HIGH-RESOLUTION MILLIMETRE-WAVE HOLOGRAPHY ON THE JAMES CLERK MAXWELL TELESCOPE

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ABSTRACT

A system for measuring the surface of the JCMT is described. It operates at either 80 or 160GHz and measures the phase and amplitude of signals from a source ~700 metres away. Frequency modulation is used to reduce the effects of multipath propagation. An efficient data acquisition system ensures that the time to make a map is limited only by the scanning speed of the telescope. A high-resolution map (~8cm on the 15m aperture) takes less than two hours and a lower resolution one ~30 minutes. The goal is to achieve a measurement accuracy of 5 microns.

INTRODUCTION

For many years the surface of the JCMT has been measured using a version of phase-retrieval holography which employs a 94 GHz source at a distance of about 700 metres from the antenna. Although this provided high resolution images with good sensitivity, its limitations have become apparent in recent times. These limitations are that: 1) two large maps at different focus settings are needed, which takes nearly 2 hours to complete; 2) the data processing is somewhat complex; 3) when panels are a long way out of position, the phase-retrieval method does not find the full amount of the displacement and makes errors in measuring other parts of the surface; and 4) we found that errors were being caused by multipath propagation involving reflections off the teflon membrane which is normally held in front of the dish to protect it from wind and solar heating. This paper describes a new system, which has been developed to overcome these limitations.

HARDWARE

The source is again located at the UKIRT building, which is about 700 metres from the JCMT and at an elevation angle of about 8.6 degrees. It transmits two signals on the same beam, one at 80.35GHz with horizontal polarization and one at 160.70GHz with its E-plane vertical. The main reason for using two different frequencies is to enable us to identify, and hopefully correct for, any systematic errors arising from things like diffraction effects and the phase of the feed horn patterns. Both signals are derived from a phase-locked Gunn oscillator, which is driven by a frequency synthesizer remotely controlled from the JCMT. This arrangement makes it possible to scan the frequency over a few 10's of MHz so that the effects of multipath propagation can be separated out. Typically the scan pattern consists of 10 or 20 frequencies emitted in sequence with a stepping rate of a few hundred Hz.

The receiver is located in the cabin at the Cassegrain focus of the JCMT. It has two channels at each of the two frequencies: a reference channel which views the source through a hole in the roof of the cabin and, via a pair of relay mirrors, through a further hole in one of the panels forming the primary mirror; and a signal channel which receives the signal gathered by the primary reflector via the secondary and tertiary mirrors in the normal way. The receivers are mixers, driven by two Gunn oscillators, one driving the signal and reference channels at 80.0GHz and the other the two 160GHz channels (which are sub-harmonic mixers pumped at 80.5255GHz). The first Gunn is locked to the 80GHz signal received by the reference channel, with a 350MHz offset and the second is locked to the first with a 525.5MHz offset. The result of all this is that the IF signals emerge at 350MHz in the case of the 80GHz system and 351MHz for the 160GHz case. One or other of these outputs is selected for a given observation.

The IF's are amplified and processed in an IF units which generates the real and imaginary components of the signal using the IF from the reference channel as the phase reference. Two versions of this are produced, one with high gain and the other low, to give a overall dynamic range of over 60 dB.

DATA AQUISITION

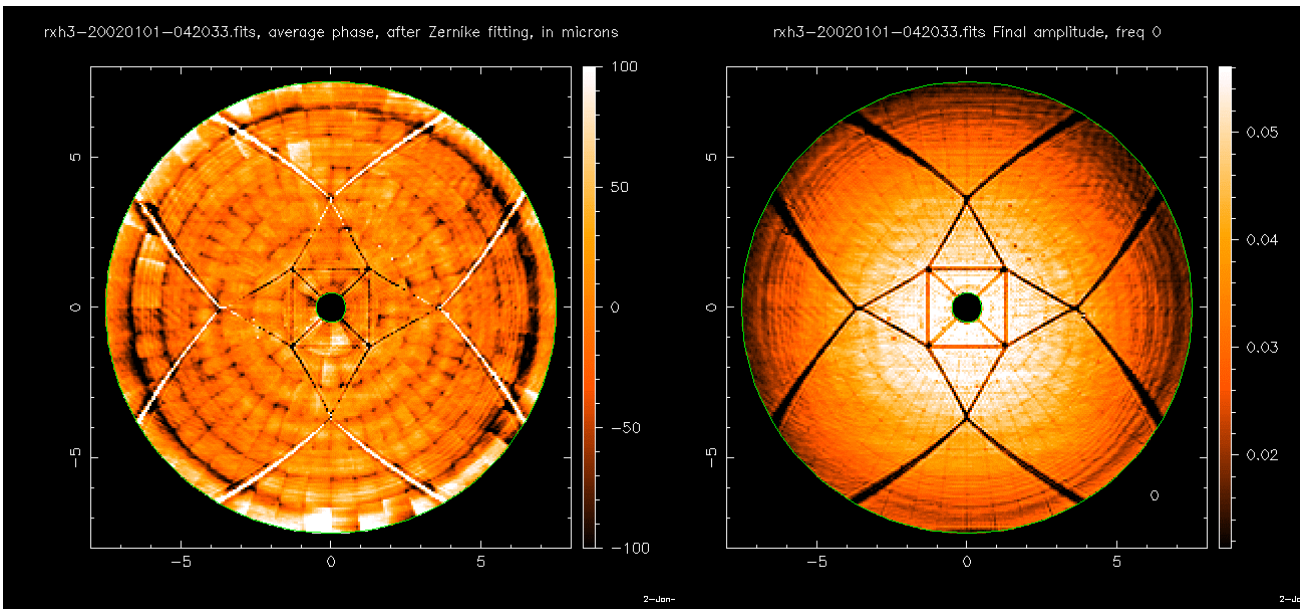
The data acquisition is synchronised to the stepping of the frequencies in the source. Each time the source moves to a new frequency a large but very brief frequency excursion is deliberately introduced. This produces a pulse on the phase-lock control line in the receiver which is sensed and relayed to the data acquisition unit (the DAU). After a pause of a few hundred microseconds to allow the voltages to settle, the signals are then read out. Samples can be taken at a rate of up to 1 kHz. The DAU consists of a VME-based computer running the VX-works operating system and equipped with A-to-D converters, etc. See [1] for more details. The observations are made with the telescope performing a raster motion at quite high scanning speeds (up to 400 arc seconds per second) so the positions of the telescope at the times of the samples also need to be recorded accurately.

DATA ANALYSIS SOFTWARE

The data samples are first corrected for any offsets, for non-orthogonality of the real and imaginary outputs and for phase and amplitude drifts (which are measured by making observations of the centre point from time to time in the course of a map). The low- and high-gain values of the signals are also combined and the samples taken at each of the different frequencies are grouped together for further processing. Phase corrections for the geometrical paths of the reference channel also need to be applied. Since the sampling is on a somewhat irregular grid (due to the irregularity of the sampling times and the telescope motions) the data are then interpolated onto a regular grid. The Fourier transform can then be taken including the terms needed to account for the fact that the source is in the near-field. The result is a series of maps representing the phase and amplitude of the signal in the aperture of the dish at each of the frequencies in the scan pattern. These are averaged together to reduce the effects of multipath propagation. The surface errors are of course seen in the phase pattern while the amplitude shows the effects of the illumination by the feed, the shadowing caused by the legs which support the secondary mirror, and the diffraction rings due to the edge of the secondary. The phase pattern should be corrected for these diffraction effects before the adjustments required are derived.

RESULTS

The system is now operating with a fair degree of reliability. The diagram shows high resolution maps obtained using the 160GHz system. Phase is on the left and amplitude on the right. The pattern of 7 rings of surface panels is easily seen and the dark ring shows that some readjustment is needed especially in the outer two rings.



The maps above have resolution of about 8cm but take nearly 2 hours to produce. Using the 80GHz system, maps of lower resolution but still sufficient to determine the adjustments needed to the individual panels can be made in about 30 minutes. The accuracy of the system has not yet been fully established, but the goal is to achieve a precision of 5 microns. It is likely that even on Mauna Kea the limiting accuracy will in fact be set by the stability of the atmosphere for much of the time.

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REFERENCES

[1] I. A. Smith, . "The New JCMT Holographic Surface Mapping System – Implementation", in *ASP Conf. Ser., Vol. 238, Astronomical Data Analysis Software and Systems X*, eds. F. R.Harnden, Jr., F. A. Primini, & H. E. Payne (San Francisco: ASP), pp 93, 2001.