A proposal to use Pulsecal Amplitudes to Estimate Phase shift Variations due to Atmosphere

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ABSTRACT

Pulsecal amplitudes have high signal to noise ratio ($\gtrsim 30$ dB), and do not have problems of the total power measurements to represent the system temperature. Therefore its variations can be used to determine the system temperature changes (reasonably) accurately. If we now assume that the phase variations due to the atmosphere are related to the (atmospheric) opacity, then we should be able to estimate those variations from the system temperature changes using the pulsecal amplitudes. In this memo we suggest using this approach to estimate the phase variations introduced by the atmosphere. These estimates can then be used during data processing to correct for the phase variations due to the atmosphere. This will, for example, allow to increase coherent integration time in phase referencing observations.

INTRODUCTION

While tracking a radio source, the system temperature varies due to the antenna temperature changes caused by variations in the ground pickup and other spillover, and changes in the atmosphere. It is the atmospheric variations which affect the signal propagation (to a first order path length). This changes phase of the signal reaching an antenna. The phase variations due to the precipitable water vapor in the atmosphere can be estimated by the absorption in the atmosphere. Zivanovic (Zivanovic, S. 1993, Ph.D. Thesis, University of California, Berkeley) has successfully used system temperature changes to reduce phase variations in the BIMA telescope. She has developed theory relating the variations in the phase shift introduced by the changes in the atmosphere and the system temperature changes. She used total power measurements for estimating the system temperature changes. Total power measurements have generally large errors in representing the system temperature. On the other hand pulsecal amplitudes have good signal to noise ratio, and are not affected (to a first order) by the receiver gain variations etc. Therefore it should be possible to use these measurements to estimate variations in the system temperature accurately (VLBA Electronics Memo. No. 137). Hence, it should be possible for us to estimate the phase variations introduced by the atmosphere using variations in the pulsecal amplitudes. These estimates can then be applied during the data processing to correct for the phase variations. This approach assumes that the ground pickup and spillover etc. are either constant or can be modelled and accounted for, and to a first approximation this does not look like a bad assumption for reasonable elevations.

If one is observing two closeby sources (as in the case of the phase referencing observations), then the variations in the ground pickup and spillover should be similar for the two sources, and should vary smoothly with time/hour-angle. This should allow an easy way to remove the contributions due to the ground pickup/spillover from the target source (using variations on the reference source), allowing to correct for the phase variations due to the atmosphere. This should enable longer coherent integrations, especially in phase referencing observations.

METHODS TO ESTIMATE VARIATIONS IN T_{SYS}, AND THEIR LIMITATIONS

In principle any method which can estimate the system temperature variations can be used for estimating the path length changes. It should be possible to use the noise calibration system to determine the system temperature changes caused by the variations of the attenuation in the atmosphere, but its accuracy is limited. The total power measurements are flawed by the system gain variations caused by the temperature sensitivity of the receiver gain etc. The measurement accuracy of the switched power data is grossly inadequate for this purpose because the injected noisecal signal is only about 5% of the total power, and therefore all the measurement errors (compared with the total power measurements) get magnified by this ratio.

On the other hand pulsecal amplitude measurements generally have good signal to noise ratio, and they are not sensitive to the receiver gain changes. This is because the pulsecal amplitude measures ratio of the signal in a tone to the total receiver input over the baseband bandwidth. Also the stability of the amplitude of the injected pulsecal signal should be at least as good as the noise calibration signal (VLBA Electronics Memo. No. 137), if not better.

We may have a problem here. This is due to the receiver passband ripples changing with time. However this affect should get averaged out by combining results of pulsecal amplitude mesurements for various tones from all the Baseband Converters. Further, we should be able to correct for this affect by using the autocorrelation spectrum of the baseband signal which will be easilly available for the VLBA (due to the FX correlator).

In case of the 7 mm system, where correction for the variations in the signal phases are likely to be most needed, the pulsecal signal is injected (at present) at the first IF in the frontend. However there is only about 28 dB gain amplifier and a mixer before it, and the amplifier is inside the dewar. The amplifier will not experience all the temperature changes which other electronics is exposed to. Therefore this should not become a limitation. However, in case this becomes a limiting factor, it should be possible to build a pulsecal generator to inject the comb signal at the input of the RF amplifiers (low noise amplifiers in the dewar, as is done at other bands) at 43 GHz.

ACCURACY OF THE T_{sys} MEASUREMENTS AND THE PHASE SHIFT ESTIMATES

Currently we inject the pulsecal signal in the input of a receiver at about 1% of the system noise level. This gives (pulsecal detector) output signal to noise ratio of $\approx$ 30 dB for a single tone using one second integration and the baseband bandwidth of 1 MHz. This can be improved by increasing the integration ($\approx$10 seconds, assuming we want to sample atmospheric irregularities of the size of the (25 m diameter) antenna aperature, and wind velocity of $\lesssim$ a few m/s). Also we can combine the information from all the pulsecal detectors (we have total 16 pairs of detectors). This should further improve the signal to noise ratio by more than an order of magnitude. It means we should be able to measure the variations of $\leq 10^{-3}$ in the the system temperature. This will allow us to measure the variations of $\lesssim$0.05°K at 2 cm (assuming $T_{sys} = 50°$K), and $\lesssim$0.1°K at 1.3 cm and 7 mm (assuming $T_{sys} = 100°$K).

To get an idea of the extent to which we can correct variations in the phase shift introduced by the atmosphere, we will assume that we can estimate the the atmospheric attenuation induced system temperature variations to the accuracy allowed by the signal to noise ratio of the pulsecal amplitude measurements. For calculating the phase variations introduced, we assume that the path length L(cm)=6.5*V (Hogg, etal. 1981, A&A, 95, 304), where V is precipitable water vapor (PWV) expressed in cm. Schwab and Hogg (1989, MMA Memo. No. 58) have given plots of atmospheric opacity for different values of PWVs, and at various frequencies. These plots are quite crowded at frequencies below about 20 GHz (these plots were given for application at mm wavelengths), but we can use them to get an idea of the order of magnitude variations of the opacity for different values of the PWVs at frequencies below 20 GHz, and a reasonable estimtes of attenuations at frequencies above about 25 GHz. Using these plots, and assuming an effective radiation temperature of the atmosphere to be 260° K, we calculate rough values of the path length variations at different frequencies for various values of PWVs. For PWV changing from 3 mm to 4 mm, the path length varies by 6.5 mm, and the opacity changes by ≈0.001 Np at 15 GHz, and ≈0.002 Np at 25 and 43 GHz, where Np= Nepers. This causes atmospheric contribution to the system temperature of about 0.5°K at 15 GHz, and about 1°K at 25 GHz and 43 GHz. This gives estimates of the atmospheric path length variation accurate to ≈0.65 mm at 15, 25, and 43 GHz (—it is just a coincidence that we got the same value of 0.65 mm at all these frequencies). This is about 12°-35° of phase error. In general at frequencies below about 15 GHz the atmospheric attenuation is low, and therefore the contribution to the system temperature variations due to it are going to be somewhat smaller. But, as the system temperature values are also somewhat smaller than 50°K, and wavelengths are longer than 2 cm, therefore the estimates of the phase errors should not be much worse than this ($\lesssim$15°). Also, if necessary, we can afford to inject a little larger pulsecal signal in the input without affecting the receiver performance (sensitivity) appreciably.

SUGGESTED APPROACH

We can try this out by observing (1) a strong VLBI calibration source and correlating its phase changes with the pulsecal amplitude changes, and (2) some closeby VLBI calibration sources. Measurements of some of the the meteorological parameters (like surface temperature, pressure, humidity, etc.) will help in relating atmospheric attenuation changes to the path length variations.

Success of this approach to correct the phase of the signal reaching the antenna (to increase the coherent integration time in the phase referencing observations or any other experiment) depends on (1) how good are the estimates of the variations of the ground pickup and spillover etc., (2) how accurately are we estimating the atmospheric attenuation values from the system temperature measurements, and (3) how good is the representation of the path length variations by the atmospheric attenuation changes. We need to learn a lot to develop use of this approach. We have to learn how to account for the ground pickup/spillover. Also we need to develop relationship between the variation in the atmospheric attenuation and the path length introduced by it.

CONCLUSION

Using changes in the amplitudes of the pulsecal signal to correct the phase variations of the signal reaching an antenna, due to atmospheric path length changes, looks promising. A first guess suggests that we should be able to estimate the phase variations to an accuracy of ≈15°-35° at most cm and mm frequencies of our interest (used in VLBA) for reasonable elevations.

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