3. Description of Hardware for Phase-Coherent Holography

This section describes the choice of hardware for the holography system that will be used to measure the surface profile of the MMA 12 meter antenna. The hardware required for phase coherent holography consists of a beacon transmitter operating at 92.4 GHz and a prime focus dual channel receiver. A simplified diagram of the system in shown in Figure 1.

The transmitter is located at a distance of 300 meters from the antenna and it is mounted on top of a 61 meters tower. The signal from the transmitter is received via two feeds. One direct from the transmitter using a 10 cm diameter feed (reference feed) on the front of the receiver; the other from the main feed that is used to illuminate the main reflector in a conventional way.

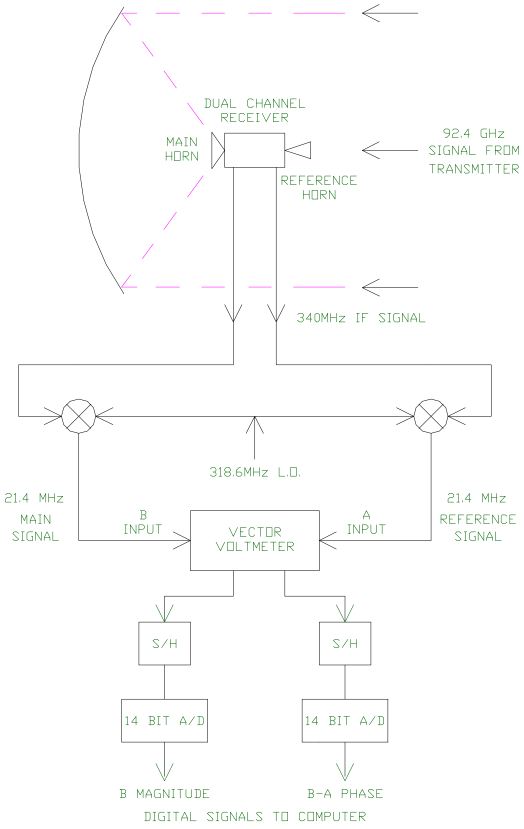


Figure 1. - Block Diagram

The signals from the two feeds are down converted to a 340 MHz IF using common local oscillators and are sent to the antenna receiver cabin via coaxial cables. Further down conversion in the holography receiver back-end converts the two signals to a nominal 21.4 MHz frequency suitable to be applied to the HP 8508A Vector Voltmeter. The voltmeter detects the two signals and generates two analog outputs, one is the amplitude of the main channel signal, the other is the phase difference between the reference and main channels. These two analog outputs are then sent to A/D converters and the converters outputs are sent to the antenna M&C bus through an interface box.

The basic hardware requirements are:

Phase accuracy:	< 0.3 degree RMS
Amplitude accuracy:	< 1%
Dynamic range:	≥ 43 dB
SNR	≥ 40 dB
Channel cross-talk:	> 100 dB
Data rate:	> 100 samples/second

Interfaced to the antenna M&C bus.

Phase accuracy, dynamic range and SNR values are calculated for a pathlength error of 10 microns and $\lambda = 8.2$ mm.

The holography system design described in this document is based on a system built by the Smithsonian Observatory to measure the SMA antennas at the Haystack test site. The SMA holography system (Zhang, 1996) easily achieved phase accuracy of 1 degree and lab test result shows measurement accuracy to the level of 0.1 degree.

3.1 Transmitter Location and Electronics

The transmitter signal source is a Gunn oscillator operating at a frequency of 92.4 GHz. A simplified block diagram of the transmitter is shown in Figure 2. Two main circuits, phase lock and automatic gain control (AGC), provides frequency and amplitude stability. Also, the AGC system provides a convenient way for verifying if the holography receiver signal levels are not saturating by inserting a calibrated power attenuation value in the signal path. Auxiliary circuitry provides remote monitor and control of all important functions.

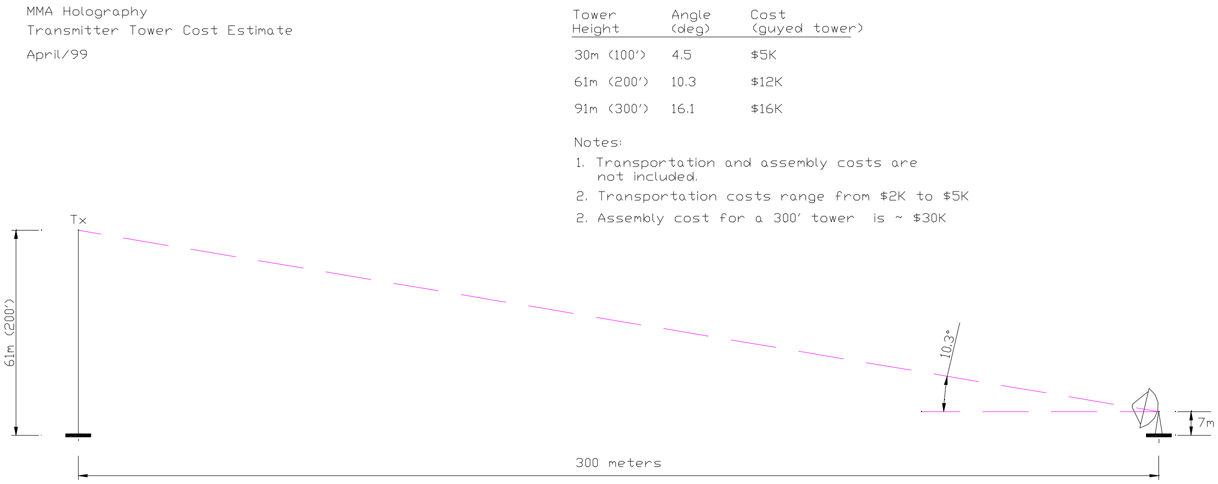
The transmitter box will be installed on or near the top of a 61 meters (200 ft) tower erected 300 meters away from the MMA antenna at the VLA test site or on the 12 meter Kitt Peak site for pre-testing the holography system performance. Under calm or low wind conditions, the tower will provide a stable platform for the beacon transmitter. A drawing of this arrangement is shown in Fig. 3. The choice of tower height is based on price, easy of assembly and stability problems. The cost estimate shown in Figure 3 doesn’t include assembly of the tower. This cost can be as high as $30k for a 91 meters (300 ft) guyed tower.

The enclosure that contains all transmitter components is weather proofed and temperature controlled in order to withstand extreme weather conditions when mounted on the tower.

Specifications:

Frequency:	92.4 GHz
Frequency stability:	≤ ±5Hz/day @ 92.04 GHz
Output power:	10mW at feed input (nominal)
Output power stability:	< 0.1%
Feed horn:	conical horn (1.63cm dia.), WR-10 waveguide, 21dB gain

All waveguide components are WR-10 size (75-110GHz band).



MMA Holography
Transmitter Tower Cost Estimate
April/99

Tower Height	Angle (deg)	Cost (guyed tower)
30m (100')	4.5	$5K
61m (200')	10.3	$12K
91m (300')	16.1	$16K

Notes:
1. Transportation and assembly costs are not included.
2. Transportation costs range from $2K to $5K
2. Assembly cost for a 300' tower is ~ $30K

Figure 2

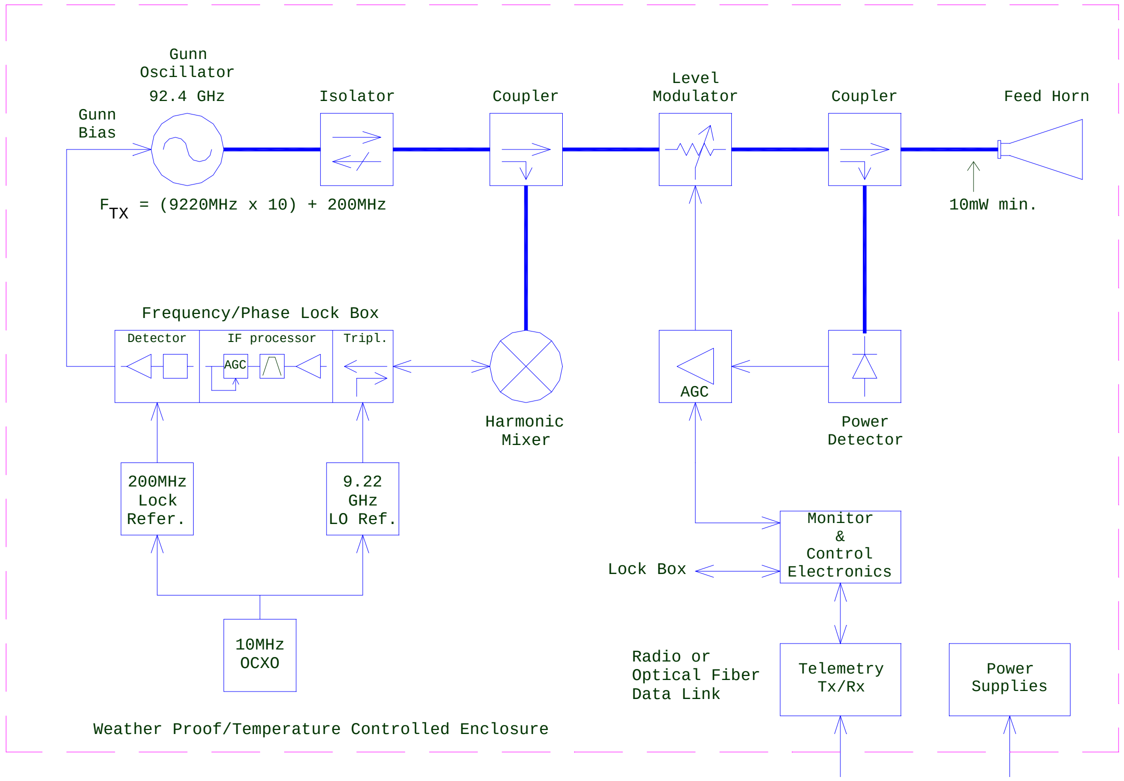


Figure 3: 92.4 GHz Transmitter Block Diagram

3.1.1 Transmitter Phase Lock System

This system uses phase lock loop that locks the output frequency of a Gunn oscillator to a low phase noise, high stability reference signal employing conventional heterodyne technique. A part of the 92.4 GHz signal is downconverted to an IF near 200 MHz by mixing it with a harmonic N (N = 10) of the output frequency of a phase locked oscillator at 9.22 GHz. The IF and LO signal paths are separated in the triplexer.

The IF signal is amplified, filtered and adjusted to a constant level in an AGC circuit. In the digital frequency/phase detector chip, phase and frequency of the IF signal are compared with those of a reference signal from a second phase locked oscillator operating at 200 MHz. The detector’s output is an ±error signal proportional to the frequency and phase difference between the 200 MHz IF and the 200 MHz reference signal. Frequency and phase lock acquisition is achieved by applying this error signal to the Gunn bias tuning. The frequency locking range is ± 100 MHz. The output of the phase-locked Gunn oscillator is determined by:

$$F_{gunn} = (9220 \text{ MHz} \times 10) + 200 \text{ MHz}$$

Both the 9.22 GHz PLO an the 200 MHz PLO are locked to a common 10 MHz OCXO which determines the long term stability of the output frequency of the phase-locked Gunn. The OCXO stability specs are:

≤ ±5 x 1E-11/day
≤ ±5 x 1E-9 for -40◦ to +50◦ C
Short term stability: 100ms: ≤ ±1 x 1E-11
1s: ≤ ±1 x 1E-12

3.1.2 Transmitter Automatic Gain Control (AGC)

The transmitter output is leveled by an AGC circuit. A portion of the Gunn signal is coupled to a power detector. The detector produces a voltage proportional to the incident power. This voltage is connected to one of the inputs of a differential amplifier and the other input is connected to a reference level that sets the desired output power of the transmitter. The output of the differential amplifier is buffered and applied to a voltage controlled ferrite modulator that is in the line before the detector’s directional coupler. The ferrite modulator voltage drive is adjusted by the loop until the detected power level matches the selected output level.

The transmitter output power is adjusted to 10mW measured at the feed horn input and the maximum output power available is estimated at 20mW. Calibrated attenuation values of 3dB and 10dB can be inserted by the AGC circuit. This is an useful feature when troubleshooting problems in the receiver system..

3.1.3 Auxiliary circuitry

Auxiliary circuitry built into the transmitter provides temperature control of the transmitter enclosure and remote monitor and control of the Gunn oscillator output power and phase-lock status. The transmitter telemetry is sent to the control room via an optical fiber link or radio transceiver link. The choice of data link type between the tx tower and control room will be made on basis of cost and other considerations (installation, RFI etc).

3.2 Dual Channel Receiver Electronics

A detailed block diagram of the receiver system is shown in Figure 4. The signals from the main feed and the reference feed are down converted and amplified in identical IF chains. The IF gain of both channels is adjusted to offset the large signal level difference between the main and reference channels.

A phase locked Gunn oscillator operating at 92.06 GHz provides the common LO for a pair of room temperature balanced mixers. Using a common oscillator makes the coherence problem more tractable. Enough isolation is built in the LO path to decrease channel cross-talk levels by more than 120 dB.

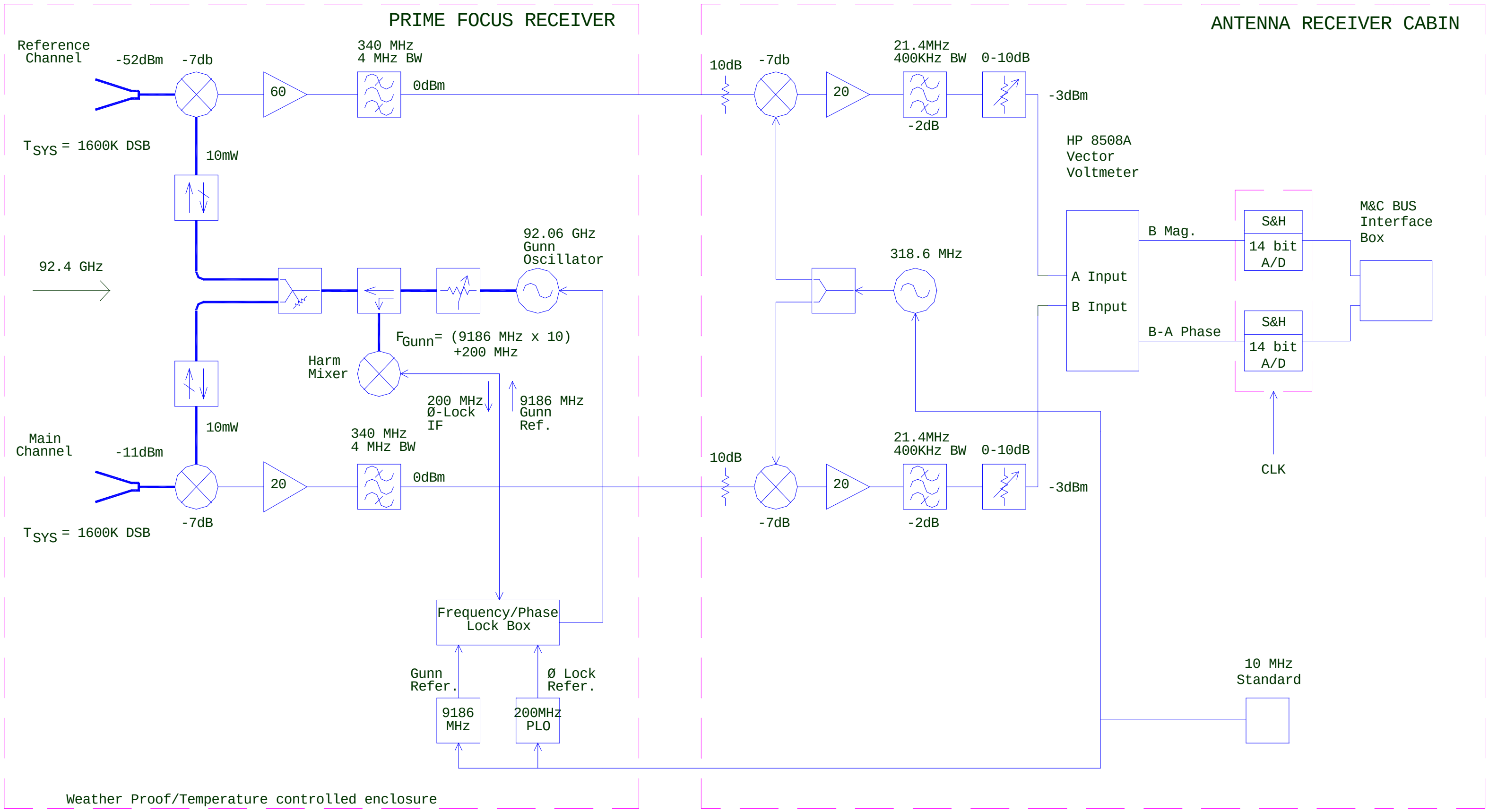


Figure 4: Dual Channel Receiver Block Diagram

In the receiver front-end, the two 340 MHz IF signals are amplified and passes a 4 MHz wide BPF, before the signals are sent to the receiver back-end inside the antenna rx cabin. In the back-end each path is further down converted to 21.4 MHz using DSB mixers. The local oscillator for the second conversion is a phase locked oscillator operating at 318.6 MHz.

The 21.4 MHz reference and main signals are amplified, pass through a 400 KHz BPF and adjusted by a step attenuator to a suitable level before it is detected by the HP 8508A Vector Voltmeter.

3.2.1 Receiver Gunn Oscillator Phase Lock System

The Gunn oscillator frequency/phase lock system is very similar to the system used for the transmitter and it is described in section 3.1.1

The Gunn frequency output is determine by:

$$F_{gunn} = (9186\ \text{MHz} \times 10) + 200\ \text{MHz} = 92.06\ \text{GHz}$$

The 200 MHz and 9.186 GHz phase locked oscillators are locked to a 10 MHz OCXO signal from the back-end receiver or the MMA antenna 10 MHz frequency standard.

3.2.2 The Signal and Reference Feeds.

The phase shift as a function of angular displacement in both the main and reference feeds is an important parameter for the holographic measurements. The main feed should be designed to have a well behaved amplitude and phase response over the telescope aperture.

The main feed should overilluminate the 12 meter dish to prevent phasefront distortions and avoid phase fall off at the edge of the primary.

The reference feed will be a 10 cm diameter lens corrected conical scalar feed horn.

Both feed horns phase and amplitude patterns will be measured on an antenna range and the results used to correct the far-field antenna response.

3.2.3 Signal Levels and S/N ratio

Assuming that the transmitter is mounted 300 meters away from the antenna under test and the available power at the input of the transmitter feed horn is 10 mW, the received power by the holography receiver main and reference feeds at boresight position are:

Main feed:	-11 dBm
Reference feed:	-52 dBm.

(Power levels are calculated for D = 12m, reference feed diameter of 10 cm and coupling efficiencies of 80%).

The calculated signal-to-noise ratios before the signals are received by the vector voltmeter are:

Main channel:	94dB
Reference channel:	52dB

(Values calculated for Tsys=1600K DSB and BW=400KHz)

The measurement signal-to-noise ratio is given by (D'Addario 1982):

$$SNR \cong \sqrt{\frac{\mathrm{P_{REF}}}{\mathrm{t}k\mathrm{T_{SYS(SSB)}}}}$$

For an integration time of 10ms the system SNR is approximately 66dB which is adequate for the MMA holography experiments.

3.2.4 HP 8508A Vector Voltmeter Specifications

An important component of the receiver back-end is the dual-channel vector voltmeter. The HP 8508A is a high-sensitivity receiver with a frequency range from 300 KHz to 2 GHz when used with the 8502A 50 ohm input module. The instrument achieves its best accuracy when operated in the 1 to 100 MHz frequency range.

The voltmeter is used in the direct analog output mode. This mode provides continuous direct output signals from the internal magnitude and phase detectors through 800 Hz low-pass filters.

Specifications:

Maximum input level:	16dBm
A (Ref) channel minimum level:	-57dBm
B (main) channel noise floor:	-87dBm
Measurement bandwidth:	1KHz (nominal)
Input Crosstalk:	>100dB

Direct analog output sensitivity:
Output 1 corresponds to linear amplitude of main channel.
Sensitivity: 1V equals full scale deflection.
Output 2 corresponds to B-A phase.
Sensitivity: 1mV per 0.1 degree

3.3 M&C Bus Interface

It is required that the holography back-end be interfaced to the antenna M&C bus. The back-end should be sampled at 100x per second. The single complex magnitude and phase analog values will be digitized and sent to the M&C bus.

The expected data rate is :

2 * 100 samples/s * 14 bits/sample * 2 bytes/14 bits = 400 bytes/s or 2 bytes/10ms

3.4 Holography System Tests.

The complete system will be extensively tested for performance and reliability before it is installed on the MMA antenna. Preliminary testing of the hardware will be made in the lab.

After all basic electrical and physical specifications of the hardware are verified and met, the system will be moved to Kitt Peak and installed on the 12 meter telescope. The complete system including software will be evaluated under conditions as close as possible to the VLA test site.

3.5 Time Schedule

Task	Start	Finish
Critical Design Review (CDR)	1999-11-29	1999-11-29
Procurement, fabrication, assembly	1999-11-30	2000-09-31
System tests	2000-10-01	2001-03-26
Deliver Holography System	2001-03-30	2001-03-30

References:

X. Zhang, et al, 1996, "First Result of the SMA Holography Experiment", SMA Memo No. 102

L. R. D'Addario, 1982, "Holographic Antenna Measurements: Further Technical Considerations" NRAO 12-Meter Telescope Memo No. 202.