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VLA ELECTRONICS MEMO. 225

A PROPOSAL TO MONITOR T_{SYS} IN NEW K-BAND FRONTENDS FOR ESTIMATING ATMOSPHERIC PHASE VARIATIONS

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ABSTRACT

We propose adding system temperature monitoring in the new 18-26.5 GHz frontends being built for the VLA to measure atmospheric phase variations. We hope to get less than about third of a radian phase accuracy at 7 mm due to atmosphere using this. It will cost additional about $6k worth parts.

1. INTRODUCTION

During the recent VLA Test discussions (1995Sep18) Barry Clark suggested developing technique of estimating the atmospheric phase variations for the VLA high frequency observations using the system temperature measurements. Barry said that it will be quite useful even if one can get a radian phase accuracy over several minutes using this technique; then one can use selfcal to map weak sources. Mark Holdaway has been testing scheme of fast switching between observations of a target source and a nearby calibrator to correct for the atmospheric phase variations for the target source. But the VLA is not designed to switch observing rapidly from one source to another and also there is appreciable overhead in observing time requirements using this approach. Further we are building a couple of new k-band (18-26.5 GHz) receivers to replace the existing receivers and these are intended to be prototypes for the VLA Upgrade. Therefore it seems an appropriate time to consider adding some sort of monitoring for system temperature variations in these frontends to estimate atmospheric phase changes. Our basic requirement is to correct for relative atmospheric phase variations between different antennas with an accuracy of $\leq$ one radian at highest observing frequency over time scales of up to a few minutes (maximum integration period).

2. SUGGESTED SCHEME

The BIMA and OVRO groups are also developing techniques of estimating atmospheric phase variations using the system temperature measurements. The BIMA group uses system temperature variations at the observing frequency; they have tried to make measurements of the system temperature variations as accurately as possible. The OVRO group is building a system of three 2 GHz bandwidth filters centered at 19.2, 22.2 and 25.2 GHz to estimate the water vapor. We propose seperating 22 GHz line contribution to the system temperature by subtracting average of the continuum contributions at two frequencies, one on either side of the line, from the system temperature at the line frequency in a gain stabilized environment. A block diagram of the proposed monitoring scheme is shown in Figure 1. Similar to the OVRO system we propose monitoring system temperature at three frequencies of 19.7, 22.2 and 25 GHz in the frontend. Use of 1 GHz bandwidth for the filters is based on getting enough signal to noise ratio in each channel for 1 second integration and minimising chances of any radio frequency interference. Filter center frequencies are chosen such that the end filters are well seperated from the line but are still well within the passband of the system so the average of systematic variations at these frequencies cancel the systematic variations at the line frequency. Also it is desirable to have good gain stability for these channels in the frontend or atleast tracking of gain variations at all the three frequencies. Importance of monitoring at the three frequencies and maintaining gain stability will be clear from the following.

3. JUSTIFICATION FOR THE SUGGESTED SCHEME

Output of a receiver can be written as

$$P = T.G$$

On differentiating we get

$$\Delta P = \Delta T.G + T.\Delta G$$

The system temperature variation ΔT at any frequency can be expressed as sum of changes in the atmospheric contributions in the forward direction and variations in the pickup in sidelobes of the antenna beam (ϵ). The variations in the atmospheric contribution at any frequency are essentially due to changes in the continuum radiation from water vapor and liquid. In addition at 22 GHz there is line contribution due to the water vapor. The continuum contribution at a frequency f which causes v mm of delay due to water vapor and l mm of delay due to liquid water can be written as $0.35v(f_{(GHz)}/100)^2\ {}^\circ K$ and $270l(f_{(GHz)}/100)^2\ {}^\circ K$. The line contribution at 22.2 GHz is $0.27v\ {}^\circ K$. These values are taken from Colloquim Notes of David Woody at NRAO, Socorro on 94Mar17. Plotting the differential attenuation values at various PWV between 22 GHz and average of 19 and 25 GHz, using attenuation tables from Fred Schwab (private communication, also see Schwab and Hogg, MMA Memo. 58), gives linear dependence between excess temperature contribution at the line frequency and the water vapor. Also Liebe (1989, International J. Infrared and Millimeter Waves, 10, p631) gives f^2 dependence for the continuum contribution due to water vapor and liquid. This means the frequency dependence of the radiation due to vapor and liquid water in continuum and water vapor at the line frequency given by Woody look reasonable though the values of the constants may be somewhat uncertain.

Threfore we can now express variations in difference of the outputs at the three frequencies as measured quantity

$$\begin{aligned}
&(\Delta P_{f_0} - (\Delta P_{f_1} + \Delta P_{f_2})/2)/(K_1 G_0) = \\
&0.27\Delta v \\
&+0.35\Delta v[(f_0/100)^2 - (G_1/2G_0)(f_1/100)^2 - (G_2/2G_0)(f_2/100)^2] \\
&+270\Delta l[(f_0/100)^2 - (G_1/2G_0)(f_1/100)^2 - (G_2/2G_0)(f_2/100)^2] \\
&+[T_{f_0}(\Delta G_0/G_0) - T_{f_1}(\Delta G_1/2G_0) - T_{f_2}(\Delta G_2/2G_0)] \\
&+[\epsilon_{f_0} - (G_1/2G_0)\epsilon_{f_1} - (G_2/2G_0)\epsilon_{f_2}]
\end{aligned}$$

Here K_1 is proportionality constant to account for bandwidth, power units etc. f_0, f_1, and f_2 are used for effective frequency of 22.2, 19.7 and 25 GHz channels, and G_0, G_1, and G_2 are gains for these channels. The first term on right hand side is due to vapor line contribution, second term is due to vapor continuum, the third term is due to liquid continuum, the fourth term is due to gain variations and the fifth term is due to variations in sidelobe pickups etc.

One way for the measurements to represent water vapor variations will be to try to make each of the second to fifth term as close to zero as possible. From practical considerations this is likely to be achieved only if we make the receiver as flat as possible (gain and system temperature constant), make the gain variations as small as possible, and monitor the the system temperature variations at three frequencies such that the line frequency f_0 is located between f_1 and f_2 so that any changes at f_0 are average of changes at f_1 and f_2.

Also it is possible to assign a constant for the quantity in the square brackets in the second and third terms. The quantity in the fourth term can be approximated by product of a constant and temperature variations of the enclosure in which the electronics is located. The temperature variations can be measured and the values of the constants can be determined using observations of calibration sources and applied on the target sources.

If we assume that variations in the pickup term over the three frequencies is small or atleast difference of the pickup between different antennas is small, and use synchroneous detector outputs so that fourth term is negligible, then the difference of the synchroneous detector outputs can be expressed as

$$[\Delta V_0-(\Delta V_1+\Delta V_2)/2]K_2 = 0.27\Delta v+(0.35\Delta v+270\Delta l)[(f_0/100)^2-(G_1/2G_0)(f_1/100)^2-(G_2/2G_0)(f_2/100)^2]$$

Here $\Delta V_0, \Delta V_1$ and ΔV_2 are variations in the outputs of the synchroneous detectors at frequencies f_0, f_1 and f_2, and K_2 is a scaling constant. From this equation it is clear that the difference of the measured variations in the synchroneous detector outputs will represent the vapor term with accuracy depending on how small the second term can be made compared to the first term on the right hand side. This depends on how well the average continuum contribution (due to both vapor and liquid) of f_1 and f_2 cancells the continuum contributions at f_0. Filter bandwidth of 1 GHz and exject values for f_1 and f_2 do not seem critical and depend on circumstances like signal to noise ratio considerations, spillover variations with frequency and rfi. An overall accuracy of $0.1°K$ variations due to 22 GHz line contribution looks a reasonable goal.

4. CONCLUSION

We hope to achieve an overall accuracy of $0.1°K$ variations due to the 22 GHz line contribution. This should provide an accuracy of about 0.4 mm of delay for each antenna due to the atmosphere. It will give about third of a radian phase accuracy for 7 mm observations. Jack Campbell estimates that it will cost additional about $6k worth parts per antenna to implement this.

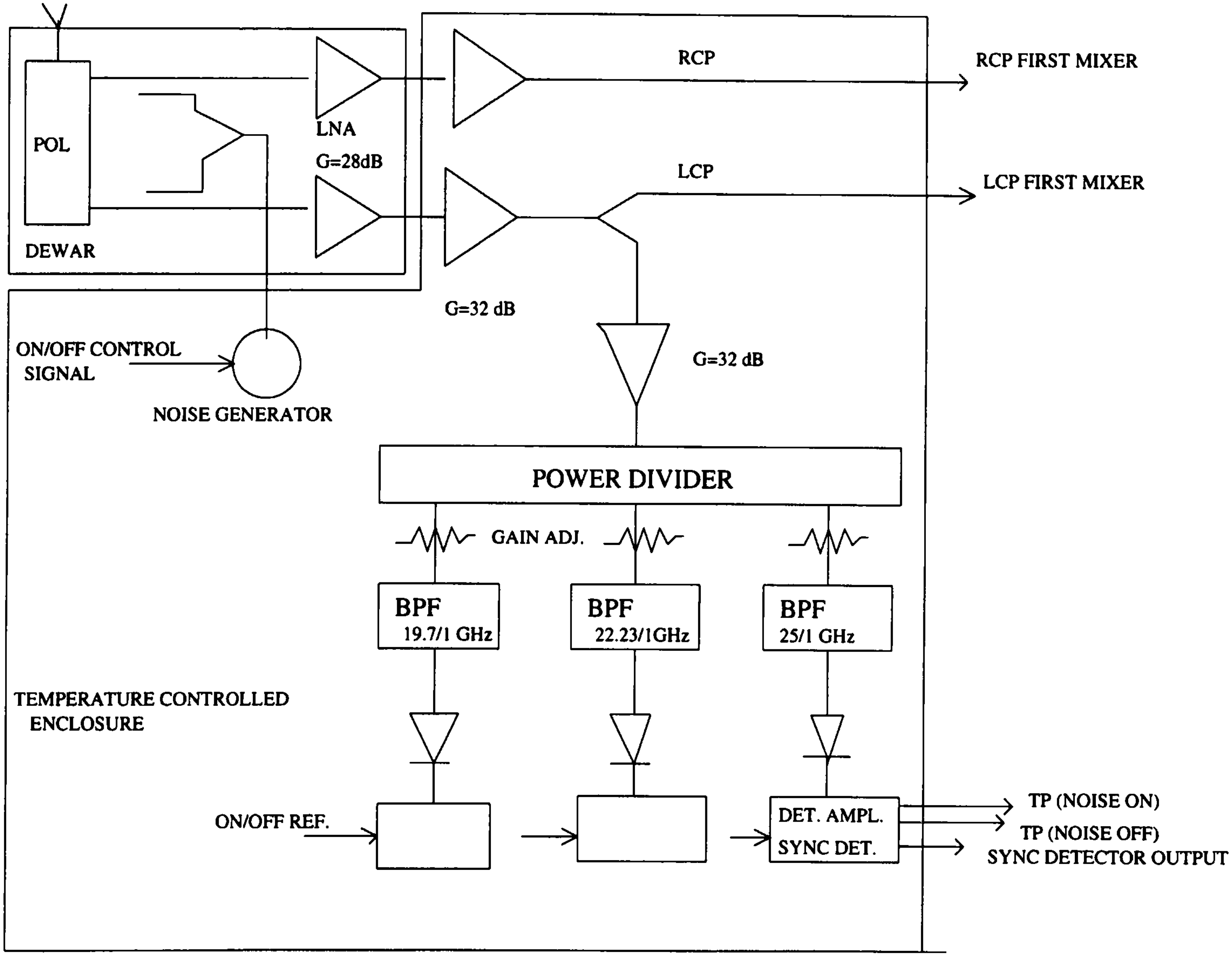

FIG. 1. PROPOSED SYSTEM TEMPERATURE MONITORING SCHEME IN 18-26.5 GHz FRONTEND FOR MEASURING ATMOSPHERIC PHASE VARIATIONS