Holography Receiver Design

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1. Summary

An overall block diagram of the holography receiver is shown in Figure 1. The signal path is described in section 2, and then details of the local oscillators are given in section 3. Design considerations for the horn antennas are described in section 4. The digital assembly, including correlation and monitor/control, is covered in section 5. Finally, the packaging is described in section 6.

2. Signal Path

As shown in Figure 1, the signals received by the reference and main antennas are down converted to a fixed 30 MHz intermediate frequency (IF). The use of a fixed IF frequency should reduce phase errors in the IF system.

Two Millitech biasable balanced mixers and a common local oscillator (LO) are used for the signal first down conversion. The mixers are optimized for operation at 79 and 104 GHz, have a typical conversion loss of 11 dB and require about 1mW of LO power. Specifications for the mixers are given in Appendix B.

The two IF signals are first amplified by low noise figure (1.3 dB) bipolar amplifiers, yielding an estimated SSB noise temperature of about 3900K. The signals are then band limited using a 1.5 MHz band pass filter centered at 30 MHz. The IF levels of the channels will be different; on boresight, the signal channel level is about 40 dB higher than the reference channel.

Two programmable signal attenuators, one for each channel, are used to set the relative level between channels, prevent saturation of the second 30 MHz IF amplifier and set the appropriate input level to the SSB mixer. The attenuators have a 63 dB range in 1 dB steps and require 6 bits for attenuation control.

The receiver's predicted interstage signal levels are shown in Figure 3. The power levels shown assume a 1uW photodetector output power, 30 dB gain for the transmitter and reference feed horns and IF attenuator set at 0 dB.

Both 30 MHz main and reference signals are further down converted to a baseband signal and a SSB mixer is used to select the upper sideband in this final mixing process to 15 KHz. The required IF to baseband gain is about 45dB.

The two baseband signals are filtered using an anti-aliasing 8 KHz band pass filter (10 KHz at -3db points). The main signal is divided in two and one half is shifted 90^o in phase by a broad band phase shifter resulting in the **S** and **Q** signals. **S** is the instantaneous voltage (proportional to field intensity), **Q** is this voltage shifted by 90^o.

The reference channel is also divided in two, but only the instantaneous voltage **R** is required for correlation. The 15 KHz S, R and Q output signals are amplified to 5Vp-p nominal and connected to the DSP card where the signal are digitized and correlated and sent to the AMB interface (CAN bus).

2.1 IF Chain Control and Monitor

Control:	Signal Attenuator	6b
	Reference Attenuator	6b
Monitor:	30 MHz signal monitor	0-5 V
	30 MHz reference monitor	0-5 V
	15 KHz signal monitor	0-5 V
	15 KHz reference monitor	0-5 V

3. Local Oscillators

To minimize the number of oscillators required for the holography receiver, the input signals are down converted from mm-wave to baseband with just two frequency conversions. A phase locked Gunn oscillator system is used as LO for the first downconverter and a high stability oven-controlled crystal oscillator (OCXO) as the LO for the second downconverter.

3.1 First LO system

A block diagram of the holography receiver first local oscillator is shown in Figure 2. The LO signal for the millimeter wave mixers is generated by two varactor tuned Gunn oscillators, one operating at 78.920 GHz (LO_L) and the other at 104.020 GHz (LO_H). Both have an electrical tuning range of +-150 MHz.

The choice of employing two oscillators instead of one single mechanically tuned unit was based on the difficulty of purchasing oscillators with the required wide tuning frequency band and output power. Also, remotely servo-controlling two mechanical micrometers (back-shorts for frequency tuning and power peaking) would add an extra complexity to the system. The specifications for the varactor tuned Gunn oscillators are given in Appendix B.

As is shown in Fig. 2, just one Gunn oscillator can be turned on at a time. The selection of oscillators is accomplished by switching the Gunn diode and varactor bias to the desired oscillator with a Gunn_Select bit from the MC card. The oscillator will be automatically selected when the desired holography frequency is entered in the control system.

Power levels shown in Fig. 2 are estimates based on typical components insertion losses and with the mechanical attenuators set at their minimum value. All millimeter wave components are in the 75-110 GHz waveguide band. Oscillator output power is monitored at the power detector, amplified and sent to the MC card.

The oscillator power is split in the matched hybrid tee and fed to the reference and signal mixers. There is enough isolation between the mixers to prevent any channel crosstalk problems.

There are two important frequency related requirements for the first local oscillator: a) Capability to tune to the transmitter frequency and tuning step size and b) Automatic Gunn oscillator phase-lock acquisition.

The Gunn oscillator frequency is phase-locked to a high stability 95 MHz OCXO employing conventional heterodyne technique. A sample of the Gunn 78.89 or 103.98 GHz is downconverted to a Lock-IF near 95 MHz by mixing it with a harmonic N (N=9,11) of the output frequency of a 8.6 - 11 GHz frequency synthesizer (F_{SYN}) which is phase locked to a 25 MHz reference. The Lock-IF and Fsynt paths are separated in the triplexer.

The Lock-IF signal is connected to a digital frequency/phase detector where its frequency and phase are compared with those of the 95 MHz (F_{OFFSET}) OCXO. The detector's output is an error signal proportional to the frequency and phase difference between the Lock-IF and F_{OFFSET}. Frequency and phase lock acquisition is achieved by applying this error signal to the Gunn's varactor bias tuning. The frequency locking range is approx. +- 100 MHz. If the Lock-IF frequency is within this range the receiver LO will acquire lock automatically.

The frequency/phase detector circuitry design is the same used in NRAO mm-wave receivers and it will only require modification for the varactor bias voltage range.

The holography frequency tuning scheme is designed to give a fixed IF for any transmitter signal frequency. This is done by making the receiver frequency synthesis scheme similar to that of the transmitter:

$$f_{XMTR} = N\, f_{SYN1} + f_{OFFSET1}$$

$$f_{LO} = N\, f_{SYN2} + f_{OFFSET2}$$

For the same harmonic number N:

$$f_{IF} = f_{XMTR} - f_{LO} \qquad \text{(USB)}$$

$$= N\, \Delta f_{SYN} + \Delta f_{OFFSET}$$

$$= N\, (i\, \delta f1 + j\, \delta f2) + \Delta f_{OFFSET}$$

where $\delta f1$ and $\delta f2$ are the resolution of the synthesizers.

Let $\delta f1 = \delta f2 = \delta f$ and $f_{OFFSET1}$ = 125 MHz (fixed). We choose $f_{OFFSET2}$ so that $f_{IF} = \Delta f_{OFFSET1}$ giving a fixed IF for any available signal frequency. In our LO scheme, f_{IF} = 30 MHz and $f_{OFFSET2}$ = 95 MHz.

The synthesizer is a Micro Lambdas model MLSL-0811. It has a frequency resolution of 125 KHz and phase noise of -60 dBc/Hz @ 1KHz offset. The synthesizer's frequency can be set by commands that are sent to the MLSL synthesizer via a three-wire bus consisting of a Select line, a Data line, and a Clock line. The 3-wire bus will be driven by the DSP (see section 5 below).

The 95.0 MHz offset oscillator is an free running OCXO from Temex with frequency vs temperature change of <2E-8 and long term stability of < +-1E10-7/year. It requires 12V @ 500mA at warm-up and 120mA at 25° C.

3.2 Second Local oscillator

The receiver's second local oscillator is also a free running 29.85 MHz OCXO from Temex with similar frequency stability and power requirements. Its output power is approximately +6dBm.

3.3 LO Control and Monitor

The required monitor and control parameters are:

LO status:	Gunn Oscillator Lock Alarm	1b
	Synthesizer Lock Alarm	1b
Control:	Gunn Oscillator On/Off	1b
	Gunn Oscillator Select	1b
	PLL open	1b
	Synthesizer Frequency	Serial Data
Monitor:	LO level	Analog
	LO plate temperature	Analog

4. Horn Antennas

The receiver will incorporate two horn antennas, mounted on opposite ends of the same box at the apex of the 12 m antenna. One horn is a prime focus feed for the antenna, and the other (pointing outward) receives the reference signal directly from the transmitter. In addition, the transmitter will use a horn antenna. Each horn will be designed and fabricated specifically for this application. Each has different requirements, summarized in the following table.

The transmitter's beamwidth is determined by the need to illuminate the 12 m antenna with reasonable uniformity. Variations in phase, if uncorrected, lead directly to errors in the reflector surface deviations being measured. It is expected that the horn can be made to produce a far-field spherical wave to the required tolerance within the part of the beam being used, but this will be checked by careful measurement on a test range (see below).

The reference antenna is the least critical. Its gain in the direction of the transmitter should remain high over the scan angle range. The complex gain pattern over this range, to the extent that it is not constant, has a small effect on the transverse resolution of the final surface deviation map because its Fourier transform is convolved with the ideal point spread function determined by the sampling of the beam map.

The transmitter and reference horns will have gains of 34 dB if the beamwidths are as specified. A conservative value of 30 dB is used in the power budget calculations.

It can be seen that the transmitter and reference horn beamwidths are the same, so the same design will be used for both. A circular, corrugated, narrow-angle horn is appropriate, in view of the circularity and frequency range requirements. A lens-corrected aperture is necessary in order to keep the length from being impractically large. A broad-band design covering the 75-110 GHz waveguide band will be used. The 0.5 dB beamwidth will vary somewhat over the band, but should remain within 5% and this should be satisfactory.

The signal feed is the most critical horn for this application. The f/0.4 reflector subtends an angle of 128 deg at the prime focus. The feed needs to illuminate it with reasonably uniform amplitude; we choose -3 dB edge taper. The critical thing is the phase pattern, which directly affects the surface deviation measurements. It does not seem feasible to achieve uniform phase within 0.6 deg over such a large angle, so we will rely on careful measurement of the feed on a test range. The facilities at IRAM (Grenoble) will be used for this measurement. Similar measurements will be made on the other horns. A wide-flare-angle, corrugated, circular horn (scalar feed) is appropriate. It will probably be possible to scale an existing design to our frequency range.

There is considerable experience within the NRAO in the design and fabrication of corrugated horns. Although the detailed designs for this project have not yet been done, we anticipate no difficulty in meeting the requirements.

Horn Antenna Requirements

General

Frequencies	78.9 and 104.0 GHz
Weatherproofing	Lens or membrane across aperture Dry air pressurization Radiant de-icing

Transmitter

Beamwidth, -0.5 dB	2.3 deg (subtended by 12m antenna)
-3.0 db	4.6 deg nominal
Polarization, nominal	vertical
cross	<-30 dB within 1.2 deg
Beam circularity	<0.5 dB within 1.2 deg
Phase uniformity	<0.3 deg within 1.2 deg (2.5 microns)

Reference Antenna

Beamwidth, -0.5 dB	2.3 deg (scan angle)
-3.0 dB	4.6 deg nominal
Polarization, nominal	vertical
cross	<-30 dB within 1.2 deg
Beam circularity	<0.5 dB within 1.2 deg

Signal Feed

Beamwidth, -3.0 dB	128 deg (edge of 12 m dish)
Polarization, nominal	vertical
cross	<-20 dB within 64 deg of center
Uniformity, amplitude	<0.2 dB from best-fit circular gaussian within 64 deg
Uniformity, phase	<5 deg from constant within 64 deg
Knowledge, phase	<0.6 deg within 64 deg (5 microns)

(includes measurement accuracy and stability)

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5. Digital Assembly

5.1 Summary

The digital assembly provides analog to digital conversion for the baseband signals from the receiver, performs all auto- and cross-correlations, and makes the correlation results available for reading by the monitor-control system over the AMB (CAN bus). It also handles control and monitor data between MC and the receiver. Timing of the data sampling and of the integration is determined within this assembly, based on system-synchronous references at 20.833 Hz and 25 MHz.

A block diagram of the assembly is shown in Figure 4. The main signal path is from the baseband inputs through three 16-bit ADCs to a digital signal processor (DSP), where the correlations are performed, and then via a serial link to the AMB interface. At low priority, the DSP also acts as host to the microwave synthesizer, which requires serial data for control. The AMB interface uses the AMBSI board described in [1], with firmware specific to the holography receiver. It supports latched control bits to the receiver, as well as input of analog and digital monitor signals. The logical interface over the AMB is described in detail in [2].

5.2 Dynamic Range

The ADCs are a significant factor in determining the dynamic range of the receiver. We calculate the required range as follows. From [3], the minimum transmitter power is 9\micro W EIRP when the receiver system temperature is 3200K. The ratio of these, which determines the on-boresight SNR via the geometry and antenna gains, is fixed by the desired surface measurement accuracy. If we process a 10 kHz bandwidth with Nyquist rate sampling, the noise power at the receiver input is 4.4e-16 W and the on-boresight signal power is 9e-10 W, for an SNR of 63 dB. It is likely that we will achieve a much higher SNR because the transmitter power will greatly exceed the minimum required and the system temperature may be lower. Allowing for 20 dB additional SNR, we have a maximum SNR of 83 dB (power) or 1.4e4 in voltage, which corresponds to 14 bits. The ADCs selected (Analog Devices type AD976) have 16 b of resolution, and in addition are specified to have a spurious-free dynamic range of 100 dB.

5.3 Data Rates and Processing Speed

At a sampling rate of 20 kSps, the total input rate for the three signals is 60000 16b words per second. To perform all six correlations (three self-products and three cross-products) then requires 120000 multiply-accumulate (MAC) operations per second. In most DSPs, a MAC is performed in a single instruction. If we allow another instruction per signal sample for reading the ADCs and yet another per sample period for triggering all three conversions, we get a total rate of 200 kips for the basic processing. This is easily handled by many kinds of microprocessor, including DSPs from at least three manufacturers (Motorola, Texas Instruments, Analog Devices). A fixed-point processor with 16b word length and 10 MHz clock is more than adequate.

Several factors may require a much higher instruction rate. First, higher than 16b precision is needed in the MACs to avoid overflow. Some processors provide this inherently, otherwise double-precision calculations would need to be programmed; this would approximately double the instruction rate. Second, we may wish to operate at higher than Nyquist sampling rate as a contingency against various difficulties, like achieving sufficient tuning resolution or transmitter line width. Third, we may wish to try implementing the 90 degree phase shift of the Q channel digitally (Hilbert transform filter); this requires at least 2x oversampling as well as additional processing. Finally, some processor instructions are needed to handle the data transfer to the AMB interface, as well as to handle control of the microwave synthesizer; however, these last functions will produce an extremely small load compared with the main signal processing.

Data transfer to the AMB interface will involve 6 32-bit words for each integration. At the rate of one integration every 12 msec, this is an average of 692 bytes/sec. Such a rate is easily handled by an SPI interface, which is the planned method. Actual transfers will be in higher-speed bursts, once per 48 msec timing interval. This is 96 bytes per timing interval. The AMB interface then transfers the data to the Antenna Bus Master computer using the CAN bus. Each CAN transaction can transfer 8 data bytes, so 12 transactions are needed per timing interval. The bus capacity is around 50 transactions per timing interval for system-synchronized monitor data. Although this is a significant load, it is easily handled because very few devices are active on the bus during holography observations. The only other significant load in this mode is the antenna control unit.

Efficient organization of the DSP firmware implies that the input data should be buffered for an entire integration before being correlated. This is because no DSPs have six MACs that can be operated in parallel. It is thus better to compute each of the six correlations completely before going on to do the next. If the maximum integration time is 48 msec, then 2880 words (16b) are needed for the buffer. Much larger on-chip data memories are available on most DSPs, so that longer integration times can probably be accomodated within this structure.

Based on these considerations, the Analog Devices ADSP-2185 has been identified as suitable. It is capable of 33 Mips, but will be operated at 25 Mips (see Timing, below); it has 32kwords of on-chip RAM. Many other choices are possible, and the final selection will be based on practical considerations such as the availability and cost of development tools. There is experience in the group with other Analog Devices DSPs of the same family. In view of the relatively low complexity of the code, programming in assembly language is efficient for coding and documentation, as well as for execution; however, any available high level languages will be considered during the detailed design.

It is intended to operate the DSP and ADCs at higher than Nyquist rate to the extent that processing speed permits.

5.4 Timing

The 20.833 Hz (48 msec) system timing signal is brought directly to the DSP chip, where it generates an interrupt. This triggers the start of an integration cycle, consisting of four 12-msec integrations. An internal timer in the DSP is used to start each integration after the first. The DSP clock is taken from the 25 MHz system reference, rather than from a free-running crystal. This ensures that any time interval generated within it is exactly known and synchronous. The sampling clock (nominally 20 kHz) will also be generated by the DSP and will be synchronous with the system.

It should be possible to make successive integrations contiguous, with no intervening blanking time. However, should such blanking be desired it can easily be programmed with a resolution of one sampling interval (1/20kHz = 50 \micro sec).

5.5 Other Circuit Details

A small PLD chip will be used for miscellaneous "glue" logic for control of the ADCs.

The ADSP-2185 includes two hardware serial ports. One will be programmed as a bi-directional SPI for communication with the AMB interface. The other will be programmed to control the microwave synthesizer. (This may be done differently if another DSP chip is selected during detailed design.)

The receiver requires 16 control bits, consisting of two 6-bit IF attenuator settings (one each for signal and reference channels), 1b to turn the Gunn oscillator on or off, 1b to the select either the low- or high-frequency Gunn oscillator, 1b to force the PLL open for testing, and 1 spare bit. Two status bits, indicating phase locking of the microwave synthesizer and of the Gunn oscillator, are returned; and two spare status bits are provided. Ten analog monitor points are supported at 10b resolution, including 5 signal levels, harmonic mixer current, Gunn oscillator tuning voltage, temperature control heater current, and 2 temperatures; 6 spare analog monitors are also available. All of this is handled by the AMBSI board.

The assembly thus consists of the AMBSI board (existing hardware design, additional firmware needed) and one other PCB containing the remaining circuits (to be designed). Each of the boards will be smaller than 150 cm^2. Total power consumption is expected to be less than 5W, using only a single d.c. supply at 5V.

5.6 Alternatives Considered

The data processing rate for correlation is far lower than is provided by even "slow" DSPs. The correlation could also have been implemented in hardware, e.g. by using a small FPGA. The NRAO has considerable experience and development tools for the Xilinx family of FPGAs, so this would be straightforward. Still, a small microprocessor would be necessary to manage the data transfer and to perform the auxiliary control and monitoring functions. For this reason, and to maintain maximum flexibility for future uses, the DSP solution was selected. The total chip count is probably smaller, and there is no significant effect on cost.

A more extreme option would be to move even more of the processing into the digital domain by digitizing at the ~30 MHz IF. This is feasible, but then the necessary digital filters and correlators would have to be implemented in hardware. A large and fast FPGA would probably be able to accomplish this. It was our judgment that this implementation would be less straightforward and therefore would pose considerable risk to the schedule than the one planned. The cost saving in RF hardware (eliminating the second downconversion) would be offset by having to use faster and more complex digital devices and by increased manpower for design and debugging. No performance improvement could be identified. For these reasons, this approach was not adopted.

6. Packaging

All receiver electronics (except power supplies) are packaged in a compact, temperature stabilized box. The power supplies are inside an auxiliary chassis mounted in the antenna’s receiver cabin and the DC power is sent to voltage regulators in the receiver using a multi-conductor cable.

To maintain phase and gain stability all critical components will be mounted on a thermally regulated base plate. The power dissipation in the receiver is about 35 watts.

The receiver box size is designed to fit inside the apex trough hole (375 mm dia) and it will be installed on the translation stages mounting plate. The requirement of focusing the receiver to both near and far field positions is met by choosing between two receiver's box mounting flanges. The package relative small size will facilitate the installation process. The details of the mechanical interface are given in Figure 5 "Holography/Apex Mechanical Interface".

Receiver physical dimensions and electrical interface requirements are given in the table below:

Size:	250 x 250 x 620 mm
Mass:	Approx. 25 Kg (includes mounting flange)

Cables required to run receiver:

25 MHz Reference	1	RG-214
Monitor & Control	1	AMB
DC Power Supplies	1	Multi-conductor (TBD)

Cables run from apex to the antenna's receiver cabin

REFERENCES

[1] M. Brooks, "ALMA Monitor and Control Bus Draft Specifications," Version 1.3, 2000-April-18.

[2] M. Pokorny, "Holography Receiver/Monitor Control Interface," ICD ALMA09003.08000.0001, draft dated 2000-Oct-02.

[3] "ALMA Holography System Overview," NRAO, document prepared for holography system CDR, 2000-Oct-01.

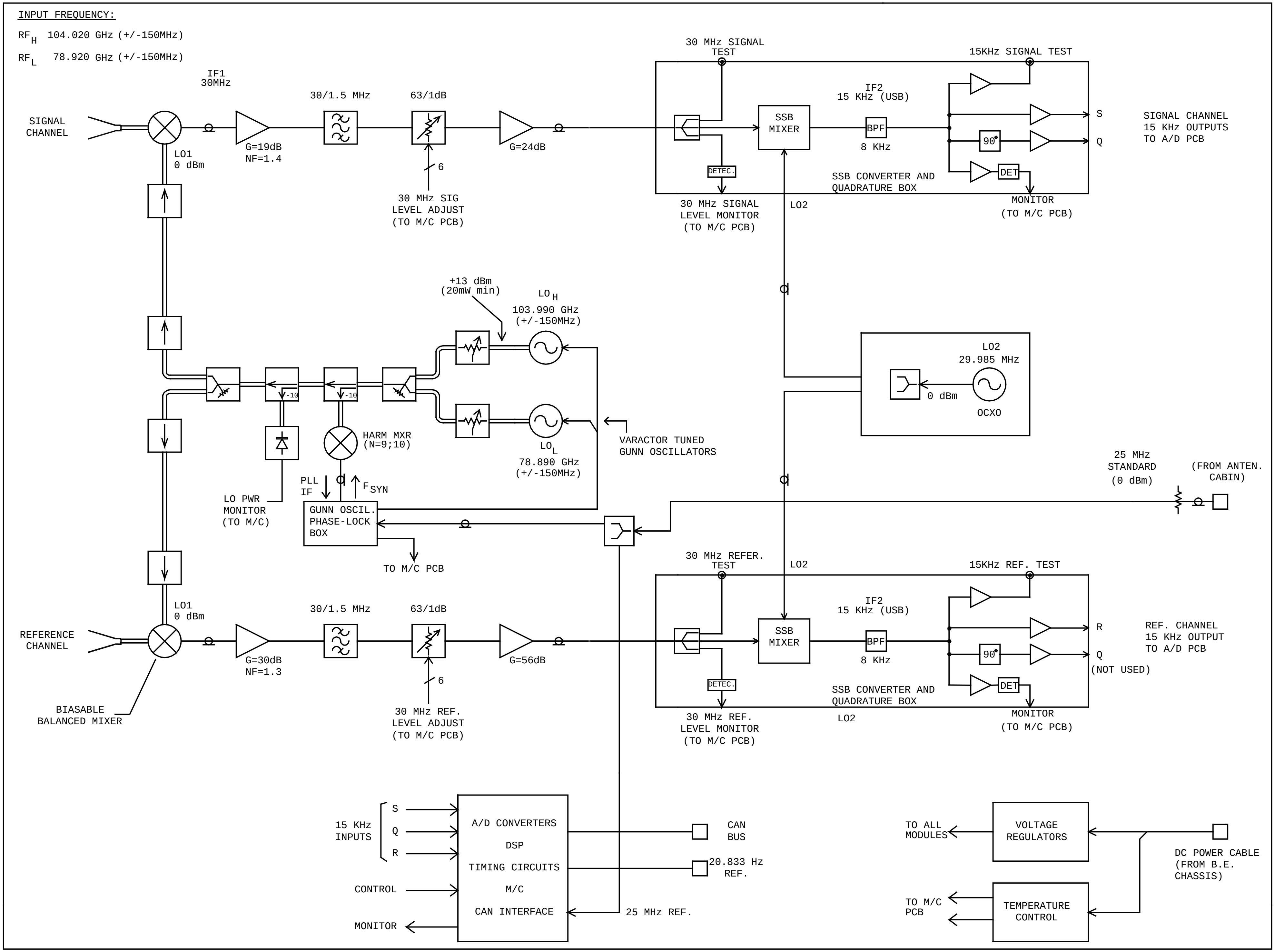
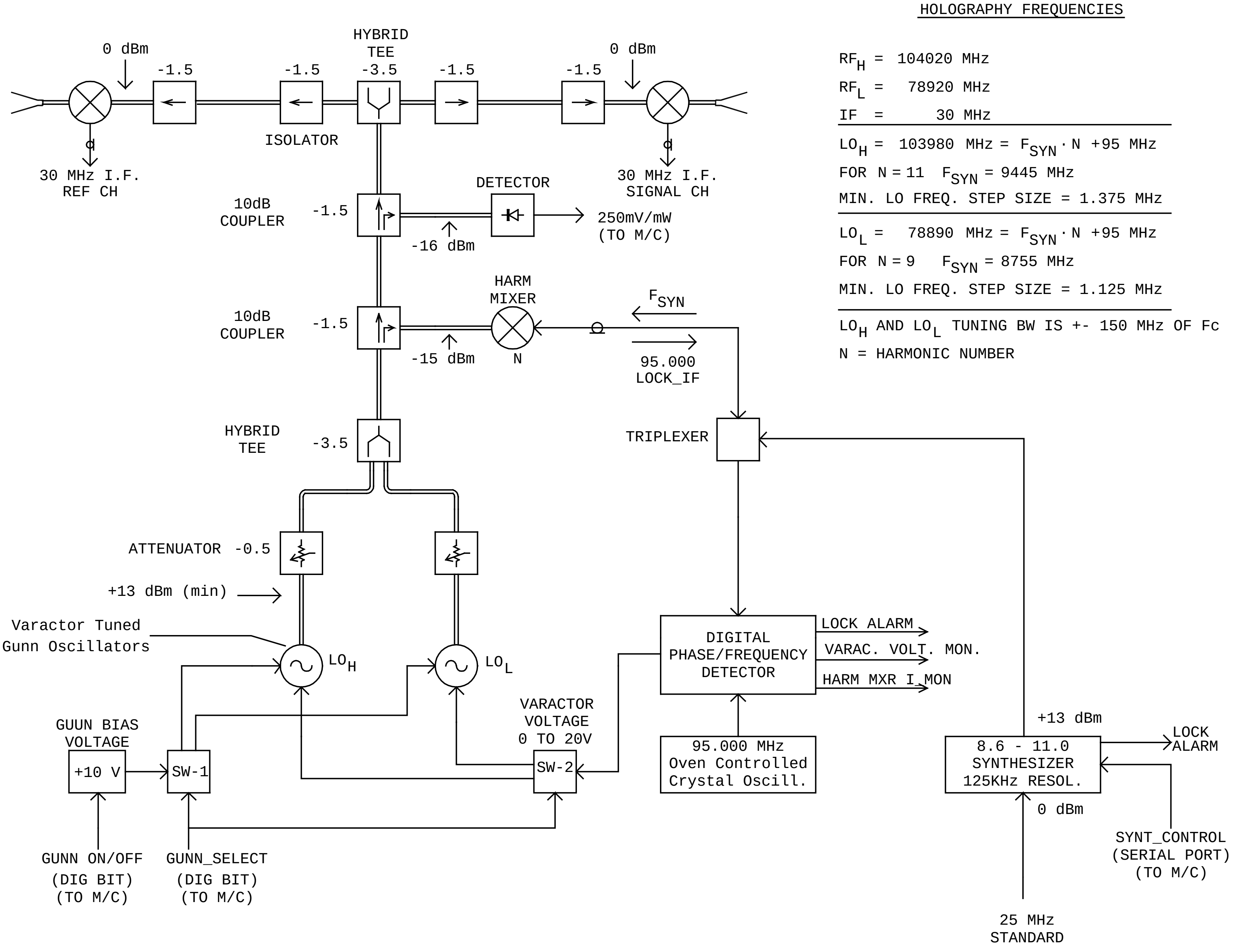


Fig. 1 - Holography Receiver Front-end



HOLOGRAPHY FREQUENCIES

RF_H = 104020 MHz
RF_L = 78920 MHz
IF = 30 MHz

LO_H = 103980 MHz = $F_{SYN} \cdot N + 95$ MHz
FOR N = 11 F_{SYN} = 9445 MHz
MIN. LO FREQ. STEP SIZE = 1.375 MHz

LO_L = 78890 MHz = $F_{SYN} \cdot N + 95$ MHz
FOR N = 9 F_{SYN} = 8755 MHz
MIN. LO FREQ. STEP SIZE = 1.125 MHz

LO_H AND LO_L TUNING BW IS +- 150 MHz OF Fc
N = HARMONIC NUMBER

Fig. 2 - Holography Receiver 1st LO Diagram

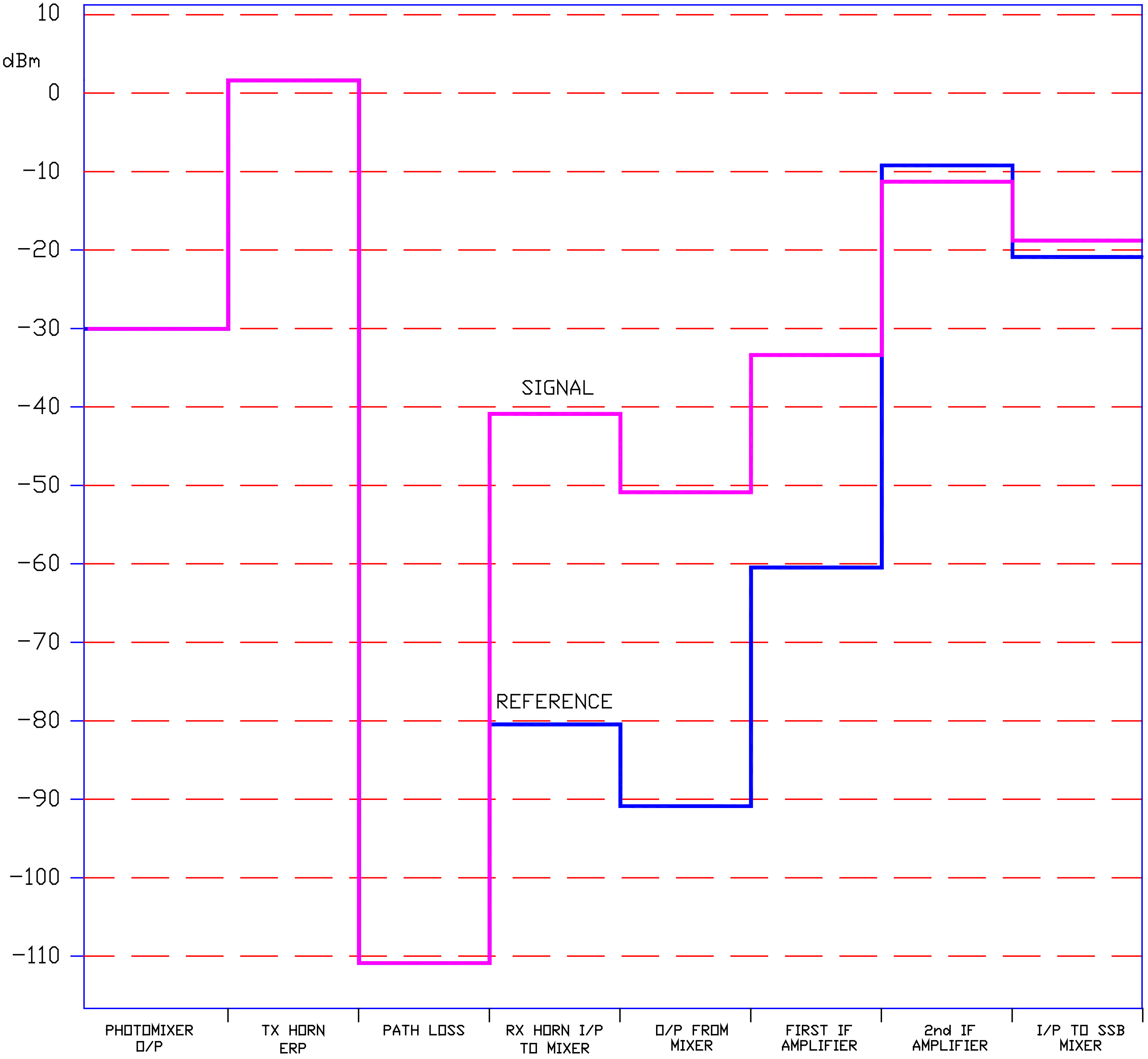
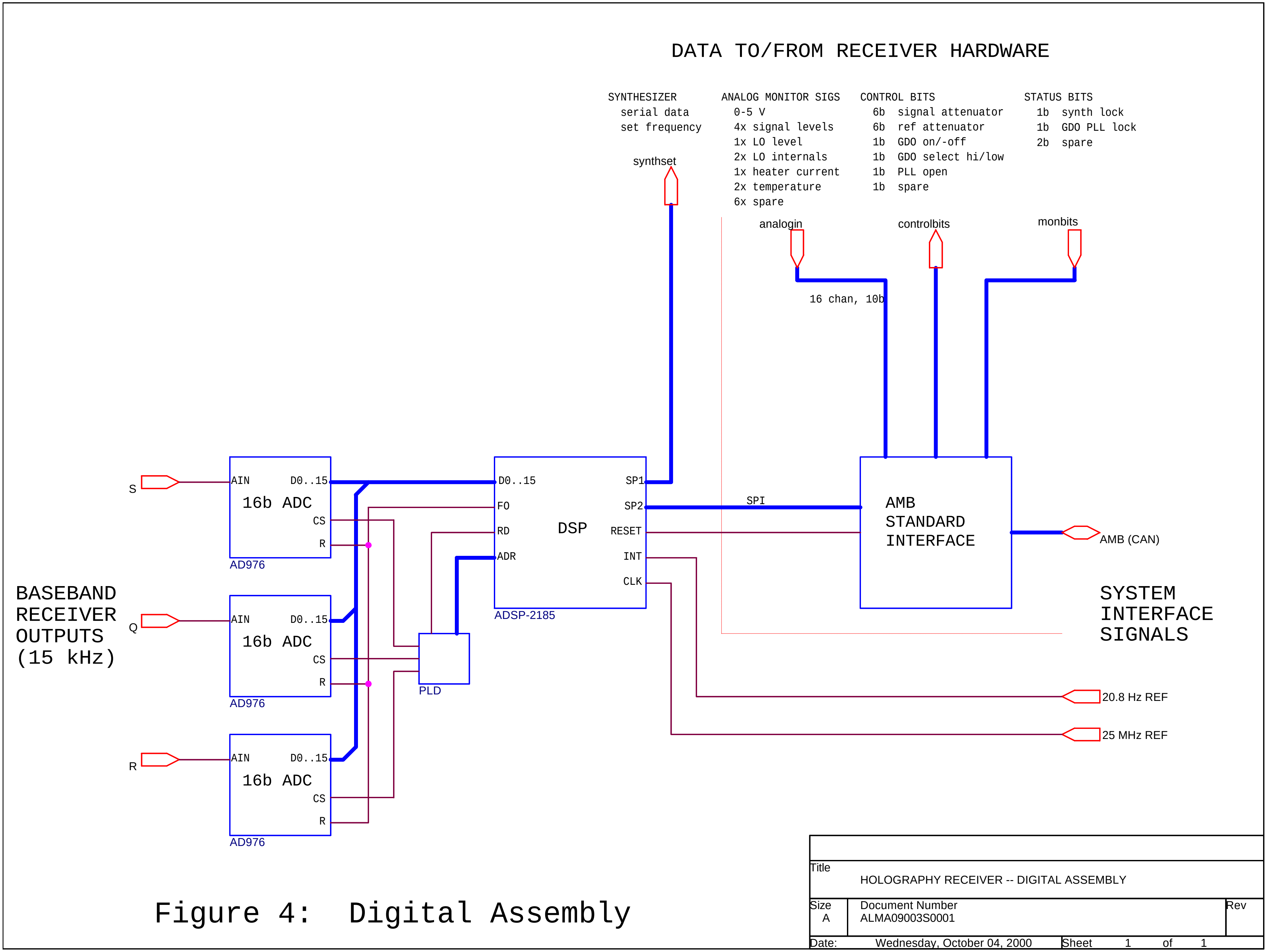


Fig. 3 – Interstage power levels for signal and reference channels



Title
HOLOGRAPHY RECEIVER -- DIGITAL ASSEMBLY

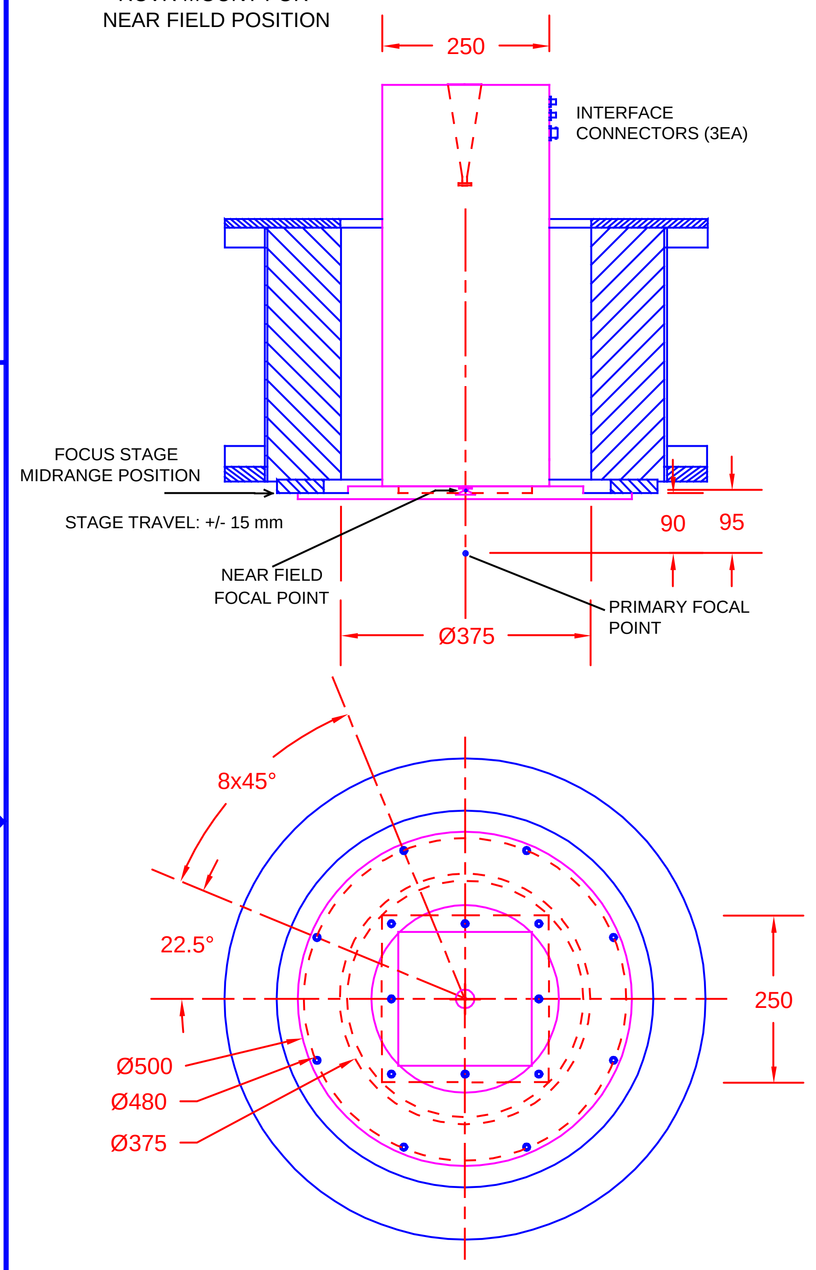
Size	Document Number	Rev
A	ALMA09003S0001	

Date: Wednesday, October 04, 2000 Sheet 1 of 1

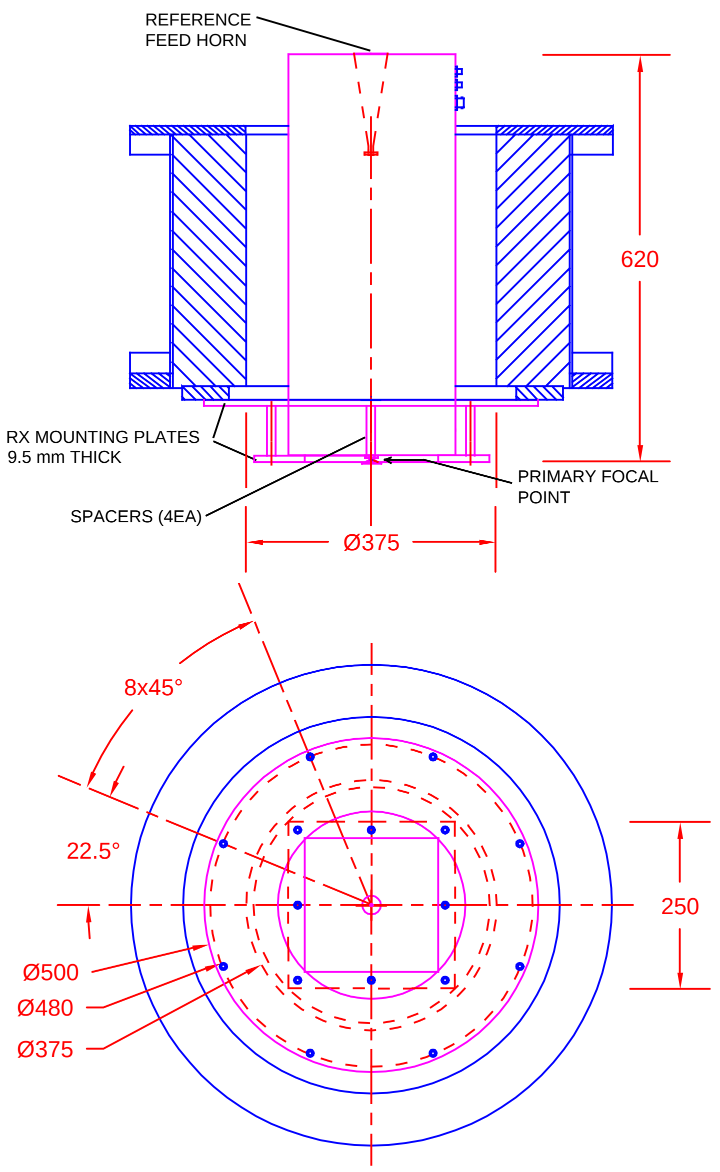
Figure 4: Digital Assembly

REVISION HISTORY				
ZONE	REV	DESCRIPTION	DATE	APPROVED

RCVR MOUNT FOR
NEAR FIELD POSITION



RCVR MOUNT FOR
FAR FIELD POSITION



LOOKING INTO HOLOGRAPHY
MAIN FEED HORN

HOLOGRAPHY RECEIVER PHYSICAL DIMENSIONS AND REQUIREMENTS:

1. SIZE: 250 x 250 x 620 mm
2. MASS: APPROX. 25 Kg
3. RECEIVER WILL BE INSTALLED ON THE SUB-REFLECTOR'S TRANSLATION STAGES MOUNTING FLANGE.
4. NEAR AND FAR FIELD FOCAL POSITIONS ARE SET BY CHANGING RECEIVER MOUNTING FLANGES.
5. CABLES REQUIRED TO RUN RECEIVER:

25MHz REF. CABLE:	1	(RG-214)
MONITOR & CONTROL CABLE:	1	(AMB)
DC POWER SUPPLIES CABLE:	1	(MULTI-CONDUCTOR)

CABLES RUN FROM APEX TO ANTENNA RECEIVER CABIN.

NOTE: RELATED DOCUMENT AND DRAWING: ALMA-US ICD No. 2
ANTENNA/APEX INTERFACE DWG # 03020810M002A

	QTY REQD	CAGE CODE	SYM	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	FIND NO.

PARTS LIST

METRIC

THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES ARE:

DECIMALS ANGLES
.X±0.1 ±0.5°
.XX±0.01

DO NOT SCALE DRAWING

TREATMENT

FINISH

SIMILAR TO

SPECIAL MARKING SYM

CONTRACT NO.

APPROVALS	DATE
DRAWN A.A.Perfetto	2000-10-03
CHECKED	
ENGR.	
SYSTEMS GROUP	

NATIONAL RADIO ASTRONOMY OBSERVATORY
operated by ASSOCIATED UNIVERSITIES INC. in agreement with
THE NATIONAL SCIENCE FOUNDATION

TITLE
Holography/Apex
Mechanical Interface

SIZE	CAGE CODE	DWG NO.	REV.
B		ALMA09003MX0002	

SCALE
CALC. WT
ACT. WT
SHEET

APPENDIX 'A' - HOLOGRAPHY RECEIVER PARTS LISTS AND COSTS

Item	Description	Supplier	Model #	Qty	Cost each	Cost Qty	Delivery	Basis
	Millimeter-wave Compontes :							
1	Biasable Balanced Mixers - 78 - 105 GHz	Millitech	MXB-10-RR0WF	3	$2,475	$7,425.00	8 w	quote
2	Gunn Oscillator - 104 GHz	Spacek Labs	GW-103	2	$2,590	$5,180.00	8w	quote
3	Gunn Oscillator - 78.9 GHz	Spacek Labs	GW-789	2	$2,590	$5,180.00	8w	quote
4	Reference Feed Horn	TBD	N/A	2	$1,000	$2,000.00	Feb/01	estimate
5	Main Feed Horn	TBD	N/A	2	$1,500	$3,000.00	Feb/01	estimate
6	Matched Hybrid Tee	Aerowave	10 2911	2	$1,400	$2,800.00	4w	catalog
7	10 dB Coupler	Aerowave	10 3000	2	$950	$1,900.00	4w	catalog
8	Harmonic Mixer	Pacific Millimeter	WM	2	$640	$1,280.00	4w	catalog
9	Detector	Pacific Millimeter	WD	2	$770	$1,540.00	4w	catalog
10	Isolator	Quinstar	QIF-1000-AA	4	$890	$3,560.00	6w	quote
11	Attenuator	Aerowave	10 2220	2	$725	$1,450.00	8w	catalog
12	75-115 GHz Miscel. wavequide	Aerowave	10-xxxx	1	$1,000	$1,000.00	4w	catalog
	RF and BB Components:							
13	Phase Locked Freq. Synthesizer 8.6 - 10.5 GHz	Micro Lambda	MLSL-xxxx	2	$3,200	$6,400.00	8w	quote
14	Oven Controlled Crystal Oscillator - 95.000 MHz	Wenzel	500 08181	2	$612	$1,224.00	10w	quote
15	Oven Controlled Crystal Oscillator - 29.985 MHz	Temex	QEO-67-CO-...	2	$650	$1,300.00	10w	quote
16	Digital Frequency/Phase Detector Box	NRAO	N/A	2	$1,000	$2,000.00	Mar/01	estimate
17	Triplexer	Pacific Millimeter	MD2A	1	$220	$220.00	4w	quote
18	RF Amplifier +19dB	Miteq	AU-1A-0520	1	$290	$290.00	8w	
19	RF Amplifier +30dB	Miteq	AU-2A-0120	1	$300	$300.00	8w	
20	RF Amplifier +24dB	Miteq	AU-1421	1	$300	$300.00	8w	
21	RF Amplifier +56dB	Miteq	AU-1494	1	$350	$350.00	8w	
22	Band Pass Filter 30MHz / 1.5 MHz BW	Reactel	AB6-30-1.5S11	2	$400	$800.00	8w	quote
23	Programmable Step Attenuator (63 dB /1dB)	Weinschel	3230	2	$500	$1,000.00	8w	quote
24	3-Way Power Splitter	Mini-Circuits	ZFSC-3-13	2	$52	$104.00	2w	catalog
25	2-Way Power Splitter	Mini-Circuits	ZFSC-2-6	2	$50	$100.00	2w	catalog
26	Miscel. RF (e.g. connectors, pads)	N/A	N/A	1	$500.00	$500.00	Mar/01	estimate
27	SSB Mixer and Quadrature Box	NRAO	N/A	3	$700	$2,100.00	Mar/01	estimate
28	DSP Card	NRAO	N/A	2	$500	$1,000.00	Mar/01	estimate
29	Voltage Regulators Box	NRAO	N/A	2	$300	$600.00	Mar/01	estimate
30	Receiver Enclosure and Mounting Plates	Machine Shop	N/A	1	$4,000	$4,000.00	Mar/01	estimate
	General							
31	Power Supplies/Eclosure/RF and Power Cables	TBD	N/A	1	$2,000	$2,000.00	Mar/01	estimate
	Note: Machine Shop estimates: $50/hour				**TOTAL:**	**$60,903.00**		

APPENDIX ‘B’ - MM-WAVE MIXERS AND GDO SPECIFICATIONS

COMPONENT	**SPECIFICATION**	
Biasable Balanced Mixer Millitech MXB-10-RR0WF	RF	104 GHz, 78.9 GHz
	IF	30 MHz
	LO	103.97 GHz, 78.875 GHz
	LO Power	1 mW
	NF or Conv. Loss	11 dB (max) (SSB)
	Bias Voltage	+15V
Varactor Tuned Gunn Oscillator Spacek Labs GW-103	Center Frequency	103.98 GHz
	Output Power	30 mW min
	Tuning Bandwidth	+ - 150 MHz
	Varactor Voltage	0 - 20 volts
	Gunn Bias	+10 volts
	Waveguide	WR-10
	Connectors	SMA-F
Varactor Tuned Gunn Oscillator Spacek Labs GW-789	Center Frequency	78.890 GHz
	Output Power	50 mW min
	Tuning Bandwidth	+ - 150 MHz
	Varactor Voltage	0 to + 20 volts
	Gunn Bias	+10 volts
	Waveguide	WR-10
	Connectors	SMA-F