EVLA Project Book, Chapter 6

6 LO / IF SYSTEMS

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2001 -July-20: Initial Release
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2002-July-15: Added Phase stability specs
2002-Sept-17: Updated UX converter specs
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Deleted 4096 synthesizer
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DDS specs, Switch specs, T304 specs, Vswr specs on
Converters.
2004-Dec-08: Major revision Updated UX, LSC, 4P specifications, Changed
L305 driver specs. Added equalizer to T304. Deleted L301, L302
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2006-Mar-23: Major revisions. Added LO fiber requirements.Updated
Converter input power, head room and gain. Revised Reference
Generator frequencies. Added L300. Moved sections on sampler
To chapter 7.

Summary

*This chapter describes the LO/IF system for the Expanded Very Large Array (EVLA) Project. The requirements and specifications are presented for each part of the LO/IF system***.** *Transition issues for making antennas with new electronics hardware compatible with antennas that have existing hardware is also discussed.*

6.1 Introduction

The Very Large Array (VLA) was designed and built more than 20 years ago and since that time the need for a more sensitive instrument has arisen. The scientific requirements for a more sensitive instrument coupled with aging electronic equipment has lead to the much needed Expanded Very Large Array (EVLA) project. The EVLA project is designed to increase the overall system bandwidth by a factor of 80 and replace antiquated electronics with a new state of the art electronic system. The waveguide system will be replaced with a fiber optic system. The fiber optic system will transmit LOs to the antennas and receive digitized IFs from the antennas. The EVLA will contain new synthesizers, reference generators, and IF converters, which are described in this document.

6.2 Specifications and Requirements

The specification and requirements for the LO/IF system are contained in this document. General specifications that apply to every piece of the system are contained in the first few paragraphs while the more specific requirements for each module are shown in paragraphs particular to that module. As a general rule, all specifications will be equal to or better than the specifications for the current VLA system.

6.3 Environmental

The nominal temperature of each bin/rack will be within the range of +18 to +22 °C and will not vary more than ± 1 °C from nominal in any given 24 Hr period; additionally, the average slope of the temperature gradient shall not exceed 0.25 °C/(30 min). All equipment will be designed to meet all specifications over a temperature range of +10 to +30 °C, at an altitude of 12,000 ft., and humidity level ranging from 0 to 95%.

6.4 General Module Interface

Each module in the LO/IF system shall use SMA type connectors for all RF ports on the back panel. Any RF ports on the front panel shall be either BNC or SMA type depending upon the frequency range. BNC twinax connectors shall be used for all critical differential signals.

Each module shall use a 50 pin D type connector for all DC and low frequency connections.

6.5 LO Phase Stability

These specifications do not include phase instability induced by the antenna structure or the atmosphere. These specifications do include any instability induced in the front end by the LO system. These specifications have been divided up by systems engineering as follows: one-third to the front end, one-third to the T304 downconverter, and one-third to the 4P, LSC, and UX converter combination.

A) Short Term:

The rms phase jitter over any 1 second interval is to be less than 500 fs.

B) Long Term:

The slope of the phase over any 30 minute interval is to be less than 200 fs/minute. The pk-pk fluctuations of the phase about this slope are to be less than 1400 fs.

C) Phase Shift with pointing change:

Less than 700 fs between any two directions accessible with the antennas.

Less than 70 fs per degree of antenna motion for slews of less than ten degrees.

These specifications apply after correction using round trip phase data.

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Phase noise is defined as phase instability outside an offset of 1 Hz from the frequency of concern. Phase drift is defined as phase instability within an offset 1 Hz from the frequency of concern.

6.5.1 LO Phase Noise Allocation

The phase noise allocation is shown in Table 6.5.1. For each of the components shown, the phase noise is obtained by integrating the power spectral density over the appropriate bandwidth. The phase noise specification is determined by the type of component and its location.

Table 6.5.1 Phase Noise Allocation

Component	Specification (fs)	Notes
Reference	200 max	1 to 10 Hz offset
Fiber distribution system	TBD	
12 to 20 GHz LO	100 max	integrated from the loop band width to 10 MHz
10.8 to 14.8 GHz LO	100 max	integrated from the loop band width to 10 MHz
Antenna Reference Generator	230 max	Integrated from 10 Hz to the 1st LO PLL cutoff

6.5.2 Phase Drift Allocation

Table 6.5.2 is a attempt to allocate the phase noise specification to various components of the system. It is likely that some of the components will be better than these allocations and some will be worse.

Table 6.5.2 Phase Drift Allocation

Component	Drift	Notes
Round trip phase correction loop	0.36° @512MHz	over a thirty minute period
4.096 GHz LO	0.0013° /min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
12 to 20 GHz LO	0.0013°/min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
10.8 to 14.8 GHz LO	0.0013° /min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
Master LO Generator/distributor	TBD° @4GHz	
LO Transmitter system	TBD matched to ± TBD	Since all LO transmitters see the same temperature variation the phase drift as a function of temperature will be matched.
Antenna Reference Generator	TBD° @4GHz	
IF cables/switches	0.0013° /min/GHz/°C	
IF down/up converters	0.0013° /min/GHz	For a maximum average temperature slope of 0.25°C/(30 min) per converter, does not include drift introduced by the LO

6.6 Fringe Tracking, Phase Switching, Sideband Suppression

Fringe rotation is required due a sinusoidal component introduced in the system caused by the rotation of the earth. This frequency is usually called the natural fringe frequency. The fringe frequencies are dependant upon baselines and observed frequencies. The fringe frequency can be canceled by introducing a continuous phase shift or frequency offset into one of the LOs used for down conversion. The fringe rotation will be removed using a direct digital synthesizer and its requirements are shown in Table 6.6. The calculations were based on equations derived by A. R. Thompson in EM #124.

Fringe rotation will take place in the correlator. However for the transition period from the old system to the new system, fringe rotation will be required at the antenna.

The second LO is required to support fringe rotation and 180d phase switching for the transition period. The phase switching is required to suppress spurious signals and d.c. offsets between the baseband downconverter and the samplers. The hardware required to support 180d phase switching will also support 90d phase switching if needed for sideband suppression during the transition period.

Table 6.6 Fringe Generator Requirements

Item	Frequency range (min)	Frequency accuracy	Phase shift increment	update time	notes
Fringe Generator (Internal to the 1st and 2nd LO synthesizer)	±(0 to 5 KHz)	1 part in 10^6	1°	.46sec max	1

Notes: 1. Calculations are based on 86 GHz front ends and a “Los Alamos” baseline.

6.7 RFI

RFI emissions for all LO/IF equipment shall meet the requirements set forth in EVLA Memo 46.

6.8 Mechanical

All LO/IF modules shall be compatible with existing BIN hardware currently in use at the VLA.

6.8.1 General Module Monitor Requirements

All analog monitor points within each module, unless otherwise stated, will be implemented using serial peripheral interface SPI bus technology. Each command word sent, will be echoed back from the module it was sent to, if possible.

6.9 Central Reference System

The central reference system (CRS) will take a signal from one of two reference standards and either divide or multiply this signal to generate various reference signals required by each antenna. The signals will be distributed to each antenna's central fiber optic transmitting system through a central reference generator and distribution system. The primary reference standard will be a hydrogen maser and the secondary or backup reference standard will be a rubidium oscillator. The CRS in addition to generating reference frequencies will also track long term drift of the reference standards via a GPS receiver. System timing will be accomplished using a Central Reference Generator L350 and will be distributed to each antenna's central fiber optic transmitting system. There will be a backup CRS rack to duplicate critical functions. The power for each CRS rack and the reference standards will be backed up with batteries. All critical functions of the CRS and the reference standards will be monitored by the online system.

6.9.1 Frequency Standards

There will be two frequency standards. The primary standard will be a hydrogen maser and the secondary or backup standard will be a rubidium oscillator. The principal performance requirements for the maser are shown in Table 6.9.1a while the rubidium requirements are shown in Table 6.9.1b. These standards will be purchased from external vendors.

Table 6.9.1a Principal performance requirements of the H-maser

Item	**Requirement**	**Notes**
LO-Ref max frequency error	1 part in 10^{12} averaged over 10 sec	
Wide-band phase noise at 5 MHz	1.4 psec RMS	see 6.5
Allan Variance	1<t<1000secs 2E-13t $^{-3/5}$ 1000<t<10,000secs 3E-15	

Table 6.9.1b Principal performance requirements of the Rubidium Oscillator

Item	**Requirement**	**Notes**
LO-Ref max frequency error	1 part in 10^{12} averaged over 10 sec	
Wide-band phase noise at 5 MHz	1.4 psec RMS	
Allan Variance	1 sec <5E-12 10 sec <1.6E-12 100 sec <5E-13 1000 sec <5E-13	

6.9.2 Timing Generator (deleted)

6.9.3 GPS Receiver

The GPS receiver will be purchased from an external vendor. The receiver will serve as the UTC time reference for the array. All clocks can be synchronized to the GPS, so that on a long term basis, the time at the array can be known within 10 nsec.

The GPS receiver will have a built-in or external time interval counter with a computer interface that will provide time offset and slope for the data analysts.

6.9.4 LO Reference Generator L350

The LO reference generator takes the reference standard frequency and multiplies it to the frequencies shown in Table 6.9.4. The specific requirements for each frequency is also shown in this table.

The L350 generates a Time Code Output that is sent via optical fiber to the WIDAR Correlator. The Time Code is a 128 Mbps LVPECL signal that is encoded with a 1PPS and a 1 pulse per minute.

The L350 generates a .1PPS that is used by the L353 . This pulse is the divider reset pulse and is modulated onto the 512 MHz LO sent to the antenna. The pulse can be disabled at the antenna. The pulse has a width of 31.25 ns and a rise time of less than 2 ns.

Table 6.9.4 Reference Generator Frequencies

Frequency MHz	Power Level dBm ±1 dB	Harmonically Related spurious signals dBc	Non-Harmonically Related spurious signals dBc	Phase noise ps integrated from 1 Hz to 10 MHz unless otherwise noted	location	Notes
19.2 Hz	RS485 diff	N/A	N/A	N/A	reference output	switchable after transition
.1Hz	LVDS diff	N/A	N/A	N/A	reference output	to L355
128 Hz	LVDS diff	N/A	N/A	N/A	reference output	to L355
5.12	LVDS diff	N/A	N/A	N/A	reference output	to L355
128	+10	35	45	0.4	LO ref gen output	to Widar correlator
256	+3	50	50	0.6	LO ref gen output	to L351
512	+7	40	40	0.7	LO ref gen output	to L354 for dist

6.9.5 LO Ref Distributor L354

The LO reference distributor shall take the reference signals of the LO reference generator and amplify them. These signals will then be divided either internally or externally and sent to the central fiber optic transmitter system of each antenna. The specific requirements for output frequencies are shown in Table 6.9.4.

6.9.6 Fiber Optic Reference Distribution System

This section addresses the requirements for the distribution of the LO references over the fiber optic link. This includes the measurement of the round trip phase. This part of the LO reference distribution system consists of four modules, the LO Offset Generator (L351) the Round Trip Phase Receiver (L352), the Central LO Transmitter (L353)), and the Antenna LO Transmit/Receiver (L304). This system modulates a 512MHz sinusoidal signal onto the LO transmit-fiber. then Part of this signal is coupled off at the antenna, cleaned up, and distributed as the antenna reference signal. the remainder of the signal is returned on the LO-receive-fiber and mixed with a 512MHz sinusoid that has been offset by 128Hz. The resulting 128Hz is then compared to the central 128Hz to complete the measurement of the residual round trip phase.

The specifications and requirements for the LO reference distribution system are linked to the stability requirements for the over all LO system as presented in 6.5. Calculations of the predicted fiber stability with temperature are presented in EVLA Memo 10. Fiber temperature stability has improved due to advances in manufacturing and is now around 2ppm/degree C. Based on calculations, the overall temperature stability of the fiber buried at one meter will be about 0.5fs/s @ 512MHz. In 6.5 short-term stability is 0.5ps/s @ 100GHz which translates to 2.5fs/s @ 512MHz. The long-term stability requirements of 1.6ps per 30min will require round trip phase measurement. The electronics will dominate the LO reference instability and careful design will be required to compensate.

A round trip phase measurement will be taken once every ten seconds. The correlator can apply this corrected phase measurement to the data. Since the correlator runs up to 0.25 seconds behind real time, the corrected phase measurement will be time-stamped.

6.9.6.1 Master Offset Generator L351

The LO Offset Generator generates a sinusoidal signal at a frequency of 512.000128MHz by way of Direct Digital Synthesis (DDS). Driven by a 256MHz sinusoidal clock, the DDS produces a 64.000016MHz signal that is multiplied by 8, resulting in the offset LO reference signal. The requirements of the LO Offset Generator are shown in Table 6.9.6.1

Table 6.9.6.1 LO Offset Generator Requirements

Frequency	Power Level dBm	Harmonically related spurious signals dBc	Non-Harmonically Related spurious signals dBc	Phase noise ps	Notes
256 MHz	0dBm	-50	-50	0.6	input
512MHz + 128Hz	+8dBm	-70	-70	1.0	output

6.9.6.2 Round Trip Phase Receiver L352

The Round Trip Phase Receiver mixes the offset 512MHz with the non-offset 512MHz received back from the antenna. The resulting mixer product, after filtering, is a 128Hz sinusoidal signal that has been phase-shifted by the fiber path. This 128Hz signal is converted to a square wave and combined with the non-phase shifted 128Hz square wave in a DFT. The phase angle of the signal is calculated in the MIB by taking the inverse tangent of the quotient of the resulting sine and cosine terms. The input signal requirements to the Round Trip Phase Receiver are shown in Table 6.9.6.2.

Table 6.9.6.2 Round Trip Phase Receiver Requirements

Frequency	Power Level	Notes
128 Hz	LVDS	Square Wave
5.12 MHz	LVDS	Square Wave
512 MHz	-2 dBm	Output to L353
512 MHz + 128 Hz	0 dBm	Input from L351

6.9.6.3 Central LO Transmitter (L353)

The Central LO Transmitter/Receiver modulates a 0.1pps, 7.8125ns long pulse onto the 512MHz LO reference signal. This signal is modulated onto the LO-transmit-fiber. Additionally, this module performs a rough, “analog” version of the round trip phase measurement, by combining the local 512MHz LO reference with the round-trip 512MHz reference received from the L352, in a phase comparator. This provides a continuous measure of the phase of the round-trip signal, including noise to which the DFT-based round trip phase measurement of the L352 is insensitive.

6.9.6.4 Antenna LO Transmitter/Receiver (L304)

The Antenna LO Transmitter/Receiver receives LO signals sent from the central control building on the LO-transmit-fiber. A portion (5%) of the fiber signal is coupled off, demodulated, and passed to the LO Reference Generator/Distributor, where they are separated, processed, and distributed to various LO modules within the antenna. The remainder of the fiber signal is returned to the central LO racks to complete the loop for the round trip phase measurement system.

6.10 12-20 GHz LO System

6.10.1 12-20 GHz Synthesizer L301

The 12-20 GHz synthesizer provides the LO signals for the first down conversion. There will be two 12-20 GHz synthesizers in each antenna . One synthesizer is switched to one of the high frequency front ends for block down conversion or it is switched to an up converter for the low frequency front ends. The second 12-20 GHz synthesizer is switched to the UX downconverter or it is switched to the same up converter for the low frequency front ends as the first 12-20 GHz synthesizer. In the high frequency front ends, where necessary, the synthesizer frequency is either doubled or tripled. While in the UX downconverter, the LO is always doubled. The exception is that both synthesizers are used in the UX downconverter for Ku band. The synthesizer is YIG based and designed for low noise, phase coherent operation**.** See 6.14.3.2 for an explanation of the UX down converter.

The synthesizer has the following performance specifications:

Output Frequency tuning	11904-20096 MHz in 256MHz steps	
Output Power	+11dBm Nominal and Adjustable	
Output Spurious signal level	<-70 dBc except for harmonics of ref	
Output harmonics of Ref	<-80 dBc	
Phase Noise	-107 dBc/Hz @100KHz offset and -90 dBc/Hz @ 10KHz offset @20GHz output frequency Which corresponds to a phase noise of <100fs	
Harmonics	<-40 dBc	
Output VSWR	<2:1	
RF port impedances	50 ohm	
Lock time	1 sec max between any two frequencies	
Supply voltages	Voltage	Current
	+17.5	2.5 amps max
	-17.5	0.5 amps max
	+7.5	2 amps max
	-7.5	0.5 amps max
Power Dissipation	75 watts max	
Monitor Points	Synthesizer freq 1MHz Resolution Synthesizer output power Lock condition FM tuning voltage Main coil voltage Power supply voltages of +/-15v, +/-5v 2 Module Temperatures AGC Voltage	
Synthesizer out to ref in isolation	<-40 dBc	
Rear Panel connections	512MHz Comb@-30 dBm min per line VSWR @ 1.2 to 1 Max freq range 128 MHz Ref in; noise of ref: <100 fs Synthesizer out DB-50 Connector with MIB interface and supply voltages	

Front panel requirements	None

6.11 10.8-14.8 LO System

6.11.1 10.8-14.8 Synthesizer L302

The 10.8-14.8 synthesizer provides the last tunable LO for down conversion of the astronomical data before digitization occurs. This is a dual YIG based synthesizer designed for low noise, phase coherent operation**.** This synthesizer will have two integral direct digital synthesizers (DDS) to provide fine tuning for fringe rotation and phase switching. There will be four 10.8-14.8 synthesizers in each antenna.

The synthesizer has the following performance specifications:

Output Frequency	10.8 to 14.8 GHz nominal	
Output Frequency Steps	Sub milliHertz	
Output Power	+13 dBm Nominal Adjustable	
Output Spurious signal level	<-70 dBc except for harmonics of ref	
Output harmonics of Ref	<-80 dBc	
Phase Noise	-108dBc @100KHz offset and -87dBc@10KHz offset @15 GHz output frequency	
	Which corresponds to a phase noise of <100fs	
Harmonics	<-40 dBc	
Output VSWR	<2:1	
RF port impedances	50 ohm	
Lock time	1 sec max between any two frequencies	
Supply voltages	Voltage	Current
	+17.5	2.5 amps max
	-17.5	0.5 amps max
	+7.5	3 amps max
	-7.5	0.5 amps max
Power Dissipation	75 watts max	
Monitor Points	Synthesizer freq 1MHz Resolution	
	Synthesizer output power	
	Direct Digital synthesizer 1 Freq	
	Direct Digital synthesizer 2 Freq	
	Lock condition	
	Main loop; course and FM control voltage	
	Control loop; course and FM control voltage	
	Power supply voltages of +/-15v, +/-5v	
	Ref Ground	
	2 Module temperatures	
Synthesizer out to ref in isolation	<-40 dBc	
Rear Panel connections	19.2 Hz in: with <TBD ns of Jitter on risingEdge	
	DB-50 Connector with MIB interface and supply voltages	
	128 MHz Ref in: noise of ref: <100fs	

	2 Synthesizer outputs 128MHz Comb@-30 dBm min per line VSWR @ 1.2 to 1 Max freq range
Front panel requirements	None
DDS outputs	1 to 22 MHz and 22 to 42 MHz Noise: >-140dBc @100KHz

6.11.2 Fringe Generator

The fringe generator uses direct digital synthesis techniques to achieve its high frequency and phase resolution. The device is based on the Analog Devices AD9852 DDS integrated circuit. The AD9852 provides the infrastructure to obtain very sophisticated control over its output. Below is a short discussion of the features of the device that apply to the fringe generator.

The DDS contains a 48 bit digital phase accumulator which is truncated to 17 bits. This 17 bit phase word is then converted to a 12 bit sine function which drives a high speed Digital to Analog Converter (DAC). There is a programmable 48 bit frequency accumulator. At each system clock cycle, 256MHz in this application, the frequency accumulator contents are added to the phase accumulator. The result is that any frequency between DC and half the clock frequency can be generated to a resolution of sub micro hertz. In the fringe generator the lower frequency limit is established at about 8 MHz by the output coupling transformer.

There is a programmable 48 bit delta frequency word register. At each system clock cycle, the contents of this register are added to the frequency accumulator. This results in an FM chirp signal.

The DDS contains a programmable 14 bit phase offset register. The contents of this register are added to the contents of the 48 bit phase accumulator before conversion to the sign function. This register is used to produce the ± pi/2 and ±pi/4 phase switching needed in the LO system.

This phase accumulator can be reset to zero on command. This, along with the two programmable frequency control registers, allow the approximation of any desired phase profile function modeled by a polynomial with up to two coefficients in the hardware. Along with the 14 bit phase offset word, an arbitrary initial condition can be obtained with up to fourteen bit resolution. Movement to a new function with different coefficients can be accomplished in a single system clock cycle. The primary limitations are the time required for the micro controller to load the required parameters into the DDS registers and the settling time of other components in the LO synthesizer.

The DDS uses a serial interface protocol to load it’s internal registers under control of an FPGA. When all I/O registers are loaded, an I/O update pulse is issued to the DDS to cause all data in the I/O registers to be loaded to the DDS active core on a single system clock edge. There is a system pipeline delay of 17 clock cycles, from the first clock edge after the I/O update, until the time these parameters take effect. They all take effect immediately on that clock edge.

Except for the case of a reset to the DDS, the output is always phase continuous, i.e., the phase of the start of a new phase function begins where the previous one was at the time the new parameters take effect. This defines the phase offset register contents as part of the desired phase function.

The output of the DDS is a zero order hold sampled sine wave at the programmed frequency and phase.

All system timing events within the VLA are synchronized to a 52 millisecond fiducial which is distributed throughout the array. The DDS uses this signal to synchronize its activities with the rest of the array. There is a large Field Programmable Gate Array (FPGA) in the fringe generator which derives the necessary timing signals from the 52ms tick and the system clock. This FPGA contains a set of counters and state decoding logic to derive the I/O update signal for the DDS to keep all parts of the fringe generator synchronized. This FPGA is a Xilinx Spartan series XC2S30.

The board uses the SPI protocol to interface to the MIB. The SPI signals are routed through the FPGA to the DDS chip and additional synchronizer logic is implemented in the FPGA.

<u>External Connections</u>
1. 5VDC power, .5amp nominal
2. Power return. Connected to case
3. 128 MHz clock input, sine wave, terminated with 50 ohms.
4. 52 ms reference LVDS, terminated with 100 ohms.
5. Output, 50 ohm impedance, +0 dBm
6. Interface bus

6.11.3 LO Switches

There will be a set of three 12 to 20 GHz synthesizer select switches. These switches are used to select which front end and/or the UX Converter receives the 12 to 20 GHz LO. These switches are specified in Table 6.11.3. The switches will be controlled through a DCS interface module.

Table 6.11.3 12 to 20 GHz LO Switch Specifications

Item	Specification	Notes
Frequency Range	12 to 20GHz	
VSWR	2.0 to 1 Max	
Insertion Loss	4 dB Max	
Isolation	50 dB min	
Input impedance	50 Ohm nominal	
Actuating Voltage	28 V	
Actuating Current	300 ma max	
Switching Time	15 ms max	
# poles	1	Per switch
#throws	4	Per switch
RF connection	SMA	
Power Connector	Circular PT06E-14-18S-SR	

6.12 Antenna Reference System

6.12.1 LO Reference Generator/Dist. L305

The LO reference generator/dist. takes the reference frequencies which were transmitted on the fiber link and cleans them up where necessary. The Reference Generator/Dist also multiplies or divides the reference frequencies from the fiber link to frequencies required by the antenna LO system. These frequencies are shown in Table 6.12.1. The specific requirements for each frequency are also shown in this table.

The L305 generates a Time Code Output that is sent over optical fiber to the DTS/Sampler modules. The Time Code is a 128 Mbs LVPECL signal that is encoded with a 52 millisec signal.

The L305 is equipped to detect a divider reset pulse that is transmitted from the L353 module and is modulated onto the 512MHz LO sent optically to the antenna. The pulse is used to reset all of the dividers in the L305.

Table 6.12.1 Antenna Reference Generator Frequencies

Frequency MHz	Power Level dBm ±1 dB	Harmonically Related spurious signals dBc	Non-Harmonically Related spurious signals dBc	Phase noise degree rms to 10 MHz offset	location	Notes

9.6 Hz	TTL	N/A	N/A	N/A	Ant LO ref gen output	optically transmitted
19.2 Hz	LVDS	N/A	N/A	N/A	Ant LO ref gen output	To L302 switchable after transition
19.2 Hz	RS422	N/A	N/A	N/A	Ant LO ref gen output	MIB Distr switchable after transition
19.2 Hz	TTL	N/A	N/A	N/A	Ant LO ref gen output	optically transmitted
128	+6	25	40	0.025	Ant LO ref gen output	3 out to 4-way splitter
512	+3	25	50	0.058	Ant LO ref gen output	to L300

6.12.2 LO Reference Receiver L304

The LO Reference Receiver L304 is part of the fiber optic system and is described in chapter 7 paragraph 7.5 of the project book.

6.12.3 Reference Harmonic Generator L300

The L300 module provides comb lines for all the LO synthesizers as well as the 1.024 GHz, 2.048 GHz, and 4.096 GHz LO’s and clocks,derived from the 512 MHz harmonic generator. The L300 is supplied with 128 and 512 MHz to produce 4 outputs of 128 MHz comb lines between 10 and 15 GHz, 2 outputs of 512 MHz comb lines between 12 and 20 GHz. 128 MHz is supplied to the harmonic generator at a nominal 0 dBm. The harmonic generator produces output up to at least 14.976 GHz at the specified power level. 512 MHz is supplied to the harmonic generator at a nominal 0 dBm. The harmonic generator produces outputs up to at least 19.968 GHz at the specified power level. The specifications for the L300 are shown in Table 6.12.3. These specifications apply for normal operating conditions.

Table 6.12.3 Reference Harmonic Generator Specifications

ITEM	SPECIFICATION	NOTES
Input frequencies	128 MHz @0dBm +3 -0 dBm 512 MHz @0dBm +3 -0 dBm	from L305
VSWR 512 MHz Input	1.6 to 1 Max	with power on

VSWR 128 MHz Input	1.6 to 1 Max	with power on
Isolation from 128MHz to 512MHz	50 dB Min	
Isolation between 512MHz comb outputs	15 dB Min	
Isolation between any 128 MHz comb outputs	15 dB Min	
Isolation between 512MHz comb and 128 MHz comb	50 dB Min	
Isolation between 2048MHz and 4096MHz outputs	50 dB Min	
Isolation between 1024MHz and 4096MHz outputs	50 dB Min	
Isolation between 1024MHz and 2048MHz outputs	50 dB Min	
Isolation between 4096 MHz and 4096 MHz	50 dB Min	T304 LO to DTS module Clock
OUTPUT VSWR to L301	1.7 to 1 Max	with power on
OUTPUT VSWR (all outputs exc. L301)	1.4 to 1 Max	with power on
Output Frequency	512MHz comb 10.572 to14.976GHz 128MHZ comb 11.776 to 19.968GHz	
512MHz comb power	-28 to -15 dBm	
128 MHZ comb power	-28 to -15 dBm	
High Pass Filters	3 dB point shall be between 8 and 8.5GHz	
DC Combined Power	25 W Max	
Phase matching between like comb outputs	±45 degs Max	for each line of the same frequency
Phase stability	.0013°/min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
Spurious signals	-75 dBm Max	on any output
1024 MHz Output Power	0.5 ± .5 dBm	
2048 MHz Output Power	0.5 ± .5 dBm	
4096 MHz Output Power	10. ± .5 dBm	LO for T304
4096 MHz Output Power	0.5 ± .5 dBm	
1024 MHz 2nd Harmonic	-40 dBc Min	
2048 MHz 2nd Harmonic	-40 dBc Min	
4096 MHz 2nd Harmonic	-60 dBc Min	

4096 MHz 3rd Harmonic	-70 dBc Min	
512 MHz Ref leakage	-50 dBc Min	All outputs
128 MHz Ref leakage	-50 dBc Min	All outputs
4096 MHz Ref leakage	-50 dBc Min	Any non-4096 output
Comb leakage on 2048 or 4096 MHz outputs	-40 dBc Min	

6.14 Intermediate Frequency System

The intermediate frequency system selects four IFs from either the 4, P, L, S, or C Band front end or it selects two IFs from either the A, K, or Q Band front end. The selection occurs through band switches. A, K, and Q band front ends are designed with block down converters. The block down conversion scheme will converts IFs to the 8 to 18 GHz range for the UX converter. The UX converter then divides the IFs and eventually delivers 4 IFs in the 8 to 12 GHz range. See 6.14.3.2 for a better description of the UX converter. The 4, P, L, S, and C band front ends need to be up converted externally to the 8 to 12 GHz range. The lower frequency front ends are converted using two 12 to 20 GHz synthesizers. The U band front end is converted to 8 to 12 GHz in the UX converter using both 12 to 20 GHz synthesizers. The 7.5 to 12.5 GHz IFs are then switched into the baseband downconverters. The baseband downconverter takes the 7.5 to 12.5 GHz IFs, performs total power detection and either a single or double down conversion. Single conversion is used with the low resolution sampler while, double conversion is needed for the high resolution sampler. The IFs out of the baseband downconverter are either 2.048 to 4.096 GHz (for high speed sampling) or the range of 1.024 to 2.048 GHz (for high resolution sampling). The lower frequency path is provided for narrow band lower frequency front ends or observations that require high resolution sampling. The LO for the lower frequency path is provided by a 4096 MHz reference. The output of the baseband downconverter is switched into the samplers. There are two samplers provided, one is a 2.048 to 4.096 GHz 4.096GS/s 3 bit sampler and the second is a 1.024 to 2.048 GHz 8 bit sampler. The sampled IFs are then modulated onto the fiber optic system.

6.14.1 Band Switches

There will be a set of two intermediate band select switches (one per polarization). These intermediate band switches are used to select the IFs from either the L, S, or C front ends. This combination of switches was chosen because both the 4P Converter and the LSC Converter are contained within the LO-Rack thus reducing the number of signals leaving and entering the rack. These switches are specified in Table 6.14.1.

There will be a set of two high band select switches (one per polarization). These high band switches are used to select the IFs from either the Q, A, U, or X band front ends to the UX Converter. These switches are specified in Table 6.14.1.

There will be a set of four pre Down Converter switches (one per IF). These pre Down Converter switches are used to select a signal from either the UX Converter or the LSC Converter to go to the IF Transfer Switches and into the Down Converter. These switches are also specified in Table 6.14.1.

All external switches will be controlled through a DCS interface module
M301.

Table 6.14.1 Band Switch Specifications

Item	Specification	Notes
Frequency Range	1 to 18 GHz	
VSWR	1.4 to 1 Max	
Insertion Loss	.4 dB Max	
Isolation	60 dB min	
Input impedance	50 Ohm nominal	
Actuating Voltage	28 V	
Actuating Current	300 ma max	
Switching Time	15 ms max	
# poles	1	Per switch
#throws	4	Per switch
RF connection	SMA	
# of switches per antenna	10	
Power Connector	Circular PT06E-14-18S-SR	

6.14.2 Transfer Switches

After the IFs are selected with the Band Select switches, then the IFs go through a set of 2 IF transfer switches. These transfer switches allow the IFs to be transferred to a different IF downconverter**.** These switches are used to reverse the IF polarization. These switches are specified in Table 6.14.2.

Table 6.14.2 IF Transfer Switch

Item	Specification	Notes
Frequency Range	DC to 12 GHz	
VSWR	1.4 to 1 Max	
Insertion Loss	.5 dB Max	
Isolation	70 dB min	80 dB goal
Input impedance	50 Ohm nominal	
Actuating Voltage	+28 v	
Actuating Current	215ma	
Switching Time	20 ms max	
# poles	2	Per switch
#throws	2	Per switch
RF connection	SMA	
Power Connector	DC Feedthrus	

6.14.3 Converter Modules

6.14.3.1 4P Converter T301

The 4P converter module is used to convert both the 74 MHz front end and the P-Band front end to L-Band. Power dividers are used at the input to allow dichroic observations. The corresponding IFs for 4-Band and P-Band are diplexed together. Each IF is up converted with the same fixed LO. The specifications for this converter are shown in Table 6.14.3.1.

Table 6.14.3.1 4P Converter Specifications

Item	Specification	Notes
Number of modules	32	1 per antenna + 4 spares

Input RF-inputs per module -LCP -RCP	6 3 3	LCP and RCP LCP, 4-Band, P-Band or composite, spare RCP, 4-Band, P-Band or composite, spare
Input RF -frequency range	70 to 426 MHz	
Input RF- VSWR	1.35:1 Max	1.3:1 goal
Input RF -noise figure	9 dB Max	@25°C
Input RF -power level	-60 dBm -60 dBm	73-75 MHz, 4-band for the 2MHz bandwidth 308-348MHz, P-band for the 40 MHZ bandwidth
Compression point	+10 dBm	1 dB compression pt. CW or noise
Gain Headroom	45 dB	
Input LO -inputs per module	1	1 fixed
Input LO -Frequency range	1.024 GHz fixed	
Input LO -Power Level	0 ±3 dBm	Nominal
Input LO- VSWR	1.2:1 Max	
LO rejection	20 dBc	below IF Level
Output IF -# outputs per module	2	RCP and LCP
Output IF -polarization	Normal Reverse	RCP=IF-A/B, LCP=IF-C/D RCP=IF-C/D, LCP=IF-A/B for simultaneous observing with L-Band
Output IF -Frequency range	1.090 to 1.450 GHz	L-Band IF expandable to 2 GHz
Output IF -power level	-40 dBm ±2dB	To be compatible with L-band power input to T302 LSC converter for a total bandwidth of 360 MHz
Conversion gain	8dB ± 2 dB	
Output IF -spurious LO Levels	<-70 dBm spurious <-80 dBm for harmonics <-40dBc	LO spurious components on IF outputs related to any reference frequency of LO for LO harmonics
LO 2nd harmonic spur and leakage	-40 dBc	
Output IF - Image rejection	-30 dBc	where “c” is the converted IF
Output IF - Passband ripple	.2 dB	for ripple with a period less than 2 MHz
Output IF - Overall flatness	1.5 dB/360 MHz	from 1090 to 1450 MHz

Phase/delay stability	.0013°/min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
Isolation between channels	70 dB Min	80 dB goal
Interface	MIB Via M301	External with SPI bus
Control requirements	solar attenuator	
Solar Attenuators	20 dB	
Monitor requirements	IF total power, regulated voltages, temperature, solar attenuator status	

6.14.3.2 UX Converter T303

The UX converter is used to down convert IFs in the 8 to 18 GHz range to X-Band. The IFs are either from the Ku-band, K-band, Ka-band, or Q-band front end. One of the first LO synthesizers is used to block down convert either the K-band, Ka-band, or Q-band front end to the 8 to 18 GHz range. This block down converted IF is then fed to the converter where it is processed. The processing proceeds as follows: If the frequency range of the “wanted” input IF is within 8 to 12 GHz, then the IF is simply passed through the converter. If the frequency range of the “wanted” input IF is not within the 8 to 12 GHz range, then the IF is down converted using the other first LO synthesizer. For the Ku-band front end, both of the first LO synthesizers are used to down convert the IFs to X-band. Note: any converted IF will be spectrally inverted from the non-converted IF. The specifications for this converter are shown in Table 6.14.3.2.

Table 6.14.3.2 UX Converter Specifications

Item	Specification	Notes
Number of modules	32	1 per antenna + 4 spares

Input RF-inputs per module	2	LCP and RCP
Input RF -frequency range	8 to 18 GHz	
Input RF- VSWR	1.4:1 Max	1.35:1 goal
Input RF -noise figure	5.2 dB max 6.5 dB max	X-direct @25°C Ku converted paths @25°C
Input RF -power level	-48 ± 3 dBm/GHz -36 ± 3 dBm -38 ± 3 dBm -36 ± 3 dBm -36 ± 3 dBm	Spectral density power per GHz Ku band for the 8 GHz bandwidth K band for the 10 GHz bandwidth Ka band for the 14 GHz bandwidth Q band for the 12 GHz bandwidth
Variation of power spectral density	3 dB Max	per 4 GHz sub band
Compression point, X-direct path	-4 dBm -7 dBm	1 dB compression pt. noise power 1 dB compression pt. CW
Ku converted paths	-3 dBm -10 dBm	1 dB compression pt. noise power 1 dB compression pt. CW
Gain Headroom: Noise power CW power	38 dB nominal 28 dB nominal	from P1 dB 4GHz BW from P1dB, -40dBm input
Input LO -inputs per module	1 2	K, Ka, and Q Ku band
Input LO -Frequency range	12 to 14 GHz	Doubled to 24- 28 GHz
Input LO -Power Level	+10 dBm	Nominal
Input LO- VSWR	1.4:1 Max	
Output LO - frequency range	24-28 GHz	
Output LO - power level	+13 ± 1.0 dBm +13 ± 3.0 dBm	Over output LO range 24-26 GHz Over output LO range 26-28 GHz
Output LO - VSWR	1.4:1 Max	LO output port A and B
Output IF - # of channels	4	IF- A, B, C, D
Output IF -polarization	Normal	RCP=IF-A/B, LCP=IF-C/D
Output IF - frequency range	7.5 to 12.5 GHz	X- Band IF
Output IF - Power Level	-27 dBm ± 2 dB -23 dBm ± 2 dB	Total noise power, 4 GHz Bandwidth CW, with -40dBm CW RF input

Conversion gain: X-direct path Ku converted path	17 dB± 2dB 17 dB± 2dB 11dB min.	Total noise power or CW gain CW gain Total noise power gain
Output IF -spurious LO Levels	<-70 dBm spurious <-80 dBm for harmonics <-40dBc	LO spurious components on IF outputs related to any reference frequency of LO for LO harmonics
Output IF - Image rejection	-30 dBc Min	where “c” is the converted IF
Output IF - Passband ripple	.2 dB	for ripple with a period less than 2 MHz
Output IF - Overall flatness	2 dB/2 GHz 3 dB/3 GHz	
Phase/delay stability	.0013°/min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
Output IF - Isolation between channels	70 dB Min	80 dB goal
Output IF - Isolation between each polarization channel	70 dB Min	80 dB goal
Interface	MIB via M301	Fiber ethernet
M&C requirements	See A23275A003	

6.14.3.3 LSC Converter T302

The LSC Converter module is used to convert the lower frequency front ends to X-Band. This converter uses the 12 to 20 GHz synthesizer for the conversion process. The specifications for this converter are shown in Table 6.14.3.3.

Table 6.14.3.3 LSC Converter Specifications

Item	Specification	Notes
Number of modules	32	1 per antenna + 4 spares
Input RF-inputs per module -LCP -RCP	4 2 2	LCP and RCP 1 L/S/C band and 1 4/PBand 1 L/S/C band and 1 4/PBand
Input RF -frequency range	1 to 8 GHz	L, S, and C bands
Input RF- VSWR	1.35:1 Max	1.3:1 goal
Input RF -noise figure	9 dB Max	@25°C
Input RF -power level	-46±3 dBm/GHz -37±3 dBm -34±3 dBm -32±3 dBm -40±3 dBm	Spectral power density per GHz L-Band total power 1 GHz BW S-Band total power 2 GHz BW C-Band total power 4 GHz BW 4/P-Band total power per 380MHz BW
Compression point	+7 dBm +0 dBm	1 dB compression pt. noise power 1 dB compression pt. CW
Variation of power spectral density	±1.5 dBm/500 MHz	
Gain Headroom, noise power CW power	44dB Min 41dB Min 39dB Min 45dB nominal	L-Band S-Band C-Band to P1dB, -45 dBm CW input
Input LO -inputs per module	2	
Input LO -Frequency range	12 to 14 GHz	
Input LO -Power Level of LO	+7 ± 3 dBm	
Input LO- VSWR	1.35:1 Max	
Output IF - # of channels	4	IF A, B, C, D
Output IF - Polarization	RCP LCP	IF A and B IF C and D
Output IF - Frequency range	7.5 GHz to 12.5 GHz	X-band IF
Output IF - Conversion Gain	14 ± 2 dB 8 dB	CW gain Noise gain

Output IF - Power Level	-32dBm ± 2 dB -26 dBm ± 2 dB	Total noise power, 4 GHz bandwidth CW, with -40 dBm CW RF input
Output IF- VSWR	1.3:1 Max	
Output IF -spurious LO Levels	<-70 dBm spurious <-80 dBm for harmonics <-40dBc	LO spurious components on IF outputs related to any reference frequency of LO for LO harmonics
Output IF - Image rejection	-30 dBc min	where "c" is the converted IF
Output IF - Passband ripple	.2 dB	for ripple with a period less than 2 MHz
Output IF - Overall flatness	1.5 dB/2 GHz 3.0 dB/4 GHz	
Phase/delay stability	.0013°/min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
Output IF - Isolation between channels	70 dB Min, 80 dB goal 70 dB Min, 80 dB goal	Isolation between output IF channels Isolation between polarization chs
Solar Attenuators	20 dB	
Interface	MIB via M301	External with SPI bus
M&C requirements	see A23270A002	

6.14.4 Baseband Downconverter T304, T305

In each antenna there will be four Baseband Downconverter T304-T305 module pairs, one per IF. The IFs are in the to 7.5 to 12.5 GHz range and total power detection and leveling are performed on the full range IF. These IFs are then split inside each module. These two IFs are down converted with the 10.8 to 14.8 GHz Synthesizer and the resultant IFs are in the passband from 2.048 to 4.096 GHz. There will be a gain slope equalizer incorporated into this module. This equalizer will be able to correct passband slopes encountered in the front ends, downconverters, cables etc. The amount of correction to be applied will be determined by using the autocorrelation spectrum of the Widar correlator. There are 16 settings from +15dB to -15dB slope. See EVLA memo #80 for more details. Another conversion is provided for low band signals that may require higher resolution samplers due to higher levels of RFI. This conversion uses the 4.096 GHz reference generator output and is used only on one of the split 7.5 to 12.5 GHz IFs. This lower passband is from 1.024 to 2.048 GHz. The eight 2.048 to 4.096 GHz IFs from the four downconverters will be harmonic sampled by 3-bit 4.096 GS/s samplers. The four lower frequency IFs will be harmonic sampled by 8-bit 2.048 GHz samplers. The input and output noise power spectral distribution will be nominally flat over the passband. The downconverter module provides for total power measurement of each split IF as well as the total IF. Internal filters and external filter connections will be provided to either narrow the desired passband or notch out undesired areas within the passband. The specifications for the downconverter are shown in Table 6.14.4.

Table 6.14.4 Baseband Downconverter Specifications

Item	Specification	Notes
Number of modules	124	4 per antenna + 12 spares
# of IF inputs per module	1	
Input frequency range	7.5 to 12.5 GHz	
Input power level per IF per GHz	-47.5 dBm	
Variation of power spectral density	±1.5 dBm	
Headroom at input	>18 dB	Headroom measured from 1% compression with no attenuation applied
# of LOs per module	3	2 independently tunable 1 fixed
Frequency range of LO	two at 10.8 to 14.8 GHz and one at 4.096 GHz	
Power Level of LOs	+12 dBm for 10.8 to 14.8 GHz +0 dBm for 4.096 GHz	
Spurious levels of LO	<-70 dBc for spurious, <-80 dBc for harmonics related to any ref frequency, <-40 dBc for harmonics	
# of IF outputs per module	3	
Frequency range of output	2 at 2048 to 4096 MHz, or 1 at 1024 to 2048 MHz	
Power Level of output	-25dBm for 2048 to 4096 MHz -37dBm for 1024 to 2048 MHz	
Headroom after conversion	>18 dB	Headroom measured from 1% compression with no attenuation applied
1st LO 2nd harmonic spur and leakage	<-40dBc	
2nd LO 2nd and 3rd Harmonic	<-50dBc	
IF input VSWR	1.8:1 Max	
IF input noise figure	<5.5 dB	with no attenuation applied
Image rejection	>30 dBc	
Passband ripple	2dB	for ripple with a period less than 2 MHz

Overall flatness	± 2 dB/2 GHz	smooth variations only, gain slope equalized
Phase/delay stability	0.0056°/min/GHz/°C	For a maximum average temperature slope of 0.25°C/(30 min)
Isolation between channels	>40 dB	
Total power detector response time	2 ms	
Residual Phase	<20°	within a 2 MHz window and after removal of the linear slope
Interface	MIB	internal
Isolation between modules	>60 dB	
M&C requirements	SPI Bus interface to MIB	

6.16 Other Hardware

Other hardware which will be required during the transition are the current backend filter module T4 and the Baseband Driver Module T5. The T4 provides filtering of the final IF and the T5 provides amplification and automatic gain control of the IF.

6.17 Power Supplies

The power supply modules required are described in the Systems Chapter of the project book.