

Holography Transmitter Design

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Planned Photonic Reference Distribution for Test Interferometer

The transmitter for the holography receiver is made up mostly of parts that are already planned for the test interferometer photonic reference for the first local oscillator. Since the planned system is integral to the holography transmitter, a brief description of the photonic reference distribution is given here.

The reference for the first local oscillator on the test interferometer will be generated photonically at the central building and distributed to each antenna by optical fiber. The layout of the photonic reference and distribution is shown in Fig. 1. This shows the layout of the planned system *without* necessary hardware addition for the holography transmitter. A single master laser at the central building forms one half of the reference for each antenna of the test interferometer. A second laser (the slave laser) is phase locked to an offset of the master laser at a multiple of the frequency of a microwave reference generated by an RF synthesizer. This slave laser will be phase locked to frequency offsets of the master laser ranging from 27-122 GHz in the box labeled Laser Synthesizer. There are two laser synthesizers locked to independent references supplied by two RF synthesizers, which will allow independent LO frequencies at each antenna. For the ALMA array, this will be modified so that each subarray will have an independent laser synthesizer. The output of the laser synthesizer is light on optical fiber at approximately 1550 nm wavelength. This is combined with a sample of the master laser onto a single fiber, and the two wavelengths are sent to the receiver at the appropriate antenna.

Coherence between the receivers at each antenna is maintained by a continuous round trip correction of the fiber optic distribution to the antennas. This correction takes place in the module labeled "Line Length Corrector" in the figure. Although the laser synthesizer will be used in the holography transmitter, the line length correctors will not be needed, because there is only one common path for source and reference on a single optical fiber.

Not shown in the figure is the receiver layout at the antenna. For purposes of this discussion, it is only relevant to note that the two wavelengths of light are used to illuminate a photomixer device, which converts the light to the microwave frequency given by the frequency difference. The RF output is then coupled via coaxial or fundamental mode waveguide to the receiver. The same technique will be used for the holography transmitter, except that the photomixer output will be coupled directly to a horn antenna by fundamental mode waveguide.

Implementation of Photonic Transmitter for holography

Fig. 2 shows a schematic similar to the layout for the test interferometer of Fig. 1, but with additional components added to implement a photonic transmitter for holography. At the control building, the addition of two switches and an optical combiner allows for the photonic reference to be put onto a separate fiber, and the line length correctors are bypassed. The switches and combiners amount to a rather simple rearrangement that could be incorporated into a "holography switch" module, or simply by having someone change the appropriate connections before and after holography is done. In any case, the main point is that the laser synthesizers in

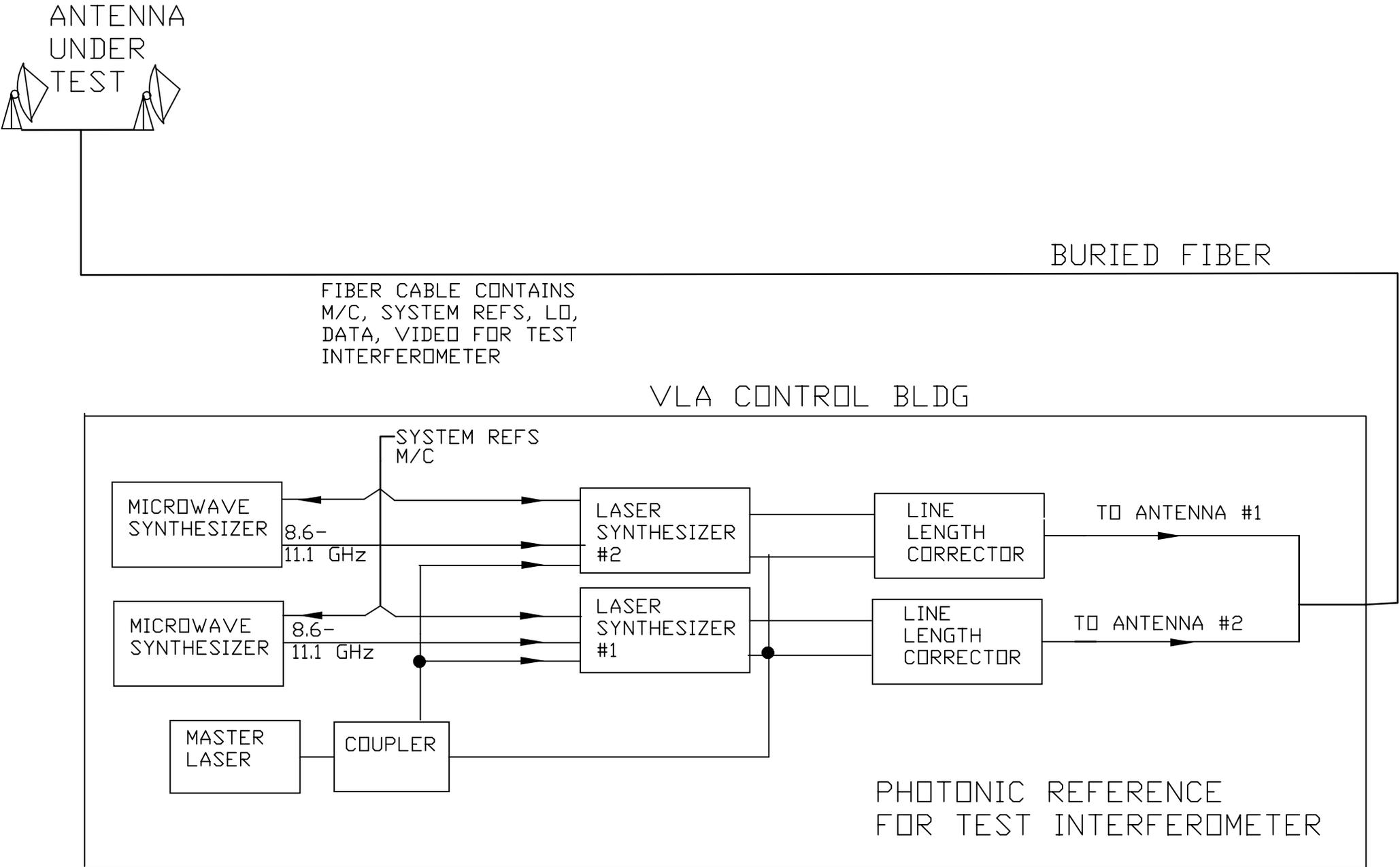
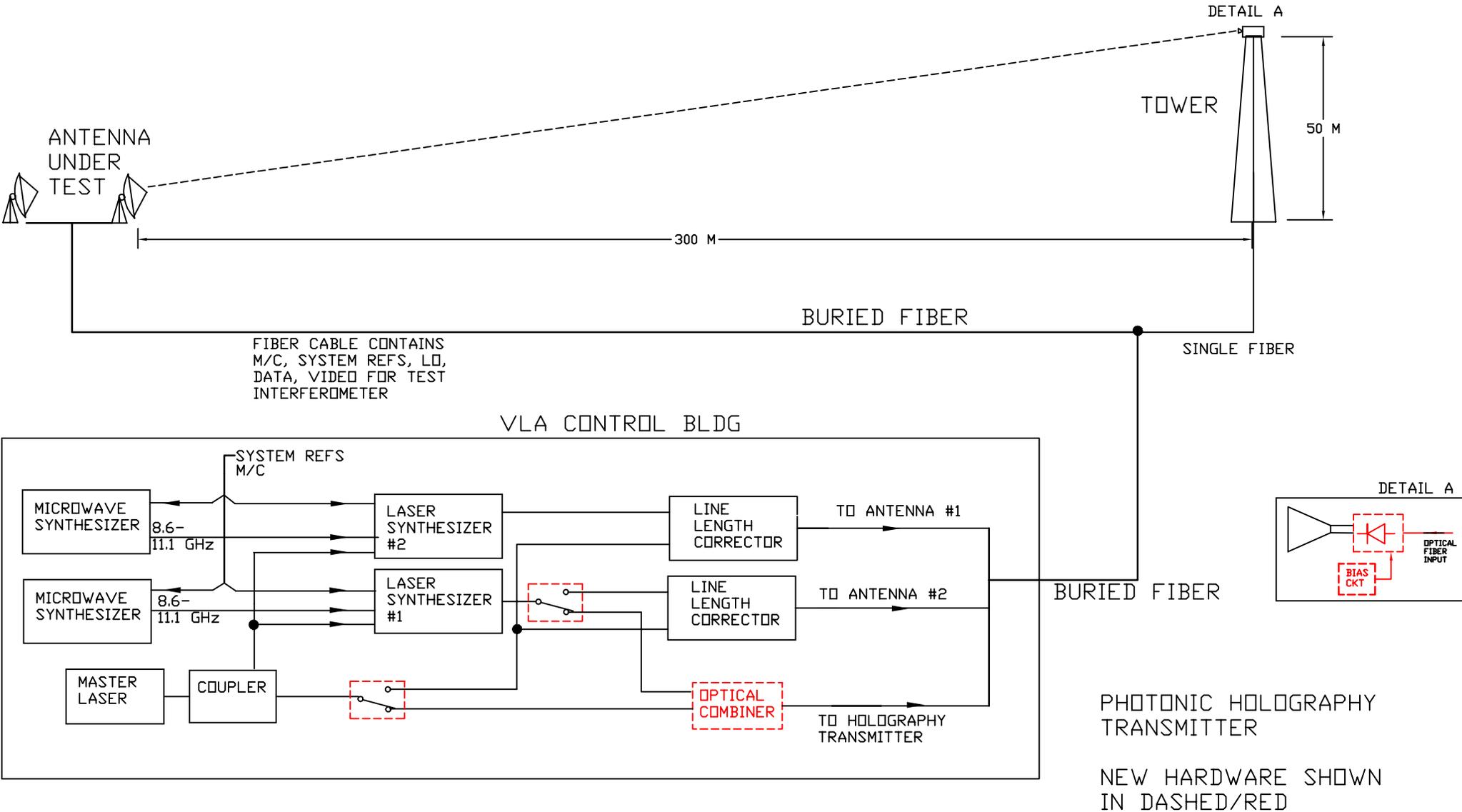


Fig. 1 - Photonic Reference Distribution for Test Interferometer



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Fig. 2: Additional Components required for Holography Transmitter

the control building will perform all of the frequency synthesis and monitor and control functions that are needed for the transmitter.

The holography tower, 50 m high, is also shown in the schematic. A single fiber that is buried and run out to and up the tower is the only signal that the transmitter requires. Upon the tower will be a small box containing a photomixer, horn, and a bias circuit consisting of a DC battery and passive components.

This implementation of the transmitter is cost effective because it consists almost entirely of already existing systems, or of components that will be duplicates of ones developed for the test interferometer (such as the photomixer). Other than cost, there is also the advantage of having a very simple box mounted on the tower, and a centrally located widely tunable synthesizer. The main drawback when compared to having a millimeter-wave oscillator as the transmitter is that the output power from the photomixer will be lower.

Specifications for the laser transmitter are shown in Table 1. The linewidth and drift specifications do not preclude use of a free-running source, but since our transmitter will be phase locked, these specifications are easily met. The tuning range is also easily met, as the holography is only expected to use 78.9 and 104.8 GHz. The tuning bandwidth comes into play if it becomes necessary to step the frequency of the transmitter in order to minimize the effect of ground reflections. The synthesizer step size is governed by the microwave frequency reference step size. For ALMA the proposed spec on this is 5 MHz, which would give a synthesizer step size of 50 MHz if we phase-lock to the 10th harmonic. However, for the test interferometer the plan has been to use a commercial microwave synthesizer as the reference, with a step size of 1 kHz. Thus, tentatively, we expect the minimum step size to be 10 kHz which easily meets the specification. The settling time specification is 10 seconds, which is made very conservative to account for some uncertainty that we have about what the tuning dynamics will be for the laser synthesizer. We will endeavor to make the settling time quite a bit faster than that but for the holography experiment it should not be too critical.

Table 1: Transmitter Specifications	Minimum Requirement	Expected Performance
Frequencies of Operation	78.9, 104.8 GHz	75-122 GHz
Tuning bandwidth	> 130 MHz required (> 200 MHz goal)	entire range
Minimum step size	< 1 MHz	10 kHz
Maximum step size	> 40 MHz	anywhere in range
Settling time	< 10 sec	TBD (1 sec goal)
RF power at flange of feed	> 1 micro-watt	> 5 microwatts
Linewidth (Frequency Jitter)	< 1 kHz in 30 msec	< 1 Hz
Frequency Drift	< 1 MHz in 30 min	< 1 Hz

Laser Synthesizer

Fig. 3 shows a schematic layout for the laser synthesizer. For the test interferometer, an external cavity diode laser will be used. This type of laser has single-mode, narrow linewidth and ease-of-tuning which makes phase locking convenient. The tuning range required for the test interferometer, 27-122 GHz, is a small fraction of the available tuning range of the laser (6 THz). A small amount of light from the laser is coupled off and combined with a portion of the output of the master laser. The output is then switched into either a low band for 27-33 GHz output, or a high band for 75-122 GHz output. (The unit cannot provide difference frequencies between 33-75 GHz which is by design only). The light is detected by a photomixer in the appropriate frequency range. Dual reference frequencies are then used to perform the phase lock. A variable reference frequency from 8-10.6 GHz is used to beat the signal down to an intermediate frequency (IF) using a harmonic mixer. The IF is then phase compared to a reference at 125 MHz, and the resulting phase error is used to correct and phase lock the slave laser to the master laser. The loop bandwidth is expected to be on the order of 1 MHz. The laser synthesizer has a much wider tuning range than a typical RF oscillator and is much more sensitive to temperature and environmental effects. The module will be shock mounted and temperature stabilized, but it is expected that frequency calibration will be required. Since the master laser will have some frequency drift, it does not make sense to calibrate the slave laser frequency to a fixed scale. Instead, a procedure will be used wherein the slave laser frequency is swept over a range until the beatnote frequency is measured. The desired frequency will then be synthesized using the known relative sensitivity of the laser.

One of the inputs to the laser synthesizer is the 8.6-11.1 GHz reference. The ALMA array specification for this module includes a step size of 5 MHz and has no requirement for frequency sweeping or modulation. Nevertheless, for reasons of expedience, a commercial synthesizer will be used for the test interferometer, and it will have a minimum step size of not larger than 1 kHz, and capability of frequency sweeping and external modulation. The laser synthesizer will likely be able to track a swept frequency over about +/- 15 MHz at all *output* difference frequencies. Swept frequencies over greater frequency ranges is a possibility currently being investigated. This is not a requirement for the holography baseline plane but may be a useful feature.

Table 2 gives a preliminary list of major interfaces for the laser synthesizer, as well as monitor and control functions and a list of some of the critical components.

Fig. 4 shows a spectrum of a photonic reference measured in the laboratory using components and phase locking technique similar to what has been described here. The loop bandwidth is a few hundred kHz, and the phase noise is about $.058 \text{ rad}^2$ in a 20 MHz bandwidth. This is sufficient for holography but needs to be improved for the local oscillator. The improvement should come from using a wider loop bandwidth, which is currently being developed.

Millimeter-Wave Photomixer

For the LO, photomixer devices spanning 27-122 GHz in discrete bands will be required. A minimum output power of one microwatt is required, although ten microwatts is expected. The latest measurements of a commercial photomixer chip performed at NRAO are detailed in ALMA memo #313. RF output power of as high as 40 microwatts at 110 GHz was measured.

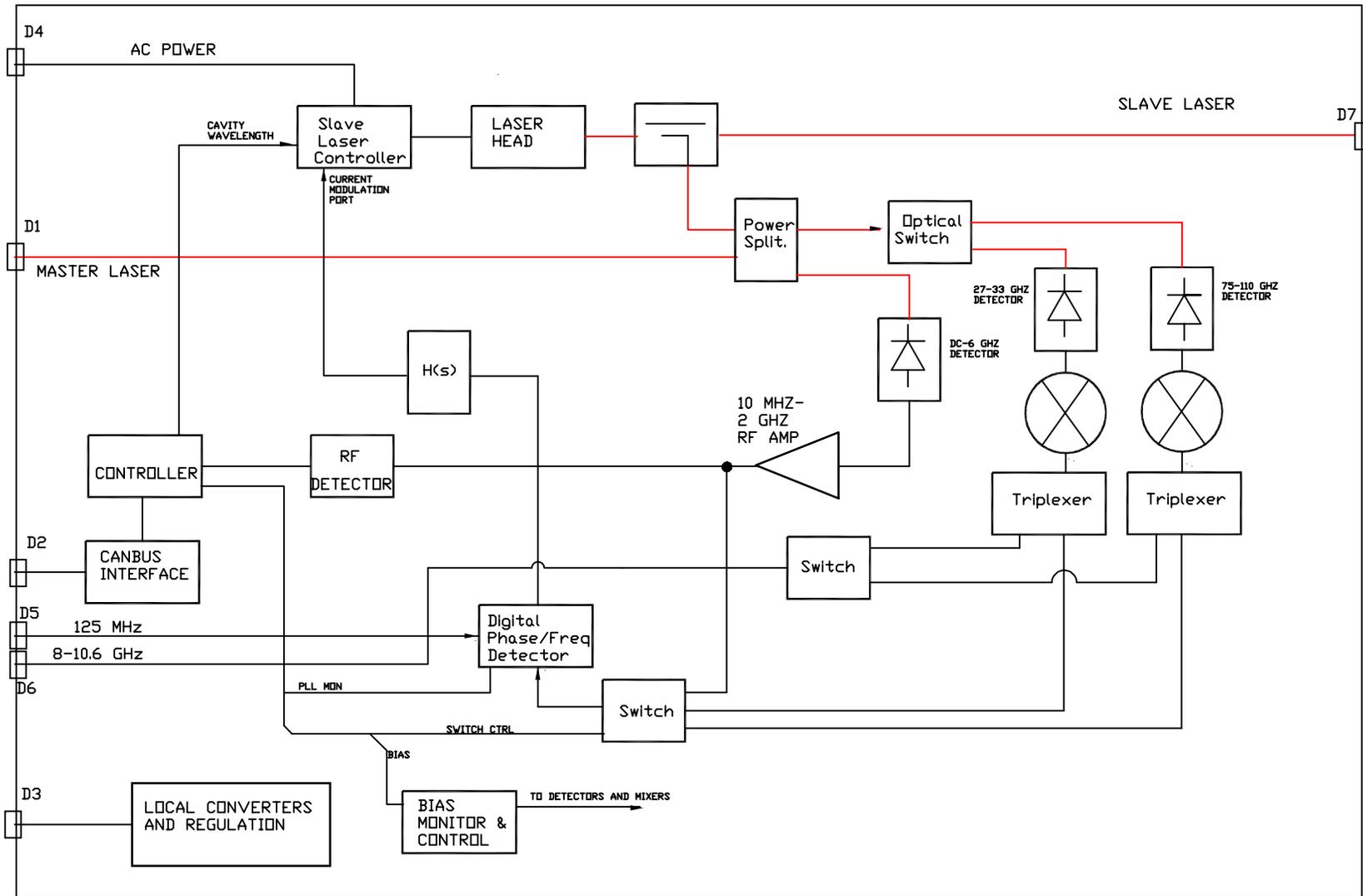


FIG. 3 - LASER SYNTHESIZER SCHEMATIC

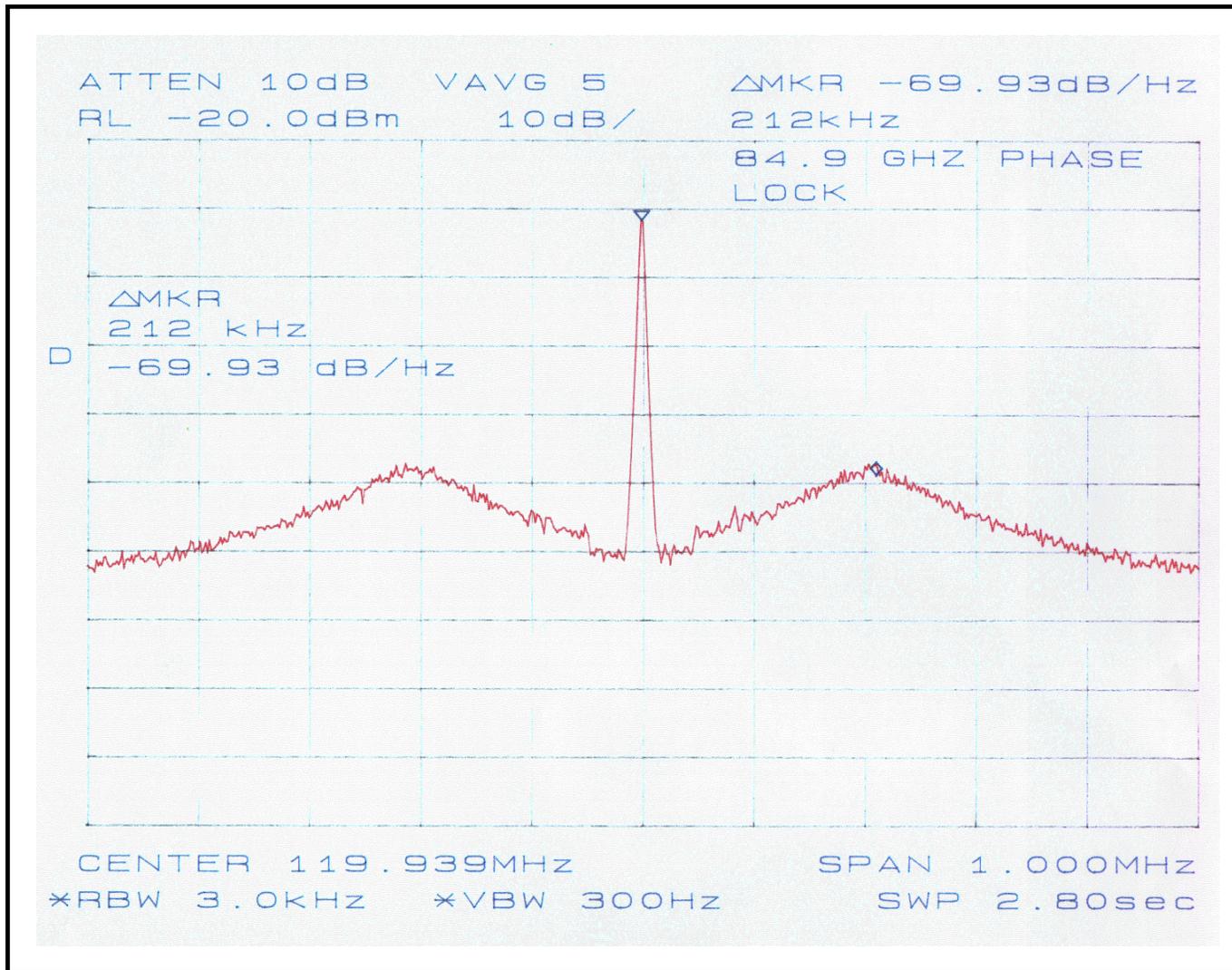


Fig. 4 : Measured Spectrum of Photonic Reference at 84.9 GHz

Integration of the photomixer chip into a package so that input light is injected via fiber, and the RF output is coupled into a WR-10 fundamental mode waveguide is an ongoing development for the test interferometer. It is expected that these packaged devices will be ready and available for the holography experiment. The backup plan will be to use the same chip in a commercially available device with a coaxial output. The coaxial output is overmoded at the frequencies used for holography but sufficient power is nevertheless expected.

Fig. 5 shows the RF output power measured from the photomixer chip versus frequency. For this test, the optical power level at the photomixer was about 4.0 mW, 2.0 mW from each laser. The chip can deliver significantly higher RF power at higher optical input levels. However, this is a reasonable estimate of the power level that will be available to the holography photomixer.

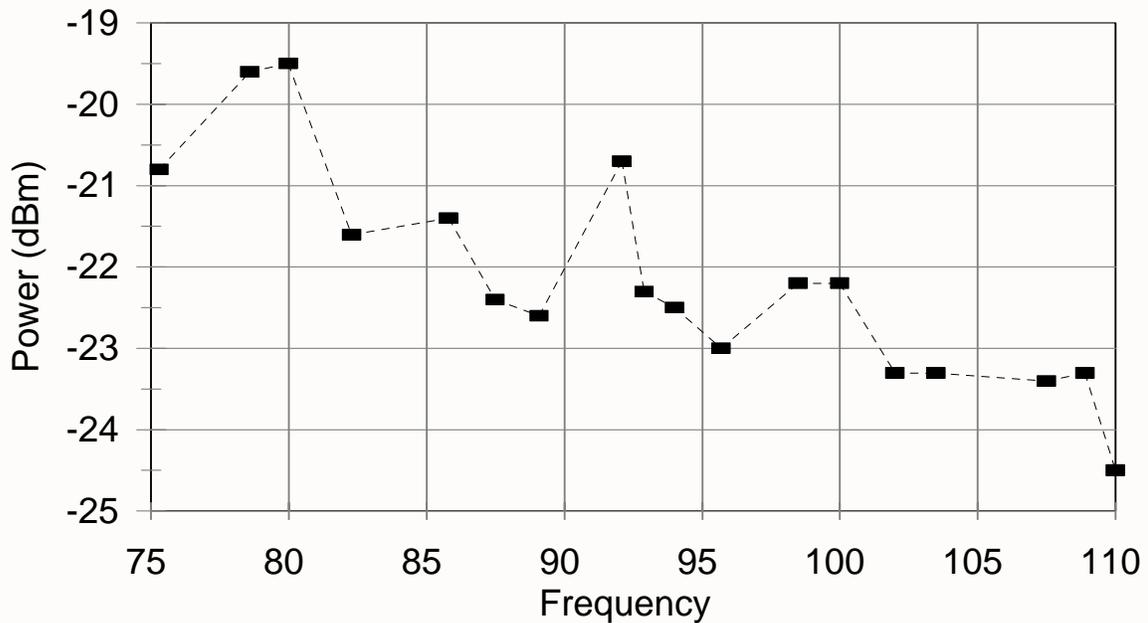


Figure 5 - Measured output power from commercial photomixer chip. Power levels are reasonable estimates of what is expected for the holography experiment.

An optical power loss budget is shown in Table 3, but it should be noted that there is some uncertainty about the loss of some components and about the power level available from the laser. In the unexpected circumstance that available power is less than the required level, a backup plan would be to add a commercial optical amplifier in the signal path at the central building. This would be an additional cost of \$12-15k, although it may be possible to use a unit that NRAO has already purchased for laboratory use.

Table 3: Transmitter power budget		Master Laser	Slave Laser
Power Available from Laser Module		35 mW	5 mW
Switch Loss	1 dB	28 mW	4 mW
Combiner Loss	4 dB	11 mW	1.6 mW
Connector Losses	2 dB	7.0 mW	1.0 mW
Fiber Loss	1 dB	5.6 mW	0.8 mW
Power Available at Photomixer	6.4 mW total	5.6 mW	0.8 mW
Photomixer Current	1.92 mA	1.68 mA	0.24 mA
Resulting RF power level	5 microwatts (-23 dBm)		

Transmitter Box

The transmitter box will sit atop the 50m tower and radiate the holography transmitter signal towards each of the two test antennas. There follows a description of the main features of the transmitter box.

Size: 150 mm x 150 mm x 150 mm (preliminary)

Inputs:

115 V AC power

Input fiber: Single mode Corning LEAF fiber with weatherproof bulkhead sleeve and interior Diamond E2000 mating adapter. This will carry the input difference frequency

Outputs:

Output fiber: Single mode Corning LEAF fiber with weatherproof bulkhead sleeve and interior Diamond E2000 mating adapter. This will carry a -20 dB sample of the input difference frequency (which is returned to the central station for monitoring purposes).

Antenna: A corrugated horn will be integrated with the transmitter box, and will be either have a lens-corrected aperture or be covered with a dielectric sheet covering for weatherproofing.

Environmental:

The box will be designed for conditions of exposure to all types of weather conditions: high winds, rain, snow, temperature extremes anticipated for year round operation at the VLA site. A radiant heater will be used to eliminate moisture on the feed horn aperture. The feed will be pressurized and desiccated for moisture control. A temperature controller will be included to keep the photomixer and bias circuit electronics within a suitable range that is to be determined.

Operational Features:

The box will have no external monitor and control except that a sample of incoming light will be sent back to the control building via a second fiber. Bias will always be applied to the photomixer, which will draw current only when the difference frequency signal is sent from the central station. Bulkhead mounted meters will indicate the photomixer voltage and current. A failure condition of the transmitter will be detected at the central station either by a detector reading no returned light on the fiber from the transmitter, or by the holography receiver not detecting the radiated signal. This will require that someone climb the tower, and unless the failure mode is obvious and easily remedied, the entire transmitter unit will be replaced by a spare unit.

The transmitter must be pointed at each of the test antennas, so the mount must be adjustable into at least two positions. At these two positions, moreover, the transmitter must be adjustable in elevation and azimuth to peak up on the 12-m test antenna. A long tube with crosshairs will be mounted on top of the transmitter to aid in the alignment.

Feed Horn:

The feed horn will radiate a beam of about 4.6 degrees FWHM, which is twice the beamwidth subtended by the 12-m test antenna. The feed aperture will be thus be approximately 50mm. For optimum power transfer to the holography receiver, the feed horn should have equal E- and H-plane patterns. Also, the feed horn should have a radiated pattern that does not change too much between the two holography frequencies. Further details of the transmitter's horn design are given in the Holography Receiver Design document, in connection with discussion of the horns required for the receiver.