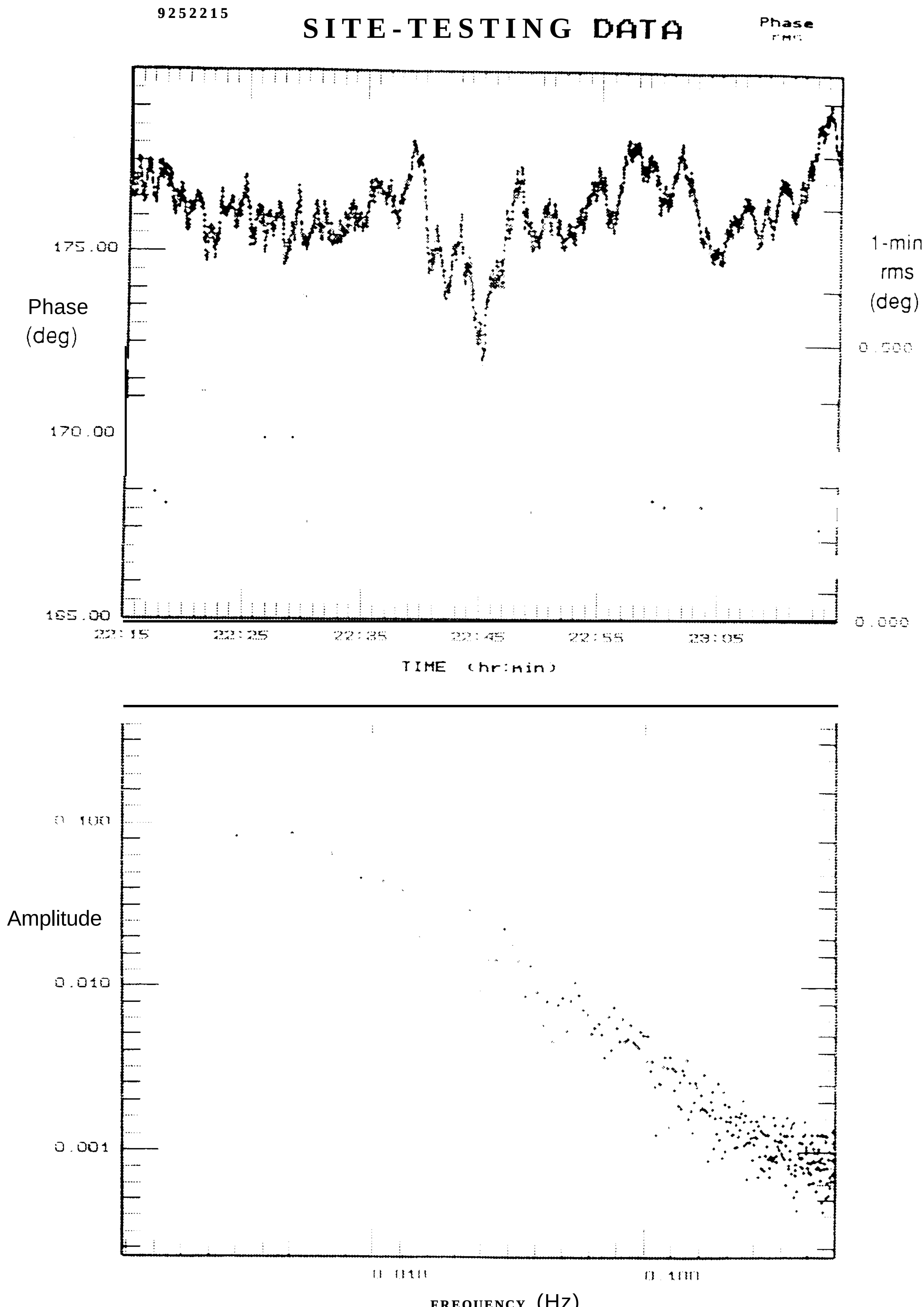

Figure 5. a) Phase and rms during one good hour (2200 - 2300 on September 25).
b) Frequency spectrum of the phase plotted in (a).

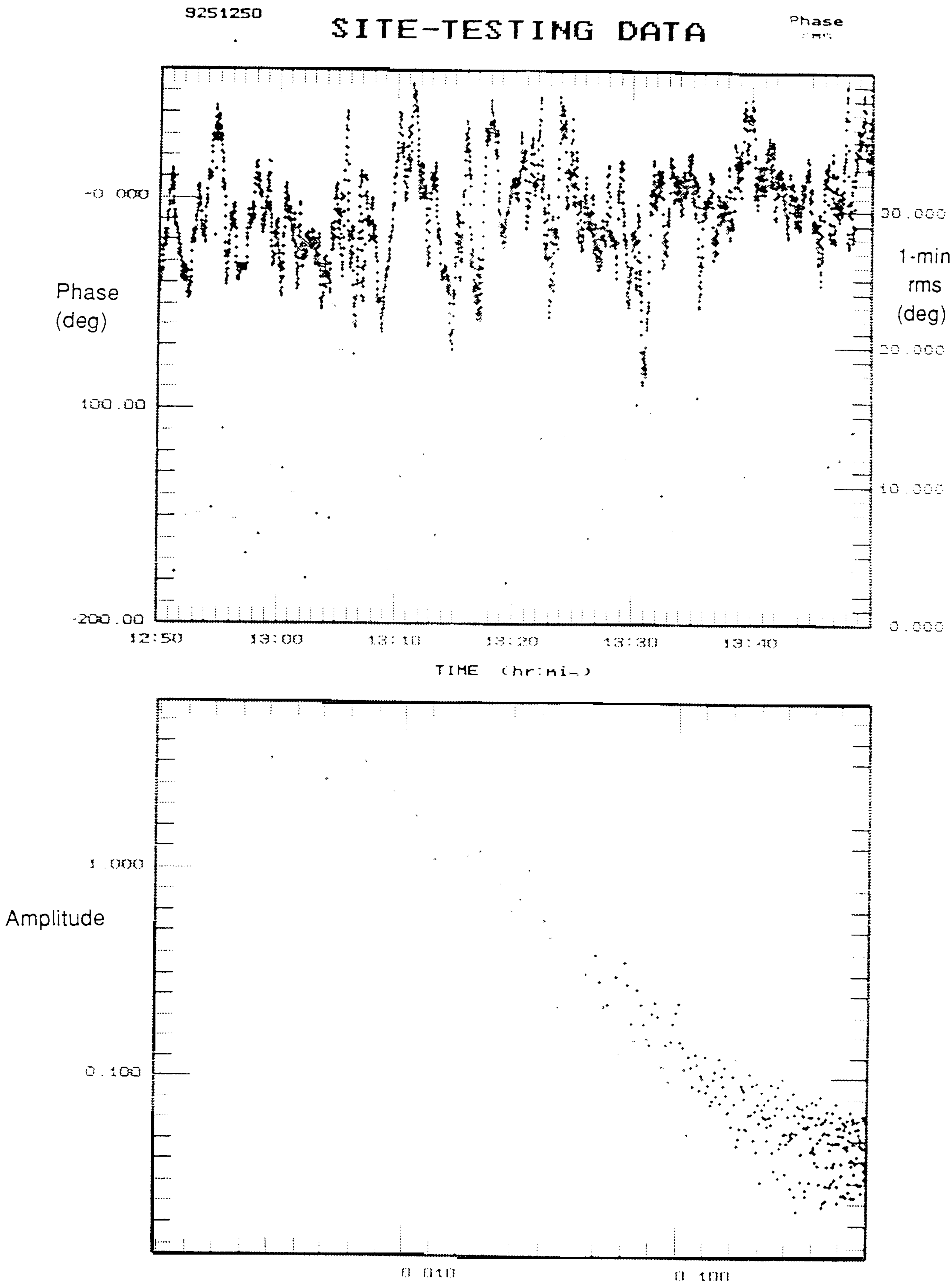

Figure 6. a) Phase and rms during one bad hour (1250 - 1350 on September 25).
b) Frequency spectrum of the phase plotted in (a).

Acknowledgements

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References

Ishiguro, M., Kanzawa, T., Kasuga, T. 1989. *Monitoring **of** Atmospheric Phase Fluctuations using Geostationary Satellite Signals. NRO* Technical Report No. 2 1.

Appendix A.

Status file format

The sample file below shows the status in the afternoon of September 26. The first set of numbers is a list of 30 average and l-minute rms phases over the half hour from 1400 to 1430. The consecutive rms phase values are 4.86, 3.30, 4.17 . . . These are relatively large values, typical of daytime conditions. At night, the rms values are normally less than 1 degree. Realtime readout of the rms phase values is available on the computer monitor in the basement of the JCMT.

The remaining numbers are monitors of various voltages and temperatures, and the remaining disk space on the Phase Monitor computer. If the Percent in lock drops below 100.0, or the amplitude is significantly less than 0.100, then the phase values may be suspect.

```
 $type [CFA]9261400.sta
   -6.39    4.86  -14.74    3.30  -11.25    4.17     2.94   11.75    24.65    5.26
   17.46    3.64   27.63    3.84   32.92    4.91    34.66    6.24    47.53    4.46
   54.79    7.07   20.15    4.72   -3.06    7.63    19.15    9.77    31.23    2.54
   73.13    4.39   69.10    1.49   69.85    4.29    56.16    4.78    58.67    6.50
   71.18    4.94   82.01    1.95   91.38    5.22    96.17    8.80    87.93   10.97
   81.69   18.27   51.23    4.35   54.22    6.60    67.54    6.30    62.28    6.50
Percent in lock: 100.0
Average amplitude:   0.147
Fluke test   990.599389
    Air Temp: 20.26     VCO1 Temp: 54.62     VC02 Temp: 56.81
  VCO1 volts: 14.96     Dome Temp:   6.63   Cable1 Temp: 23.11
 Cable2 Temp: 21.72    VC02 Volts: 14.96       Groundl:   0.19
     Ground2:   0.20  IF Box Temp: 35.53   VCO1 Ctrl V:   6.19
 VC02 Ctrl V:   5.63    Heater1 I:   0.20     Heater2 I:   0.11
Phase Switch: 0
Hard disk: 13.002
$
```