EVLA MEMO # 74
A PROPOSAL TO DESIGN AND IMPLEMENT A COMPACT WATER VAPOUR RADIOMETER FOR THE EVLA

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SUMMARY

We present a proposed project plan for implementing a water vapour radiometer phase correction scheme for the EVLA. The plan comprises four phases: (i) the design and production of a prototype Compact Water Vapour Radiometer (CWVR) for testing the K-band RFI environment of EVLA antennas; (ii) an investigation of how to apply WVR corrections to astronomical data; (iii) the outfitting of all the EVLA (Phase I) antennas with CWVRs; (iv) the outfitting of the the EVLA (Phase II) antennas of the New Mexico Array with CWVRs.

1. INTRODUCTION

Recent tests of the two existing Water Vapour Radiometers (WVRs) on VLA antennas 26 and 28 show that we have successfully met our sensitivity and gain stability goals for these instruments, enabling the astronomical phase on baseline 26–28 to be significantly improved by applying corrections derived from fluctuations in the strength of the 22 GHz water vapour line (Chandler et al. 2004). These two instruments, however, were specially designed for the VLA rather than the EVLA. As a result, they are somewhat compromised in terms of the number of channels one would ideally like in order to be able to distinguish between liquid water and water vapour, and they also include an extra filter to reject LO power both from the K-band receiver itself, and from neighbouring frequency bands. For the EVLA the goal is to have a 5-channel system, rather than the current 3. However, the EVLA may also have other LO leakage/RFI problems for the WVRs not yet identified, so we propose to build a WVR to be installed on an EVLA antenna, with the aim of testing for possible RFI and determining whether new filters will be needed for WVRs on the EVLA.

In considering a design for a new WVR there are several advantages to basing it on MMIC technology. With many of the components located in an integrated multi-chip module (MCM) block there will be fewer connectors (a significant source of maintenance problems with the current instruments), they will be cheaper to manufacture in large numbers, and their smaller size will make it easier to maintain the stringent temperature stability that is currently achieved by having all the temperature-sensitive components mounted on a thermo-electrically cooled plate. The smaller intrinsic size also facilities the inclusion of all 5 channels, and makes it easier to fit the entire CWVR module into an antenna.

This document describes a project plan for designing and implementing the new "Compact Water Vapour Radiometer" (CWVR) for the EVLA. Section 2 summarizes the design concepts for the CWVR. The project is then described in Section 3, and is divided into four phases: Phase I is the production of a prototype CWVR for investigating the RFI environment of an EVLA antenna; Phase II comprises the development

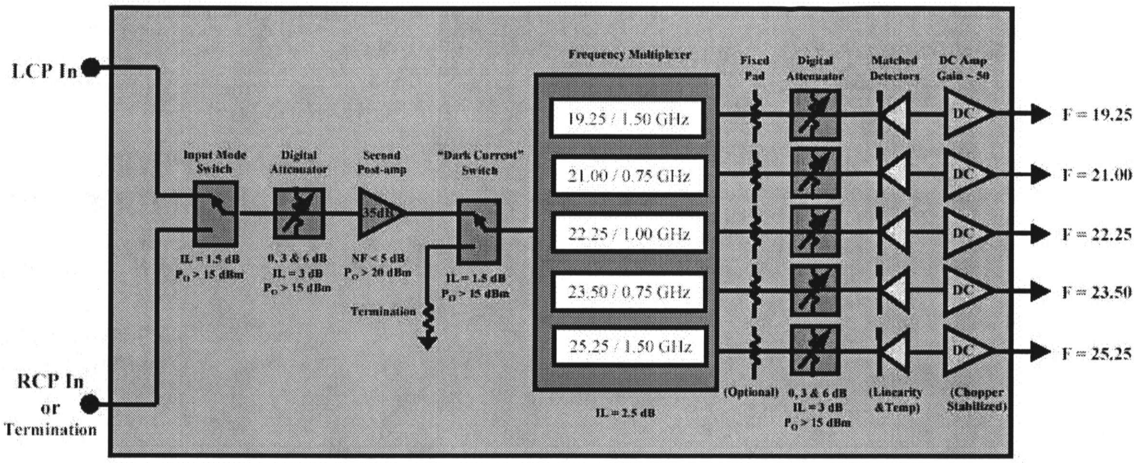

Figure 1: Design option 1 for the CWVR: the basic version.

work needed in order to have a method of applying WVR corrections to astronomical data; Phase III is the outfitting of the entire EVLA (Phase I) with CWVRs; Phase IV is the outfitting of the EVLA (Phase II) antennas of the New Mexico Array.

2. DESIGN OPTIONS FOR THE CWVR

Besides the basic differences between the current design and the CWVR design described above, the CWVR design also includes enhancements over the existing system: a "dark current" switch that allows DC offsets in the post-amps and detectors to be determined, and an input switch that allows either the selection of LCP or RCP input signals, or between the receiver and a termination (or noise source) for calibration. Three possibilities for the basic components to be included in the CWVR have been considered, and are shown in Figures 1 to 3. In summary, they are:

1. Basic version: includes an input switch that can be used to switch between LCP and RCP or to a load
2. Coupler version: also includes a 10 dB coupler as part of the CWVR followed by the input switch; has a digital attenuator on each input for gain balancing
3. Super-Compact version: also includes the first post-amp, the 10 dB coupler, and the input switch as part of the CWVR; ensures the best possible temperature stability of all active WVR components

The three possible CWVR versions above may then be implemented in one of three ways:

(a) Single channel: the CWVR is connected to only one polarization channel

(b) Multiplexed dual channel: the CWVR can select between either LCP or RCP using the input switch; the gain of the two receiver channels will have to be well matched for this to work

(c) Dual channel: CWVRs measure both LCP and RCP channels simultaneously, requiring two modules

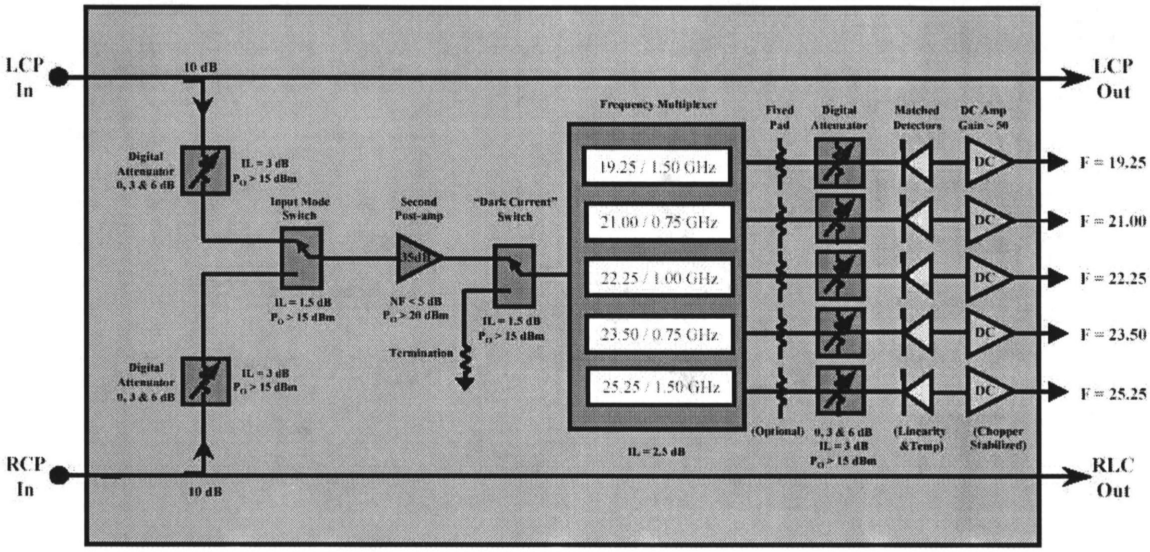

Figure 2: Design option 2 for the CWVR: the coupler version.

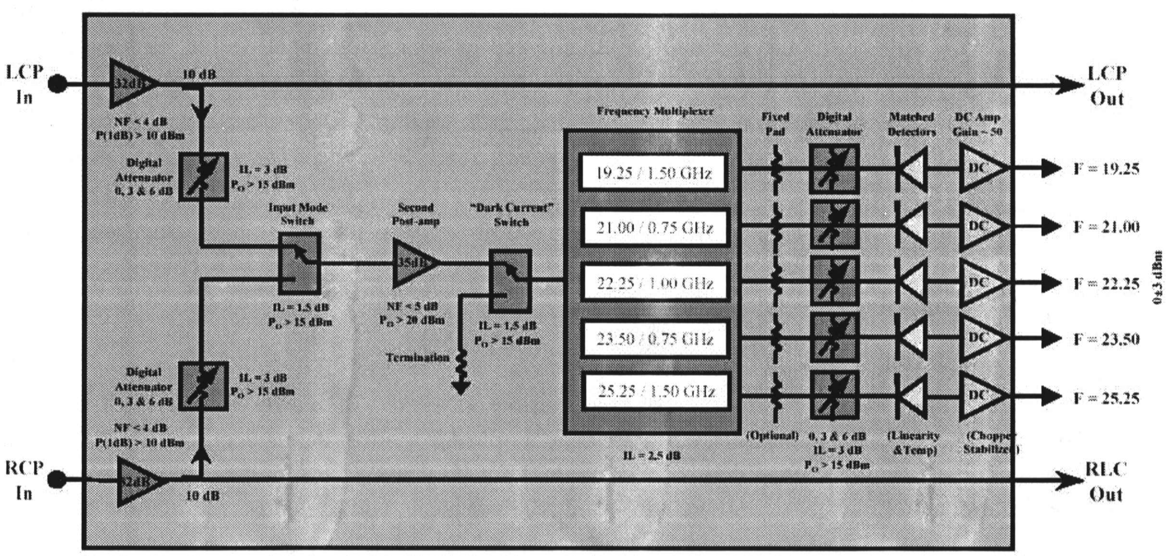

Figure 3: Design option 3 for the CWVR: the super-compact version.

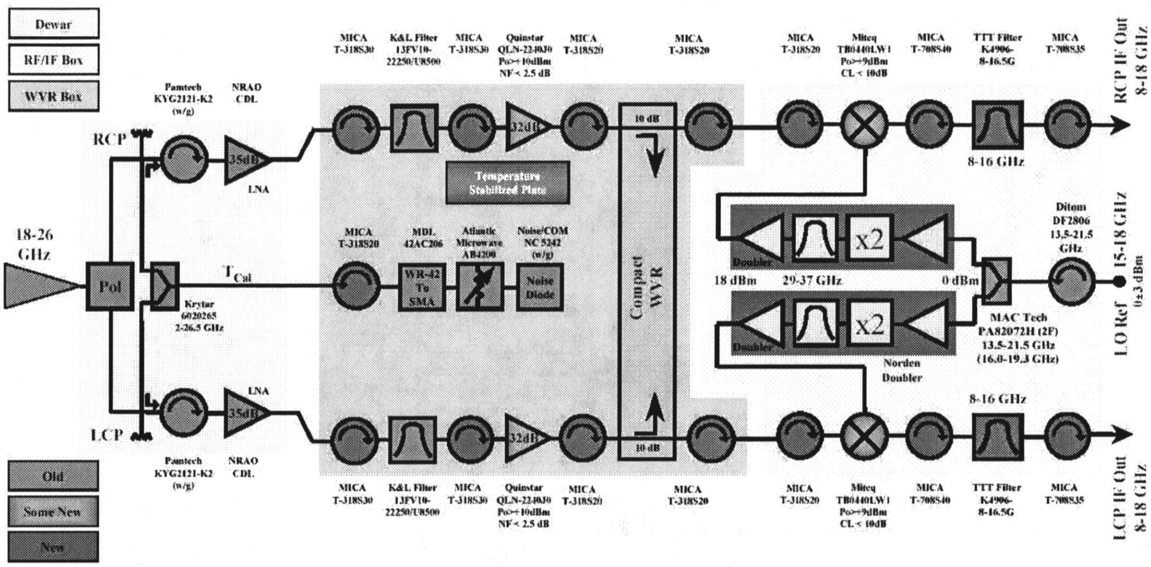

Figure 4: Example of a CWVR#2 implemented as a multiplexed dual-channel device on an EVLA K-band receiver, for illustration only.

3. THE CWVR PROJECT PLAN

Phase I: The Prototype CWVR

The prototype CWVR will be the basic version, implemented as a single channel device. Tables 1 and 2 summarize the resources required in order to build and test a prototype CWVR for an EVLA antenna.

Phase II: Application of WVR Corrections to Astronomical Data

In order to test a realistic implementation of WVR corrections applied to astronomical data we need at least 4 WVRs in order to be able to solve for closure relations for each of the 5 WVR channels on some timescale, and to demonstrate that the WVR corrections can consistently improve the dynamic range of images produced by the (E)VLA. The field tests of the prototype CWVR will establish whether its sensitivity is more determined by gain stability or thermal noise. Assuming that the tests of the prototype CWVR imply that no new design work is needed in terms of filtering out leaked LO power or other RFI, then we propose that three new CWVRs are built according to design option 2, with either one coupler (thermal noise limited) or two couplers (gain stability limited). An example of how a CWVR#2 might be implemented as a multiplexed dual-channel device for an EVLA K-band receiver is shown in Figure 4.

At this stage, further to the construction and installation of the CWVRs themselves, data calibration algorithms are needed. The development of WVR analysis software has, to date, been carried out by the scientific staff involved in the WVR project. With the new CWVR design having 5 channels it is anticipated that some investigation of atmospheric modelling may be required in order to separate the water liquid/vapour components. Furthermore, in order for WVR corrections to be applied to astronomical data to demonstrate improvements in image quality, some assistance will be required from either the AIPS or aips++ project. We have no preference as to which software should be used beyond the pragmatic consideration that the assessment of WVR corrections be achieved in a timely manner, and ultimately the ability to apply corrections based on WVR data should in any case be available in both packages if these tests are successful.

The resources needed to carry out this phase of the project are summarized in Tables 1 and 2.

Phase III: Outfitting the Entire EVLA (Phase I) with CWVRs

Here we assume that the above development of both the CWVRs hardware and the algorithms needed to enable corrections to be applied to the data have been successful, and that only one WVR per antenna (design option 2, as in Phase II) is required. The cost of this phase will be approximately doubled if two WVRs per antenna are needed. A total of 33 CWVRs are required in order to outfit all the EVLA (Phase I) antennas, with several spares, requiring 30 more CWVR#2 modules. The ability to apply WVR corrections to astronomical data will have to be implemented in all NRAO data reduction packages at this stage as well. The resources required to outfit the entire EVLA (Phase I) are summarized in Tables 1 and 2.

Phase IV: Outfitting the EVLA (Phase II) antennas of the New Mexico Array with CWVRs

Phase III can be extended to the antennas comprising the New Mexico Array by scaling most of the costs in a manner proportional to the number of extra antennas to be outfitted (10 plus 1 spare). It is expected that the field tests will take longer per module than for Phase III when travel to the various antenna sites is included. It is also expected that some further software and algorithm development may be required in order to implement WVR corrections on the long baselines of the New Mexico Array. The resources required to outfit the EVLA (Phase II) antennas with CWVRs are summarized in Tables 1 and 2.

4. TIMESCALE

The first three phases of the CWVR project are designed to fit into the current baseline plan for EVLA (Phase I). Assuming that parts can be ordered immediately the goal is to have Phase I completed by Q1, 2005. It is anticipated that Phase II will take place during 2005, and that Phase III will begin by the end of Q2, 2006. Assuming CWVR modules can be produced at a rate of 7 per year there will initially be a phase of retrofitting existing EVLA K-band receivers with CWVRs, but in Q3, 2008 the retrofitting will have caught up with the upgrading of VLA antennas, and the CWVRs can be installed as part of the standard EVLA antenna upgrades. CWVRs can be installed as part of the standard receiver suite for the antennas of the New Mexico Array beginning with the first new antenna, currently scheduled for Q3, 2009.

REFERENCES

Chandler, C. J., Brisken, W. F., Butler, B. J., Hayward, R. H., & Willoughby, B. E. 2004, EVLA Memo # 73

Table 1: Manpower requirements, in FTE.

Area Task/Suggested personnel	Phase I	Phase II	Phase III	Phase IV	Total
Design					
MCM module/Morgan	0.08	0.04	...	...	0.12
V to f/Willoughby	0.12	...	...	...	0.12
New packaging/Willoughby, Dinwiddie	0.06	...	...	...	0.06
MIB interface/Koski	0.12	...	...	...	0.12
Consultation/Hayward	0.01	0.01	...	...	0.02
Construction					
MCM fabrication/TBD	0.02	0.04	0.20	0.07	0.33
MCM chasis/machine shop	0.02	0.04	0.20	0.07	0.33
CWVR module/Willoughby, Hayward	0.12	0.36	1.80	0.66	2.94
CWVR housing/machine shop	0.02	0.06	0.60	0.25	0.93
Lab testing					
Module/Willoughby, Hayward	0.12	0.36	1.80	0.66	2.94
Performance/Brisken, Chandler	0.04	0.12	...	...	0.16
Field tests					
Installation and calibration/Willoughby	0.01	0.03	0.24	0.20	0.48
Performance/Chandler, Brisken, Butler	0.08	0.12	0.50	0.25	0.95
Software					
Algorithms/Chandler, Brisken, Butler	...	0.50	...	0.20	0.70
Implementation in AIPS, aips++/TBD	...	0.08	0.08	0.05	0.21
Totals	0.82	1.76	5.42	2.41	10.41

Table 2: Parts, costs are in $k.

Part	Phase I	Phase II	Phase III	Phase IV	Total
MCM parts	9.2	4.0	10.0	3.7	26.9
V to f plus fibre	0.5	1.5	15.0	5.5	22.5
Coupler	2.0	...	...	...	2.0
TEC[a]	1.1	3.3	33.0	12.1	49.5
Noise diode	1.8	...	...	...	1.8
Connectors, cables	1.5	4.5	45.0	16.5	67.5
MIBs	0.8	2.4	24.0	8.8	36.0
Xilinx chip[b]	0.5	1.5	15.0	5.5	22.5
Power supplies	0.2	0.6	6.0	2.2	9.0
Totals	17.6	17.8	148.0	54.3	237.7

Notes:

[a] cost includes a temperature controller, housing, and fans

[b] cost includes housing and printed circuit board