A HOLOGRAPHIC MEASUREMENT SYSTEM FOR THE SMA ANTENNAS AT 680 GHZ

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ABSTRACT

We have set up a holographic measurement system for the in-field characterisation of the high frequency performance of the SMA antennas and optics. The SMA is a reconfigurable sub-millimeter array of 8 antennas operating down to a wavelength of $\sim$ 330 μm ($\sim$ 900 GHz), on Mauna Kea, Hawaii. For the holography system, the test signal is provided by a low-power phase-locked 682.5 GHz (440 μm) CW source mounted on the nearby Subaru Telescope building, in the near-field for the 6-m diameter SMA antennas. The source also emits multiple tones and has limited tunability. The complex beam pattern of the antenna under test is measured by raster scanning, with a second antenna of the Array providing the phase reference. Due to the small power output required, the signal source could be made compact and simple for reliable field use. In this presentation, we describe the design and charaterisation of the signal source and present preliminary measurements with the system. We used a novel power measurement scheme that allows measurement of low powers in the presence of multiple comb components, to characterise the signal source.

INTRODUCTION

The Sub-Millimeter Array which recently became partially operational on Mauna Kea, Hawaii, is a reconfigurable array of 8 antennas, each of 6-m diameter (Figure 1) [1]. It will carry out synthesis imaging

Figure 1: A view of the SMA on Mauna Kea. The Array will have 8 antennas when completed.

of celestial objects over the wavelength range $\sim$ 1700-330μm ($\sim$ 180 - 900 GHz). For efficient short wavelength operation, it is necessary that the surfaces of the antennas be measured and set to high accuracy. The

SMA specifications require an rms surface smoothness of 12 μm. Near-field holographic measurement at 232.4 GHz (1291 μm) is the primary method of achieving this goal. Near-field holography at high signal-to-noise allows accurate measurement and correction of panel-panel errors and panel flexures at a high spatial resolution of $\sim$ 10 cm. So far, we have set the surfaces of 5 of the antennas to within $\sim$ 20 μm rms of an ideal paraboloid, and one of them has been adjusted to an accuracy of 13 μm rms [2]. Three of the SMA antennas have now been equipped for operation in the 690 GHz band and in order to characterise the high frequency preformance of the antennas and optics, we have set up a holographic measurement system operating at 682.5 GHz. This system will help check the overall alignment of the optics at high frequencies directly and measure the illumination patterns realised. It will render insignificant the effects of diffraction due to the small subreflector (35-cm diameter) thus providing a better measurement of the surface smoothness. In addition, the system will also allow other useful tests of the Array (e-g., Array-wide phase stability measurements).

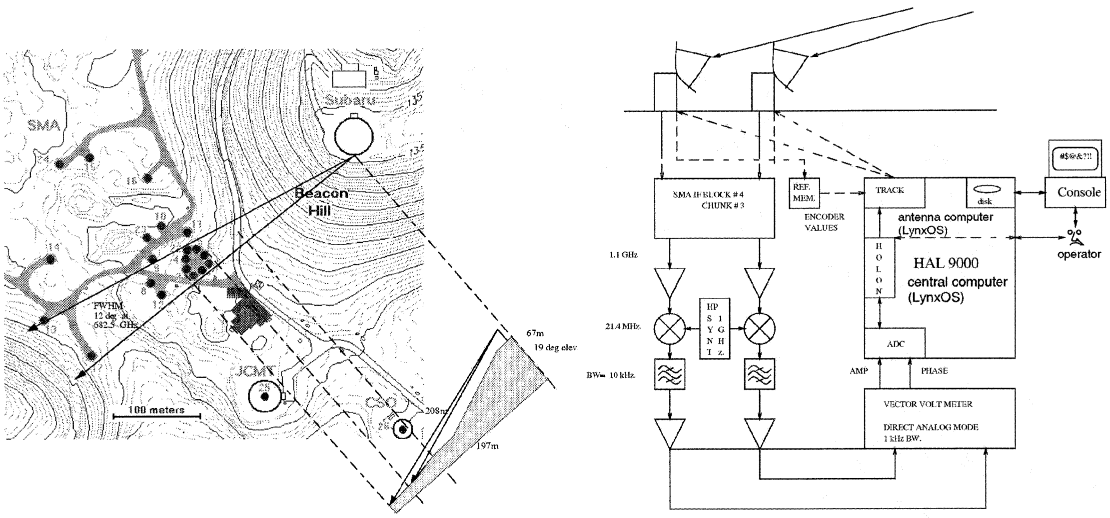

Figure 2: (a) The geometry for SMA near-field holography (b) The SMA holography system block diagram

THE SYSTEM

The holographic system is essentially same as the one used at 232.4 GHz [2], but for a higher frequency signal source. The signal-source is mounted on the cat-walk of the Subaru Telescope at a distance of 200-250-m from the antennas and at an elevation of $\sim 19°$. For the 6-m diameter antennas, this is in the near-field for all our operating bands. During the measurements, the subreflector is positioned to focus on the near-field source. The system uses the standard SMA optics, recievers and IF electronics. Currently a vector volt-meter is used as the back-end to measure the complex beam pattern of the antenna under test. The geometry of the measurements is shown in Figure 2(a) and a block diagram of the system is shown in Figure 2(b). The measurements are made on-the-fly, typically mapping a 96$\times$96 raster with an elevation spacing of $11''$. The data are re-sampled off-line on to a regular grid and Fourier inverted to obtain the complex aperture domain field distribution.

SIGNAL SOURCE DESIGN & CHARACTERISATION

We first calculate the required power output of the signal source. With $T_{SYS,SSB} \sim 1200K$ at 680 GHz, the noise floor is $kTB = 2 \times 10^{-14}W = -107$ dBm, assuming conservatively B =1 MHz, for the Array correlator back-end. The measured noise-equivalent bandwidth of the vector volt-meter which we currently

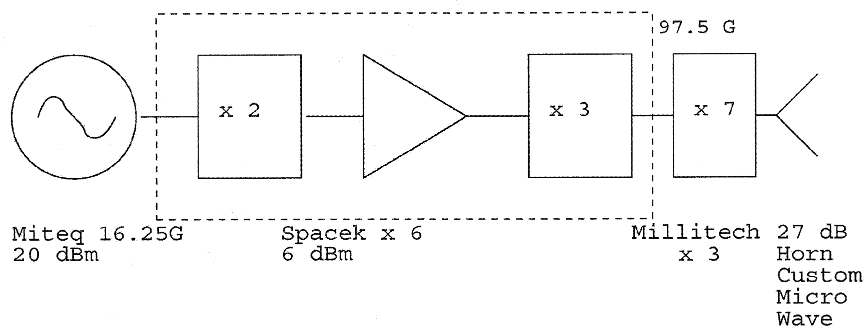

Figure 3: The block diagram for the 682.5 GHz singal source

use is 1 kHz. We require that the signal be detected at a signal-to-noise ratio of 40 dB. Based on our experience at 232.4 GHz, this will be adequate. Therefore, the required CW signal strength is $-107 + 40 = -67$ dBm. The beam coupling efficiency of a 6-m diameter antenna to a source at 220-m is -43 dB, when the antenna is focused on the source. We use a 2.5-mm square pyramidal horn with a gain of 27 dB. Therefore, the required output power of the transmitter is $-67 - 43 + 27 = -83$ dBm $\sim$ 10 pW. We conclude that 1 nW output power will be adequate with a big margin.

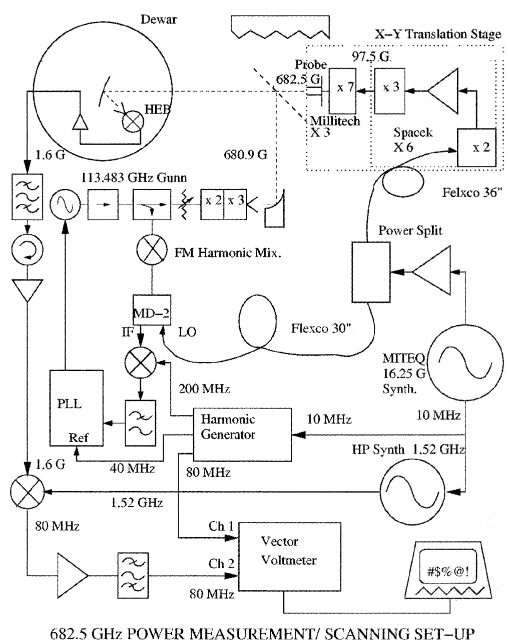

Figure 4: The system used for measuring the power output of the 682.5 GHz singal source

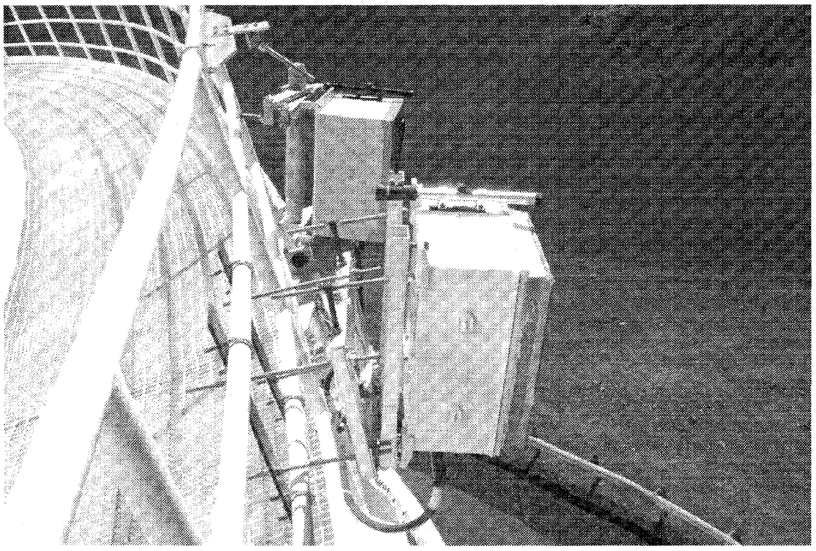

Figure 5: Test signal sources emitting phase-locked tones at 232.4 & 682.5 GHz, mounted on the cat-walk of the Subaru Telescope

Given the small power required, we use a scheme of multiplying up a phase-locked oscillator at 16.25 GHz, similar to the approach used for the 232.4 GHz signal source which has worked reliably for many years now. Such a source being simple, can be made compact and reliable and thus suitable for field use. In contrast, a Gunn oscillator based system, while providing more power, will be more cumbersome, requiring a PLL for the Gunn, and a somewhat stringent temperature control. As shown in Figure 3, a Miteq oscillator is multiplied up 6 times using a Spacek Labs active multiplier to produce 6 dBm at 97.5 GHz. This is used to pump a Millitech tripler. The tripler generates enough 7^{th} harmonic power output at 682.5 GHz which we use as our signal. In this scheme, a comb spaced 97.5 GHz is generated providing test tones at multiple SMA bands. A WR1.5 cut-off section at the horn input suppresses tones below 375 GHz. The 16.25 GHz synthesiser is tunable over the range 16.0-16.4 GHz, in steps of 50 MHz, allowing limited tunability of the final output. While this is not needed for the holographic measurements, it allows some flexibility in other tests of the Array. The square pyramidal horn used produces an elliptical beam with a horizontal major axis to optimally illuminate the central ring region of the Array, as seen projected from the signal-source. The source is locked to a 5 MHz internal crystal oscillator and has provision for an external reference input.

In order to measure the power output of the signal source, we use the system shown in Figure 4. It is based on the near-field scanning system of the CfA Reciever Laboratory used to characterise SMA recievers [3,4]. The test signal source, with an open waveguide probe replacing the pyramidal horn, is mounted on a translation platform which performs a 2-D raster scan in a plane perpendicular to the optical axis of a HEB reciever [5]. The LO for the HEB reciever and the test signal source are locked to the same reference which is also used to generate a reference signal for the vector volt-meter. The signal transmitted by the test source and recieved by the HEB receiver is down converted to feed the second channel of the vector volt-meter. Thus a map of the complex coupling between the probe and the reciever is measured. By integrating over this map, the coupling between the test-signal source and the reciever is estimated to be -30.6 dB, including the cosine profile across the probe aperture. The signal-to-noise ratio at the peak scanning position is measured to be 36 dB. Now, a calibration of the recieved power is carried out using the standard hot-cold Y-factor measuremnt. The derived $T_{RX,DSB}$ of 3000 K implies a noise floor power level of $2kTB = -130.8$ dBm with 1 kHz for B, the measured noise equivalent bandwidth of the vector volt-meter. With a peak signal-to-noise ratio

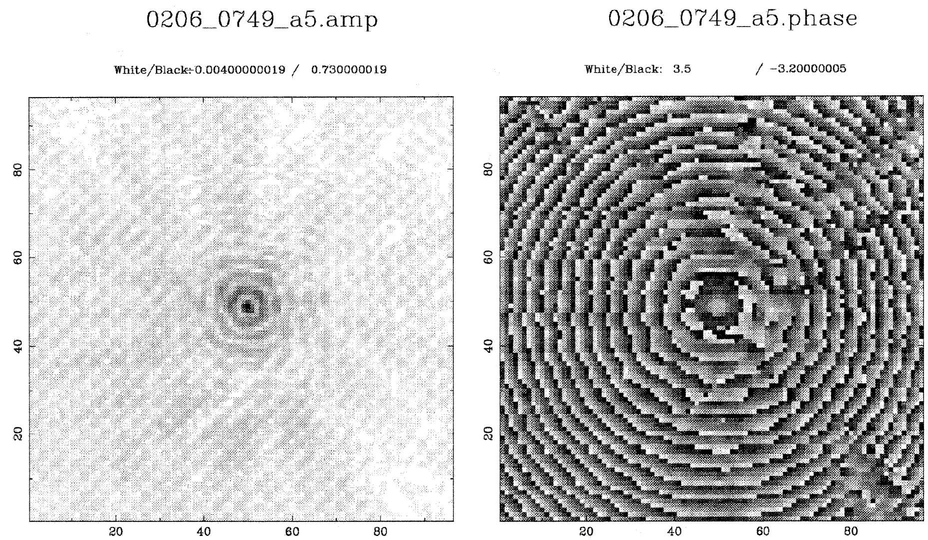

Figure 6: Beam domain amplitude and phase at 682.5 GHz obtained by raster scanning a 96×96 point grid, spaced 11″ and centered on the signal source.

of 36 dB, the CW power coupled is $-130.8 + 36 = -94.8$ dBm. Allowing for the probe-reciever coupling, the power *radiated* by CW test signal source is then $-94.8 + 30.6 = -64.2$ dBm $= 0.38$ nW. Based on our earlier calculations, this is sufficient. The method of power measurements we have used here has two

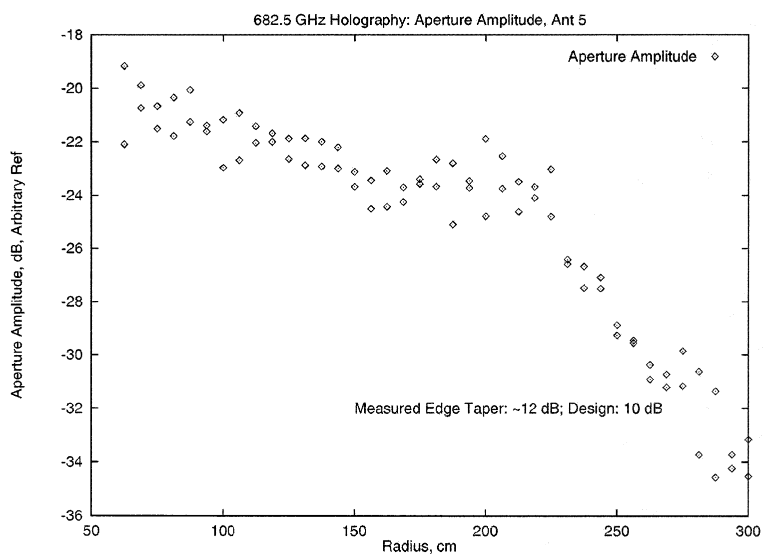

Figure 7: Measured radial illumination pattern for antenna 5. The aperture doamin amplitudes were averaged in azimuth to produce this plot.

advantages: (1) it can measure very low power levels, comparable to the thermal noise limit of the available recievers (2) it can measure the power in a single comb component as opposed to broad-band measurements.

PRELIMINARY RESULTS

We have built and installed a signal source of the above design on the cat-walk of the Subaru Telescope building, as shown in Figure 5. We have carried out preliminary antenna test measurements and the system is being curently debugged. Figure 6 shows complex beam domain maps made with this system. In the data we have so far, we are limited by phase fluctuations due to the atmosphere. Therefore, we are unable to derive surface error distributions or reliable illumination pattern after Fourier inversion. However, there is enough signal-to-noise ratio to measure the edge illumination as shown in Figure 7. Here, the amplitude in the aperture domain is plotted against the radial distance, after azimuthal averaging. This measurement suggests an edge taper of $\sim$ 12 dB to be compared with the design specification of 10 dB. These results show that we have a working system and after further debugging and tests under better weather conditions, we will be able to use the system to characterise the SMA high frequency antenna/reciever systems.

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