EVLA Project Book, Chapter 5.

5 RECEIVERS

Lilie, Mertely, Hayward, Szpindor, Latasa

Revision History
2001-July-01: Initial release.
2001-Oct-01: Sys-def & detail added.
2002-May-17: Consolidated
2003-Aug-18: Expanded Solar Info, receiver details

5.0 Receiver Parameters (Summary)

TABLE 5-1: EVLA RECEIVER PARAMETERS

Frequency (GHz)	1.2 - 2[1]	2 – 4	4 – 8	8 – 12	12 – 18	18 – 26	26 – 40	40 - 50
Band[2]	"L"	"S"	"C"	"X"	"Ku"	"K"	"Ka"	"Q"
Tsys (Kelvins)	21	27	28	31	37	55	58	78-106
Trcvr[3] (Kelvins)	10	13	13	18	24	31	40	47
Feed type[4]	compact	compact	compact	conical	conical	conical	conical	conical
Efficiency[5]	.50	.62	.60	.56	.54	.51	.39	.34
Location[6]	-84.1°	101.6°	165.2°	-156.3°	47.6°	25.9°	-16.9°	4.5°
Polarizer[7]	QR, hyb.	QR, hyb.	QR, hyb.	note[8]	PS,W-B	PS,W-B	PS,W-B	SS
L.O. Frequency	NA	NA	NA	NA	11 – 14	15 – 18	14.3 – 16.3	16.7 - 20
L.O. multiplier[9]	NA	NA	NA	NA	X 2	X 2	X 3	X 3
Frequency output	1 – 2	2 – 4	4 – 8	8 – 12	8 – 18	8 – 16	8 – 18	8 - 18
Power output[10] (dBm)	-32	-32	-32	-30	-36	-36	-36	-36
Output to module	T302	T302	T302	T304	T303	T303	T303	T303
Refrigerator model[11]	350	350	350	22	350	350	350	22
Details: **5.1.7.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

[1] 1 GHz is the nominal low end of this band, but full performance is specified only above 1.2
[2] These 60-year-old radar band designations are very obsolete, but handy.
[3] Average across full band.
[4] All feeds are corrugated horns.
[5] Total system efficiency.
[6] As seen from apex. Counterclockwise around the feed circle. 0° at right side of elevation axis.
[7] All dual circular polarization. "QR, hyb" means a Quad-Ridge OMT followed by a 90° hybrid. "PS, W-B" means a waveguide Phase Shifter followed by Wollack's implementation of a Bøifot class IIb OMT. "SS" means a Sloping Septum polarizer.
[8] Type will be decided following design studies. See 5.1.7.4
[9] The frequencies in the row above will be multiplied by this factor in the receiver.
[10] Total power contained in the output band specified, observing "cold sky".
[11] CTI Incorporated model numbers.

5.1 General: This section will cover those items common to all the receivers. Individual receivers will be discussed in the sections indicated in the "Details" row of table 5-1.

5.1.1 Cryogenics: The receiver upgrades will all be designed around the CTI model 350 refrigerator. The CTI Model 350 refrigerator was chosen over the CTI model 22 refrigerator for load and temperature stability, long-term maintenance cost and over all reliability. Two stages of cooling are provided by the 350 refrigerators the 1st stage at 50 K that will provide cooling for the thermal radiation shielding and 2nd stage15 K for the low-noise amplifiers. The heart of the cryogenic system is the piston type compressor that supplies helium gas to the refrigerator through a set of SS rigid and flexible helium lines. The three components mentioned 1; refrigerator, 2; compressor, and 3; helium lines make up what is commonly known as a closed-loop system. The compressor helium pressure typically (280/80 and as high as 300/100 psi) will be monitored by Dynisco pressure transducer Model PT 150 C 0/500 psi. Due to the number of receivers/refrigerators added by the EVLA upgrade, a third helium compressor CTI model 1020 R was required to meet the additional helium demand.

5.1.1.1 Vacuum: Vacuum pumps are required to evacuate the receivers (dewar or vacuum chamber) to 0.5 Torr in order for the cryogenic refrigerator to perform to its maximum efficiency. Receiver pump-down time is determined by vacuum pump rating, dewar volume and vacuum manifold size. Two vacuum pumps will be required for the EVLA receiver upgrade. The model number and rating of the two vacuum pumps to be used are; Alcatel model 2008 rated at 7 scfm (existing VLA vacuum pump) the second pump will be an Alcatel model 2010 rated at 14 scfm. The higher scfm pump will handle any additional receivers in the future. The vacuum manifold will be fabricated out of 1 ¼" stainless steel seamless tubing. The vacuum integrity will be maintained by incorporating a vacuum rated solenoid valve between the vacuum manifold and the receiver/dewar vacuum chamber. The vacuum pump will also incorporate a solenoid valve to bleed the vacuum manifold to atmosphere when all conditions are satisfied. The vacuum manifold and vacuum chamber will be monitored by Hasting Vacuum Thermocouples model DV-6m.

Each pump will connect to a vacuum manifold, which serves 4 receivers. 3/4" vacuum hose will be used to connect to the manifold. Each receiver controls a solenoid that can open the line between the vacuum manifold and the dewar. Each receiver can issue a "pump request" signal to the vacuum pump on its manifold. When no receivers are being pumped, a solenoid on the manifold is opened to atmosphere. The resulting pressure on the receiver's solenoid causes it to seat more firmly and reduces any tendency to leak. Control logic in the receiver controls the sequencing of pumps, solenoids, heaters, and refrigerators.

A Hastings DV-6m Tube monitors the vacuum of each receiver and manifold.

5.1.2 Noise calibration: Each receiver is provided with an injected noise signal equivalent to approximately 5% of the nominal system temperature for that band. This noise can be commanded on or off by the Monitor and Control system. During normal observing it is controlled by a 9.6 Hz square wave with 50% duty cycle. The noise for both LCP and RCP on any receiver is generated by a single source on that receiver.

5.1.3 Monitor and Control: Each receiver will have a set of ancillary electronics, traditionally called the "card cage", attached. This circuitry will control the state of the receiver, provide bias to the Low Noise Amplifiers, and provide preliminary signal conditioning for the monitor outputs. It will accept commands from, and output data to, the Monitor and Control system via the Monitor Interface Board (MIB).

The Monitor and Control system circuitry will be designed for ease of production with modern components.

The Monitor and Control system will report the following parameters:

Dewar Temperature: 15K, 50K stations and case (ambient) temperature.
Vacuum: Dewar, Manifold.
LNA FET biases: voltages and currents for each stage of each low noise amplifier.
Noise source parameters: voltage, current, and attenuator setting (if required).
Switch positions and gains for normal or solar observing.
RCP output total power.
LCP output total power.
Receiver ID: Band, Serial No., and Revision Level.

The Monitor and Control system can command the following actions:

Cool down, Warm up, Pump dewar, etc.
Set configuration for normal or solar observing.

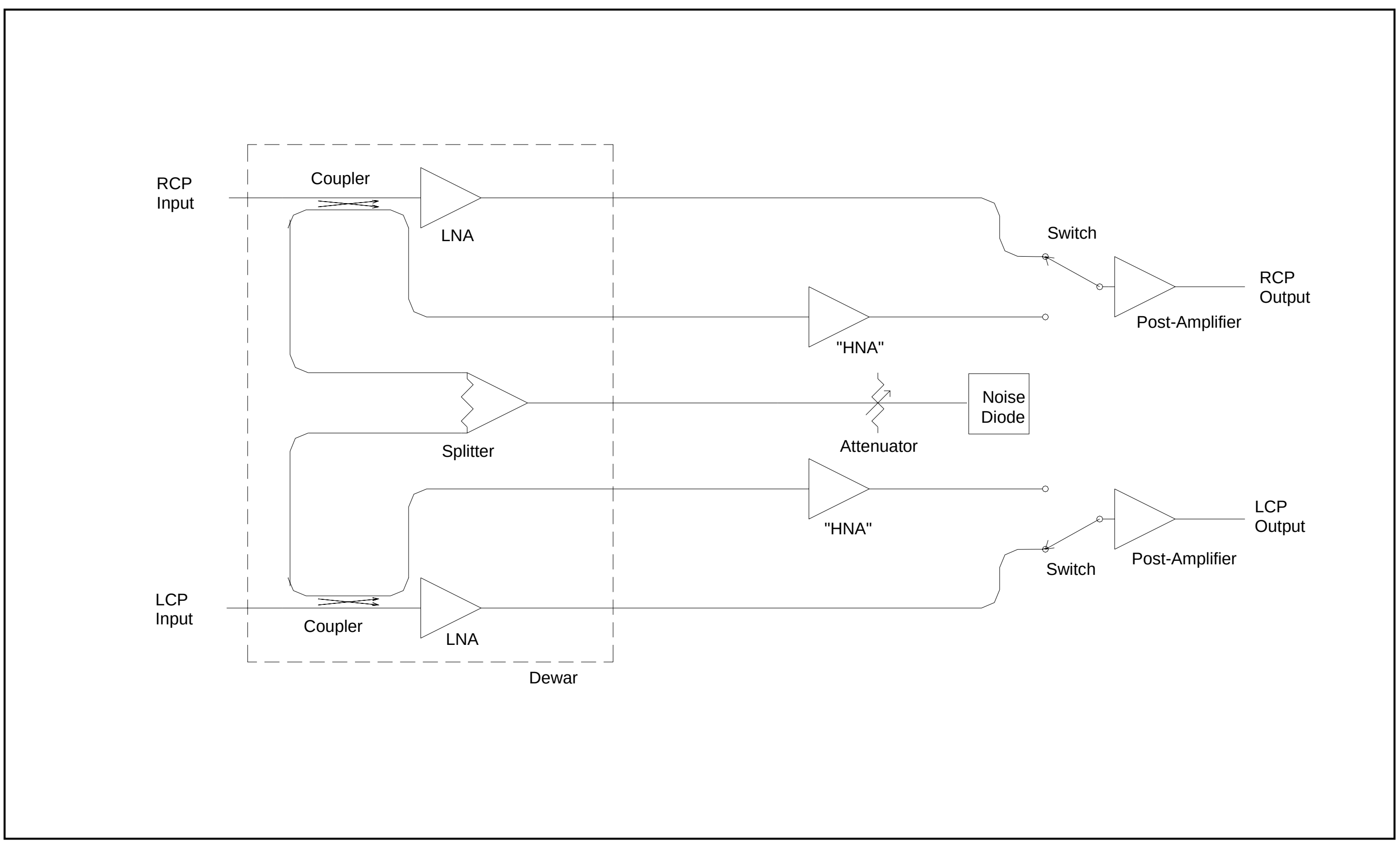
5.1.4 Solar Observing: To provide the maximum range of solar observation with minimum cost and degradation of normal observation, the so-called "coupler-fed" receiver configuration has been adopted.

In this scheme, a separate signal path is provided for observing the sun. A directional coupler before the Low Noise Amplifier (LNA) extracts a portion of the input signal and feeds it to a room-temperature amplifier which has high dynamic range (this amplifier has come to be called the "High Noise Amplifier"). A switch selects the output of either the LNA or HNA for transmission to the rest of the receiver system.

This scheme has minimal impact on normal observing since the coupler required is already in the receiver for noise calibration injection. Instead of the usual termination, the coupler's fourth port is connected to the input of the HNA by a length of transmission line.

Note that for normal observing, the source signal is fed directly into the LNA, while the noise calibration is injected through the (typically 30-dB) coupled line. For the HNA, the situation is reversed: the source signal is coupled in 30-dB down, while the noise calibration is fed in directly. This allows adequate noise calibration levels from a single noise diode without additional amplification. A settable attenuator will be required to adjust the noise calibration level across the very wide range of input powers envisioned.

Here is a simplified block diagram illustrating the coupler-fed scheme:



For source temperatures at the lower end of the solar range, the receiver temperature may not be negligible, and the assumption that all antennas have the same system temperature will not be valid. For this reason, each solar receiver will need its own solar noise calibration system. Since this consists mainly of the substitution of a controllable attenuator for a fixed one, the cost per receiver is small.

5.1.5 Polarizers: Below 8 GHz: These 3 bands will use a quad-ridge OMT and 90° hybrid. The OMT for 1 – 2 GHz has been designed and is being fabricated. OMTs for 2 – 4 and 4 – 8 GHz will be scaled from the 1 – 2 GHz design.

12 to 40 GHz: These 3 bands will use a corrugated waveguide phase shifter designed by Srikanth, followed by a Wollack's design of a Bøifot type IIb OMT. This has been done successfully at K-band on the VLA and designs for other bands will be scaled from this.

40 - 50 GHz: This band will continue to use the Atlantic Microwave sloping septum polarizer currently used on the VLA.

5.1.5 Requirements and specifications: These are listed in section 2.2 of this book.

5.1.6 Testing: The following parameters shall be recorded in easily-retrievable digital form before the receiver is installed:

Across the band:
- receiver temperature
- noise calibration values
- gain
- output power
- 1% compression (or 1 dB compression, if 1% is difficult to measure).

Frequency-independent:
- Cool-down from ambient, plot vs. time.
- Normal cold-stage temperatures and other cryogenic data as required.
- Current for each supply voltage.
- Complete set of monitor data.

Also record: Serial numbers and locations (e.g., RCP or LCP) of important components

All records to be dated and record the name of the person testing the receiver and the equipment used.

5.1.7 Receiver Details:

5.1.7.1 L-Band (1-2 GHz):

The EVLA requirement for the L-Band specifies optimum performance over the 1.2 – 2 GHz range with usable performance down to 1 GHz. The L-band feed has been designed to meet this requirement. The S- and C-band feeds, and the L-, S-, and C-band receivers, will be designed for operation over a full 2:1 bandwidth.

A new compact corrugated horn will replace the current lens-corrected L-band horn. It will be 13.5 feet long and 63 inches in aperture. It will take up nearly 90° of the feed circle and weigh about 625 lbs. The ring-loaded section, the mounting flange section, and the radome section will be machined from solid aluminum. The remaining corrugations will be formed by stacking "rings" and "bands" and coating the exterior with epoxy-fiberglass, as was done for the VLBA L-Band feeds.

New octave-band Quad-Ridge OMTs are being designed for use in the L-, S-, and C-band front ends. These will be used with commercial 3-dB, 90° hybrids for reception of left- and right-hand circular polarization.
The cooled Low-Noise Amplifiers (LNAs) will be new-generation designs from NRAO's Central Development Laboratories (CDL). Very good amplifier input impedance matching is necessary to meet the beam ellipticity specification. Since cryogenic isolators are unavailable at this frequency, balanced amplifier designs will be required.

The LNAs will be built as "gain blocks" with ~18 dB gain. Two cascaded gain blocks will be used per channel (for a total of 4 amplifiers in each dewar).

This configuration allows the possibility of adding cooled filters between the gain blocks at a later date to mitigate the effects of RFI.

Where possible, electronic and mechanical components from the current dewar will be reused in the EVLA design. As the new OMT is larger than the old design, an extension to the OMT mounting will be required.

The upgraded L-Band receivers will be built at a rate which matches the antenna upgrade schedule (i.e., 4 per year).

On the test antenna(s), L-band capability will be maintained by mounting old-design L-band receivers to the newly installed feeds with a simple adapter ring.

5.1.7.2 S-Band (2-4 GHz):

The S-band feed is a scaled version of the C-Band feed. It will be designed and fabricated using the band and ring technique used on the L-Band feed. The polarizer (combination of OMT and 90° hybrid) will be scaled from the L-Band design. Balanced amplifiers will be used.

Production of the new S-Band receivers is scheduled to begin in 2007.

5.1.7.3 C-Band (4-8 GHz):

The C-Band feed will also use the band and ring style of construction. The polarizer will consist of a quad-ridge OMT followed by a 90°hybrid coupler.

The receiver will use cryogenic isolators and LNAs from CDL based on their current 3-13 GHz design.

As receivers at this frequency and higher can be packaged in small, 10"-diameter dewars, packaging of C-band and the future X-, Ku-, and Ka-Band systems will use the same layout and components as much as practicable.

C-Band receivers will be built at a rate which matches the antenna upgrade schedule (i.e., 4 per year). This is essential since the existing C-band receiver can no longer be used after the upgrade of an antenna has begun.

5.1.7.4 X-Band (8-12 GHz):

The X-band receiver will be the last to begin production (currently scheduled for 2011). Until then the current X-Band systems will be retained, limiting coverage to 8.0 – 8.8 GHz. The existing feed and receiver will be remounted in the EVLA antenna feed circle.

A new module, the F320, will interface the existing X-band receiver and any other interim receivers to the new monitor and control system. This module will be phased out as new receivers come on line.

The X-band feed will be replaced by a new wide-band design.

The X-band receiver will not re-use the sloping-septum polarizer of the old receivers, as it is too narrow-band. However, the 1.5:1 bandwidth required is not so wide as to require a quad-ridge OMT (which would be difficult to fabricate at these frequencies). It is likely that we will use a version of the "planar" OMT design being developed at the Radio Astronomy Lab at Berkeley.

The receiver will use LNAs from CDL based on their current 8-18 GHz design.

5.1.7.5 Ku-Band (12-18 GHz):

The design of the new Ku-Band receiver will, to a large extent, be scaled from the K-Band receiver. It will require a newly designed linear-taper wide-band corrugated horn feed, which will be fabricated by precision CNC machining. The circular polarizer will be based on the Srikanth Phase-Shifter and Wollack OMT combination, as will K-and Ka-band polarizers.

The receiver will use LNAs from CDL based on their current 8-18 GHz design.

Production of the new Ku-Band receivers is not scheduled to start until 2006.

As is the case with C-band, the existing Ku-band receivers can no longer be used after an antenna upgrade has begun. In this case, no interim receivers will be provided.

New receivers should begin to come on-line in time to keep the number of Ku-band receivers on the array at 18 or more throughout the construction period.

5.1.7.6 K-Band (18-26 GHz):

The EVLA K-Band receiver will be an upgraded version of the existing VLA system. It will retain the current full-bandwidth feed horn, with modifications to improve the feed-receiver interface electrically and mechanically.

Early-generation LNAs will be replaced with newer, lower noise versions. Upgrading most of the LNAs with Cryo-3 devices in the first stage is a possible option, depending on the resources available at the CDL.

The most significant changes to the receiver are the implementation of the Block Converter scheme, which converts the entire 18-26 GHz RF band down to an 8-16 GHz IF (requiring replacement of the current mixers), and addition of a commercial frequency doubler to enable high-side LO injection.

The receiver bias, control, and monitoring circuitry (the “card cage”) will be replaced by more modern and more capable circuits.

Isolators will be added and components replaced as required to improve gain flatness and “headroom”.

The K-Band receiver modifications will be done at a rate which matches the antenna upgrade schedule (i.e., 4 per year).

5.1.7.7 Ka-Band (26-40 GHz):

The design of the new Ka-Band receiver will, to a large extent, be scaled from the K-Band receiver. It will require a new feed and its circular polarizer will be based on the Srikanth Phase-Shifter and Wollack OMT combination. These designs have already been tested at CDL and Green Bank with successful results.

The receiver will use MAP-style LNAs from CDL which are optimized for the 26-40 GHz band. The RF signal path out of the dewar will be in WR-28 waveguide, as will the calibration signal into the dewar.

The receiver will include a Block Converter which will mix a 10 GHz wide band of the 26-40 GHz RF range down to 8-18 GHz. It will be based on a custom MMIC design. This single module will include an active tripler for the 14.3-16.3 GHz LO reference, as well as a 26-40 GHz RF post-amp with 15 dB of gain and a wideband block conversion mixer followed by a 10 dB IF post-amp. This configuration is optimized for headroom and sensitivity.

Caltech has been contracted to design and build the two prototype units. Once their performance has been verified, NRAO will produce the Block Converter modules in-house.

The new Ka-Band receiver construction will be done at a rate which will match the four-per-year antenna upgrade schedule.

5.1.7.8 Q-Band (40-50 GHz):

The EVLA Q-Band receiver will be an upgraded version of the existing VLA system. It retains the current feed horn and there are no changes to the RF signal path within the dewar.

LNAs will be upgraded, including Cryo-3 devices, depending on the resources available at the CDL.

A 40-50 GHz amplifier will be added ahead of the mixer in each channel. This will improve the sensitivity of the receiver by 5-10°K.

This new RF amp will be based on a custom MMIC design. Caltech has been contracted to design and build two prototype units. Once their performance has been verified, NRAO will produce the amplifier modules in-house.

The Spacek mixers currently used in the receiver can accommodate the 40-50 GHz to 8-18 GHz Block Conversion scheme and will be retained in the EVLA system.

However, they fail to meet the 20 dB headroom specification by roughly 10 dB. A down-converter similar to the Ka-Band MMIC module is being designed which could be used to replace the Spacek mixers should the future RFI environment require increased dynamic range.

Other modifications include the addition of isolators and replacement of the old style Card Cage.

The Q-Band receiver modifications will be done at a rate which matches the antenna upgrade schedule (i.e., 4 per year).