ALMA Test Interferometer Project Book, Chapter 4

SYSTEM DESIGN

Larry D'Addario
Last revised 2000-Feb-23

4.1 General

A basic principle of the design is to follow closely the design of the array. Whenever possible, devices constructed for the test interferometer at the major subassembly level ("modules") should be prototypes of those that will be used in the array. There are necessarily some exceptions to this, either because the array design is not yet decided or because there is insufficient time to build the prototype before it is needed in the test interferometer. In the first case, we choose the design for the test interferometer that seems most likely to be chosen for the array; in the second case, an expedient substitute is used.

This section of the project book will describe each major subsystem of the test interferometer in turn, concentrating on the differences from the array design. Details that are identical to the present baseline design for the array will be covered by reference to the main ALMA Project Book.

Figure 1 is an overall block diagram of the test interferometer. We will refer to this often in the following discussion. Table 1 lists some major parameters.

Table 1: KEY PARAMETERS

	Test System	Array
Receiving bands		
#1	31.3-45 GHz HFET	31.3-45 GHz HFET
#3	85-110 GHz HFET 90-116 GHz SIS	89-116 GHz TBD
#6	211-270 GHz SIS	211-270 GHz SIS
Polarization	all: dual linear	all: dual linear
1st LO reference	laser synth, 28-110GHz	laser synth, 28-122GHz
1st LO source	YTO, GDOs	YTO, mult chain, pwr amp
IF band	#1: 4-12 GHz #3,6: 4-6 GHz	all: 4-12 GHz
IF channels	2/band (pol)	4/band (pol,sideband)
Baseband channels	2	8 (4 pol pairs)
2nd LOs	4	4 (each pol pair)
Baseband channel width	800 MHz 100 MHz	2000 MHz
Signal transmission	1 10Gb/s opt channel	12 10Gb/s opt channels
Correlator capacity		
Cross-correlation	512 chan, all pols	512 chan/BB * 8 @2GHz
Auto correlation	512 chan, 4 inputs	512 chan/BB * 8 @2GHz

4.2 Front Ends

The package containing input optics, RF stages with conversion to IF, vacuum dewar and cryogenics, along with associated bias supplies and controls, is known as an "evaluation receiver." This is to indicate that it is substantially different from the array receivers, and was originally intended only to allow evaluation of the antennas.

A basic difference from the array receiver is that only three of the 10 ALMA bands are supported, namely bands 1, 3, and 6 (see Table 1). On the other hand, two front ends are included for Band 3, an HFET version and an SIS version. This is to allow the HFET receiver to be fully evaluated at the relatively high frequency, and also because it is can provide the full

8 GHz of instantaneous bandwidth whereas the available SIS mixers cannot. The principal devices used to implement each front end are also different from those expected to be used in the array receivers, resulting in significant performance differences. The Band 1 assembly should be a true
prototype for the array, using optics, HFET amplifiers, and other components very close to those of the array. The other assemblies will be quite different. For Band 3, the HFET amplifier will likely not cover the upper end of the ALMA band; but it will extend lower in frequency, providing coverage of the important SiO line at 86 Ghz. The Band 3 SIS mixers will be single- ended with movable backshorts, unlike the fixed-tuned, balanced, sideband-separating mixers that are planned for the array. The Band 6 SIS mixers will be fixed tuned, but also single ended. The IF range of both bands' SIS mixers will be 4-6 GHz rather than the full 4-12 GHz of ALMA.

See chapter 6 of this book for further details.

4.3 Cryogenics

The evaluation receivers will include 3-stage cryocoolers that are copies of those used at NRAO. They include a commercial 2-stage GM refrigerator (CTI model 1020) and a Joule-Thomson expansion circuit whose design was developed at JPL, NRAO, and CSIRO in the 1970s. The helium compressor is based on commercial scroll pumps (Hitachi model 500RHH) and is integrated at the NRAO with the necessary oil cooling and separation equipment as well as control and monitoring electronics.

The cryocoolers for the array receivers are expected to be very different, but details are not yet known.

See chapter 6 of this book for further details.

4.4 Local oscillators

4.4.1 Central reference generation and transmission

Nearly all time-dependent functions in the array must be coherent with a single master oscillator from which reference signals are derived and distributed. For the array, this will be a hydrogen maser; for the test interferometer, the absolute frequency and stability of the master is less critical, and another type of oscillator (TBD) may be used.

As shown in Figure 4.1, we begin by generating from the master a set of fixed-frequency signals covering the range 20 Hz through 2.0 GHz. The Central Reference Generator assembly should be a prototype for the array, except that a reference at 100.0 MHz is needed for the Test Correlator clock and this frequency is not needed in the array.

A mm-wavelength reference is then synthesized for the first LO at each antenna. This process is identical to that planned for the array. It uses a microwave synthesizer to produce 8.6-10.5 GHz in 5 MHz steps (using primarily the 2 GHz and 5 MHz references from the master), followed by synthesis of 27-122 GHz as the difference between two laser-generated optical frequencies. The lasers are designated as "master" and "slave," with one master required for the array and one slave for each subarray. For the test interferometer, there is only one "subarray," but we choose to provide two slave lasers and two independent laser synthesizers so as to be able to operate the antennas independently and on different frequencies during single- dish testing (See Fig. 4.1, sheets 1 and 2). The two-frequency optical signal is sent to each antenna on a single-mode fiber. For each antenna separately, the optical signal passes through a line-length stabilizer based on two-way optical phase measurement of the master laser signal. For details, see section 7.3.2 of this book.

For the test interferometer, the mm reference range required is 27-110 GHz, but a minimum range of 27-122 GHz will be covered as the array prototype. In support of a possible direct-photonic LO system, tests of the synthesizer at much higher frequencies will be conducted. The 8.6-10.5 GHz microwave synthesizers for the array will use a custom design with careful attention to long-term phase stability and phase noise. However, for the test interferometer, commercial synthesizers may be used temporarily, so as to allow more time for development of the custom version.

Meanwhile, the 2 GHz reference is transmitted to each antenna as intensity modulation on the master laser carrier; and the 20 Hz and 25 MHz references are multiplexed and transmitted on a dedicated optical carrier (by a modulation method TBD), probably on a separate fiber. This also is identical to the baseline design for the array, and thus serves as a prototype.

At each antenna, the Reference Receiver assembly (Fig. 4.1, sheet 2) demodulates the 20 Hz, 25 MHz, and 2 GHz signals from their carriers; frequency-shifts the master laser carrier and transmits it back on the same fiber to the center for line length stabilization; produces additional fixed references at 100 MHz and 125 MHz; and distributes all the fixed references to various devices in the receiver cabin. Except for producing the 100 MHz reference (needed by the test interferometer digitizers and not needed for the array), this module is identical to the array baseline and serves as a prototype.

4.4.2 First LOs

At the antenna, the mm reference is recovered by photomixing and used to phase lock a mm wavelength VCO. The VCO is part of a "driver" module (Fig. 4.1, sheet 6), which must provide sufficient power to generate the required LO signals. In the array, five such drivers will be required to cover the necessary frequencies up to 122 GHz. In the test interferometer, three drivers are sufficient to cover bands 1, 3, and 6. The concept is the same in both cases, but the implementations of the drivers are quite different. For the array, they will consist of YTOs followed by one or more frequency doublers and power amplifiers. This allows the necessary range to be covered with electronic tuning only. For the test interferometer, two drivers will use fundamental Gunn diode oscillators; these require mechanical adjustment to cover the necessary ranges, and automated tuning hardware will be included. One driver, for 27.3-33 GHz, will use a YTO for both the test interferometer and the array.

The PLL is offset by approximately 31 MHz from the main reference, using a direct digital synthesizer. The offset reference includes fringe rotation and phase switching.

The driver modules are supported by a First LO Controller and PLL assembly (sheet 5), which may be combined in one module.

4.4.3 2nd LOs

The second conversion (IF to baseband) requires LOs at 6-10 GHz. See the discussion in 4.5 below regarding the channelization differences between the array and the test interferometer. The array requires four second-LO synthesizers to provide full tuning flexibility, but two per antenna are sufficient for the test interferometer with the addition of a transfer switch.

Each second-LO synthesizer is a prototype for the array. The design covers the range in 62.5 MHz steps, with the possibility of finely-adjustable offsets from the nominal frequencies of several MHz. The offset includes fringe rotation, sideband suppression, and phase switching capability. (See Fig. 4.1, sheet 7 and section 7.4 of this book.)

4.5 Downconversion

Each of the two 4-12 GHz IF bands (one per polarization in the test interferometer, vs. 4 at two per polarization in the array) can be converted to baseband using one or more of the four baseband channels provided by the Downconverter module (sheet 8 and section 8.1 of this book). The Downconverter is nearly identical to the array version, and serves as a prototype. However, the array will have two such modules, one for each polarization, while the test interferometer needs only one. Although there are four baseband channels, only two can be processed by the test correlator. The second LO scheme (with two synthesizers) allowsthe two active channels to be tuned independently in any configuration. There are two baseband channels that cover the lower half of the IF band (4-8 GHz) and two that cover the upper half (8-12 GHz). Each IF input (polarization) can drive one channel in any permutation, or one IF can drive any two channels.

The only difference between the array and test interferometer downconverters is in the baseband channel frequency range. This is 2-4 GHz for the array, and either 1.6-2.4 GHz or 1.6-1.7 GHz for the test interferometer. All three ranges can be supported within a single module design by replacing the bandpass filters that determine the output frequencies. For the test interferometer, we will (funds permitting) build two modules per antenna and install the 1.6-2.4 Ghz filters in one and the 1.6-1.7 GHz filters in the other; changing bandwidth can then be accomplished by swapping the plug-in modules.

4.6 Digitization and signal transmission

A major constraint on the test interferometer design is produced by the properties of the test correlator, which is a "clone" of the GBT/12m telescope spectrometers. This correlator handles two signal channels per antenna, each of maximum bandwidth 800 MHz, and it operates at a 100 MHz clock rate (see further discussion in 4.7 below). At the 800 MHz bandwidth, sampling at 1600 Msamp/sec with three-level quantization is required. To support this, digitizer
modules that are exact copies of those constructed for the GBT and 12m telescopes will be used. Each digitizer requires a 100 MHz clock (internally multiplies to 1600 MHz) and each sample is encoded into 2b and demultiplexed by 16x to provide 32 bitstreams at 100 Mb/sec.

The GBT digitizers were designed for bandpass sampling of 800-1600 MHz signals. In our system, this would make it very difficult to obtain reasonable image rejection in the Downconverter. Therefore, we plan bandpass sampling at 1600-2400 MHz, and the digitizers have been tested over this range and found to provide satisfactory performance.

All four baseband channels will be digitized. The digitizer designs already exist and are straightforward to duplicate, and it is easier to provide the 4:2 channel selection digitally.

The two selected channels will be transmitted digitally to the center. This requires a total capacity of 6.4 Gb/sec, which fits within a single 10 Gb/sec optical channel of the type planned for the array. (The array antennas will require 8-12 of these channels.) In order to make the optical channel a prototype for the array, which uses 125 Mb/sec fully-demultiplexed bitstreams, the 100 Mb/sec streams will be converted to 125 Mb/sec by inserting a dummy bit for each 4 data bits. Every 5 of the rate-converted streams will be multiplexed by 5 to produce 16 streams of 625 Mb/sec each, and these will be further multiplexed to 10 Gb/sec for modulation onto the optical carrier. At the center, a receiving system reverses these steps to recover the original 64 bitstreams of 100 Mb/sec each.

For further details, see section 8.2 of this book.

4.7 Correlation

As mentioned above, the test correlator is a clone of the GBT/12m spectrometers. Its principal parameters are listed in Figure 1. The four input channels (2 per antenna) can be fully cross correlated (four cross-spectra, including cross-polarization products) or each can be autocorrelated (four spectra), but not both simultaneously. At 800 MHz bandwidth, 512 cross-correlation frequency channels are obtained. It also supports a 100 MHz bandwidth mode in which every 8th sample is processed and the other are ignored; this produces 8x as many channels or 1/64 the frequency resolution. Support of this mode is the reason for having a Downconverter version with 100 MHz bandwidth. For autocorrelation, the number of channels is doubled at either bandwidth.

For further details, see section 9 of this book.

4.8 Additional facilities

Although not shown in Figure 4.1, each test interferometer antenna will also be equipped with a nutating subreflector, for which the electro-mechanical drive mechanism and controls will be provided by NRAO. There will also be a holography system for operation at 94 GHz, consisting of a prime-focus front end that can be mounted in place of the subreflector; a cross- correlating back end; and a CW transmitter mounted on a tower. The holography system is further described in section 5 of this book.

4.9 **Device List**

Table 2 lists the various major assemblies required to construct the test interferometer. Most of them have been mentioned above, and others are covered in the appropriate sections of this book. For each, we give the quantity needed and the status with respect to prototyping for the array.

Table 2: TEST INTERFEROMETER -- DEVICES NEEDED

	Ea.ant	Total	Status	Notes
Rcvr#1 31.7-45 GHz	1	2	P	
Rcvr#3s 90-116 GHz	1	2	x	
Rcvr#3h 85-110 GHz	1	2	P	includes downconv w/ 26 GHz PLO
Rcvr#6 211-285 Ghz	1	2	x	includes LO tripler
Rcvr M/C & bias modules	4?	8?	P	one for each receiver (?)
Receiver assembly	1	2	x	dewar and cryogenics; packaging
Driver A 27-33 GHz	1	2	s	based on YTO; includes photodet
Driver B 75-96 GHz	1	2	x	based on GDO; includes photodet
Driver C 95-110 GHz	1	2	x	based on GDO; includes photodet
1st LO controller	1	2	s	includes PLL1
Ref receiver (ant)	1	2	s	both hiref and lowref
IF select switch	1	2	s	
Downconverter	1	2	P	includes input 2x4 matrix sw
2nd LO synthesizer	4	8	P	
Fringe rot. controller	1	2	P	
Digitizers	4	8	x	2-3 GHz in, 1.6GHz sampling
Rate converter (up)	1	2	x	100 Mb/s to 125 Mb/s x 64
Formatters 10Gb/s	1	2	P	Mux and sync
Opt xmtr/rcvr pairs	1	2	P	10 Gb/s
Deformatters	1	2	P	Demux and sync
Rate converter (dn)	1	2	x	125 Mb/s to 100 Mb/s x 64
Digital filters	none			-
Test correlator	1		x	100 MHz clock
Ref generator (central)	1		s	
2-laser synthesizer	1		P	Includes 2nd ref, excludes EDFAs
8.6-10.5/.005G synth	1		P	Input to laser syn; temporary COTS
Line length corrector	1	2	P	
Low ref xmtr	1		P	
Power supplies, various	?	?	P	
Antenna bus driver	1	2	P	processor and software
Central computer	1		P	computer and software
Computer communications	1	2	P	central-to-antenna hardware
Subreflector controller	1	2	P	focus tracking; optional nutation
Holography system	1		P	FE, back end, xmtr
Antenna instrumentation	1	2	x	thermometers, tilt meters, etc.

Status column legend:
P = prototype of array design
s = similar to or subset of array design, but modified
x = temporary throw-away; for test interferometer only