Design Considerations
for a GBT 68-92 GHz Receiver

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1. Introduction

Scientific motivation for equipping the GBT with receivers for the 3mm band (68-116 GHz) has been discussed in several memos [1]-[3], and later presented in a proposal by the GBT 3mm Receiver Working Group [4]. It was decided that the first receiver module to be built should be capable of both continuum detection and spectroscopy in the 68-92 GHz band (Module 1). Other frequencies and capabilities in the 3mm band will follow soon after.

The scientific requirements led to set of receiver specifications that was revised and summarized in the published Conceptual Design Report [5]. These specifications are included in section 2 of this document for convenience.. The purpose of this report is to address each of the critical requirements of the receiver, presenting design trade-offs, and to relate system requirements to possible receiver architectures and associated component performance specs. A recommended receiver configuration is presented.

In summary, the 3mm development program will begin with the construction of a 68-92 GHz receiver, capable of supporting very sensitive continuum observations, and also spectral line work. The basis of the proposed design is a pseudo-correlation receiver, modeled after the MAP radiometers, which will achieve continuum sensitivities on the order of 2mK/rt-sec. Nearly ideal radiometer sensitivities can be attained by overcoming the HFET's instabilities in the pseudo-correlation. Added to this continuum receiver will be standard heterodyne channels, capable of converting the sky frequency to IFs suitable for a variety of back ends. These spectral line channels are connected to the output side of the pseudo-correlation differencing assembly through directional couplers.

The module 1 will be a dual beam receiver (approximately 32 arcsec beam separation), with dual linear polarizations. In continuum mode, the two beams will be continuously differenced and recombined in the front-end hardware. Phase switching in the arms of the differencing assembly will toggle the beam assignment of the detectors. The receiver will provide for continuum detection in a 20 GHz bandwidth (70-90 GHz) from each beam. In spectral line mode, the two beams are differenced and added back together as in the continuum case, however, phase switching may be turned off.

2. Review of Scientific Specifications

2.1 Frequency coverage:

Module 1: 68-92 GHz (some flexibility in this range, and wider tuning coverage is desirable)

(Module 2: 90-116 GHz)

There has been interest in extending the upper limit of module 1 to include 93.2 GHz for spectral line work. This frequency extension will be accepted as a goal, however, the performance of the receiver will not be known until prototype tests are performed. It is expected that module 2 will offer much better performance at 93.2 GHz.

2.2 Bandwidth:

Spectral Line: Minimum: 4 x 800 MHz = 3.2 GHz (=> 4 GBT Spectrometer sections end to end.)
Desired: 20+ GHz for spectroscopy with special, wideband correlator (e.g., for redshift surveys)

Continuum: Minimum: 7 GHz (BW capacity of 1 analog optical fiber)
Desired: 20+ GHz for maximum continuum sensitivity.

2.3 Noise Temperature Sensitivity: Trx < 70 K (SSB) across tuning band.
Goal: Trx = 50 K (SSB)

2.4 Continuum Sensitivity in the absence of atmosphere:
<2mK/rt-sec (corresponds to Trx=70 K, BW=7 GHz)
Goal: ~1mK/rt-sec (corresponds to Trx=70 K, BW=20 GHz)
(The GBT is expected to have about 1 K/Jy sensitivity at 90 GHz, so that 1 mJy ~ 1 mK.)

2.5 Polarizations: Dual Linear, with option for circular for VLBI.

2.6 Number of Beams: Dual (=> 4 receivers, dual polarization and dual beam)

2.7 Beam separation:
4 beamwidths => 32 arcsec at 90 GHz (3-5 beamwidths acceptable, but effort will be made to achieve 3-4 beamwidths.)

2.8 Switching Modes:

Fast beam switching

NB. The scientific specification of excellent continuum sensitivity led to a practical design of a pseudo-correlation receiver, with phase switching at up to 2.5 kHz rate with <1 microsec blanking time.

The need for faster phase switching was discussed at the CoDR. As a goal, a maximum rate of 10 kHz was accepted at the CoDR.

Position-switching: total power with antenna position switching.

Frequency switching:
±10 MHz switch at 10 Hz rate. (corresponds to ~30 km/sec velocity switch)
Following the CoDR, a switch of ±50 MHz was accepted as a goal.

Tertiary beam switching: Future add-on for optimal continuum and spectral line beam switching performance.
Switch between the two beams at ~10 Hz rate.

2.9 Observing modes:

Spectral line (requires total power with phase binning done by the backend)
Continuum
Polarization (using the polarization mode of the GBT Spectrometer)
VLBI (total power, circular polarization) Note: the native polarization of this receiver will be linear. We plan to use a removable quarter-wave plate to produce circular polarization for VLBI. The quarter-wave plate is not capable of producing circular polarization across the whole 68-92 GHz band.

2.10 Calibration:

Ambient temperature blackbody load on switchable chopper wheel or vane (hot/sky calibration). Ambient loads are typically switched in for a few seconds at a time and the beginning of a scan, or sequence of scans. Receiver saturation is addressed in section 2.6.

Desirable: Hot / Cold / Sky system (ambient loads) for improved calibration accuracy.

3. System Considerations

The receiver design has progressed with allowances for future expansion, where practicable, and where such consideration does not overly complicate the project. The addition of Module 2 in the same cryostat will be easily implemented. To preserve the option of adding tertiary optics in the future, our design leaves the area above the turret free of obstacles; any optical devices that are included as part of the “Module 1" project, for the purposed of automated thermal calibration or feed selection, will be mounted below the turret surface. The feed horns must be positioned at a considerable distance below the nominal feed plane to allow for the addition of optics . We can compensate for this axial offset using either a translation of the subreflector, or else through the use of the added optical components (re-focussing the telescope beam). As a goal, we will make every effort to keep the overall size of the receiver package within the constraints of a 24 inch turret opening. The receiver block diagram is given in figure 1.

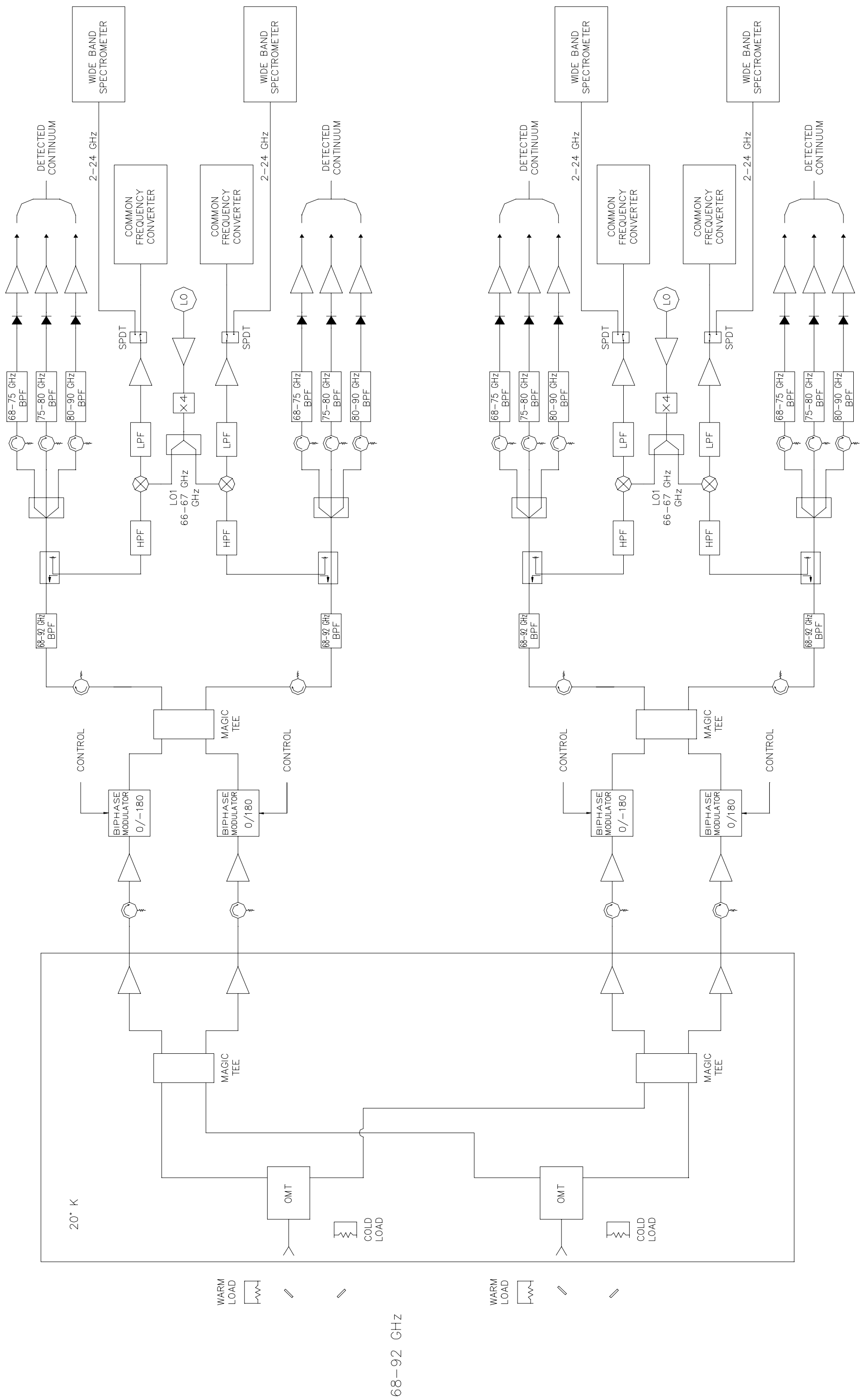


Figure 1. 3mm receiver, module 1, block diagram.

3.1 Spectroscopy: The receiver will transmit any 4.0 GHz wide band of sky frequencies to the GBT Equipment Room over optical fiber, where it can be processed in a variety of back ends. There will be four channels available: two beams separated by 32 arcsec, and two polarizations per beam. All four channels must be tuned to the same sky frequency. There will be provisions in the receiver design for a wideband spectrometer, with perhaps 20 GHz bandwidth, to be used in redshift surveys.

It has been suggested that the ability to terminate one of the beams in a cold load would be desirable, however, this capability is no longer being planned. The close feed horn spacing does not lend itself well to optical methods of terminating just one of the beams.

Frequency conversion is discussed in detail in section 4, but it is worth mentioning here that the decision to provide a wide-band (2-24 GHz) IF has brought with it some manufacturing difficulties. Image rejection and LO leakage will require special attention, in terms of filtering, and shielding of enclosures. Also described in a separate report [6], is the concept of a shared *frequency converter* module; with the anticipation of wide-band IFs being desired in other receivers (3mm Module 2, the 26.5-40 GHz receiver), it is proposed that a common frequency converter be used, capable of serving all mm-wave receivers. The converter will have at its input a multi-throw switch that will select a 2-24 GHz IF from one of many mm-wave receivers. The unit is designed to take the 2-24 GHz input and condition it as needed to make it compatible with the existing 1-8 GHz fiber optic transmission system.

3.2 Continuum detection: Continuum will be detected in the 70 GHz to 90 GHz band. To give users some spectral information, the continuum band will be segmented into three subsets: 70-77 GHz, 77-83 GHz, and 83-90 GHz. A pseudo-correlation architecture was chosen as the best method to overcome the effects of gain instabilities (1/f noise) in HFET amplifiers. Examples of pseudo-correlation receivers (also known as continuous-comparison radiometers), and the analysis of 1/f noise cancellation can be found in the literature [7]-[10]. Gain fluctuations in a radiometer can be characterized in terms of its 1/f "knee" frequency. The pseudo-correlation radiometers of the MAP project successfully reduced the knee frequency from a few kHz (typical of a simple TP radiometer) to just 10 mHz.

Pre-detection gain requirements are set by additive noise levels in the detectors and post-detection processing; at the detector outputs, we wish to have the radiometric noise level be at least 10 times greater than the input noise of the post-detection electronics. Assuming Tsys = 100K, we will need approximately 55 dB of net pre-detection gain to avoid the effects of post-detection additive noise. Given that we plan to use two cascaded LNAs (designed by CDL, with 35 dB gain each), the total insertion loss of all predetection components (with the exception of the LNAs of course) should be about 15 dB. Our current plan is to provide continuum detection at RF, but the possibility exists to detect at the first IF without a loss of sensitivity.

There are three critical design goals that will affect the sensitivity of the continuum receiver:

(a) to minimize of the loss in front of the first LNA, and to cryogenically cool the lossy components,

(b) to balance the gain and phase in the arms of the differencing assembly,

(c) to maximize the S/N at detection and post-detection circuitry.

Items (a) and (c) are really both part of the larger category of *system level analysis*; in a typical receiver system, the noise temperature is generally thought to be set by the first LNA, providing the gain is very high. A poor choice of gain distribution, however, can lead to a degradation of signal-to-noise ratio at any point in a receiver chain, leading to a reduction in radiometer sensitivity. In our 3mm receiver design, we have a situation in which noise added by the post-detection circuits can be comparable in magnitude to the radiometer noise we wish to process. Dividing the continuum detection into three sub-bands alleviates some of the difficulties, in that it gives us the option of increasing the spectral density of the radiometric noise without as great a danger of saturating the detector. Increasing the predetection gain will provide immunity to noise in the detection/processing circuitry, however, adding too much gain will increase the risk of receiver saturation (when observing bright objects, or ambient blackbody calibrators). Very high gain within the dewar could lead to oscillations, as the dewar vessel is a resonant waveguide cavity. For this reason, we place only one of the two RF LNAs inside the dewar. As a precaution, resistive elements can be fixed to the walls of the dewar vessel in strategic locations.

To minimize the effect of pre-amplifier loss in the receiver front-end, we plan to cool the feed horns and OMTs. Table 1 shows the noise budget of the 68-92 GHz receiver system.

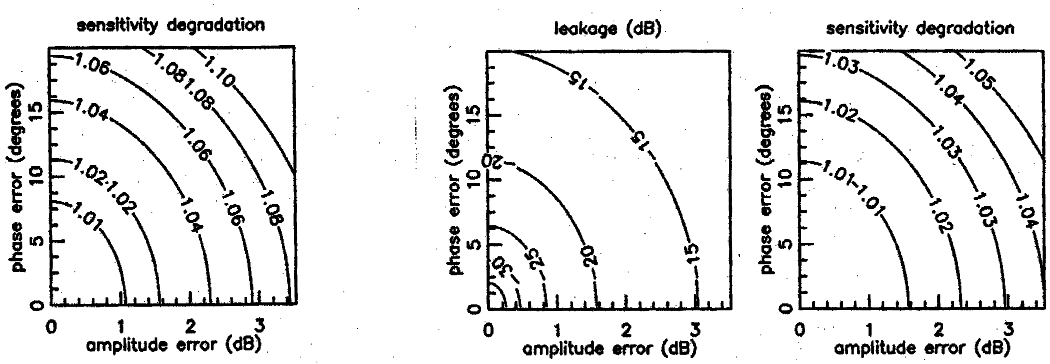
GBT 68-92 GHz RECEIVER: SYSTEM TEMPERATURE

Component	Gain/Loss [dB]	T_{amb} [K]	T_N [K]	T_{sys} [K]
Vacuum Window	-0.05	77-300	~ 3	~ 3
Feed	-0.15	20	0.7	0.7
Circ/square trans	-0.1	20	0.5	0.5
OMT	-0.20	20	0.9	0.9
Magic tee	-0.8	20	4	4
LNA	33	20	55	55

Isolator	-1.3	298	104	-
LNA	35	298	375	0.2
Biphase Mod.	-3	298	297	-
Total				64.3

Table 1. Contributors to system noise temperature.

If gain and phase are not very well balanced (between the two arms of the differencing assembly), cancellation of gain fluctuations will not be effective. Imbalances will lead to a reduction in radiometer sensitivity, and an increase in leakage between the two channels. The effect of gain imbalance [8] on radiometer sensitivity (in phase-switched differential mode) is shown in figure 2(a). Figure 2(b) shows the effect of gain and phase imbalances on sensitivity and channel leakage in the total power mode.



(a) (b)

Figure 2. (a) Sensitivity degradation as a function of gain imbalance in phase-switched differential mode, and (b) the effect of gain and phase imbalances on sensitivity and channel isolation in TP mode (from Padin, ref. [8]).

Our goal is to achieve 1 dB and 7 degrees balance for the frequency range 70-90 GHz (or equivalently 15 dB carrier suppression), and 3 dB / 20 degrees balance at 68 GHz and at 92 GHz the band edges. These goals give 1% sensitivity degradation in phase-switched differential mode, and 3% leakage and 3% sensitivity degradation in TP mode at the band edges. Gain balance outside the 70-90 GHz range can likely be improved over bandwidths up to 4 GHz by remotely varying the bias current of the biphase modulators according to look-up table.

The dynamic range of the continuum receiver will be limited by a low-level boundary set by the post-detection noise, and at high levels by saturation of the second LNA. The

LNA, when biased for optimum noise temperature, has an output 1 dB compression point of -10 dBm. This marginally gives us enough power to avoid noise contributions from the post-detection. We are in the process of experimenting with LNA bias levels to see if we can achieve higher power levels. It is desired to have a dynamic range of 6 dB, allowing a range of receiver input temperatures between 100K and 375K (cold sky and ambient thermal calibrator).

3.3 RFI

Fujitsu has developed a 76 GHz high frequency analog ICs for automotive radar systems**.** The new IC is the first to use flip-chip technology at mm-wave frequencies; it is capable of being mass-produced, and allows for rapid system assembly. System cost to the consumer has been drastically reduced.

Also see reference [11] and appendix A for a complete list of known potential RFI sources in the 3mm band.

3.4 Band-limiting components

The biphase modulators and the magic tees will limit the receiver bandwidth, at approximately 30%.

3.5 Cryogenics

The existing GBT helium compressors and distribution system will be used. An effort will be made to minimize the required helium flow rate to this 3mm receiver by using a CTI model 350 (or equivalent) refrigerator, rather than the model 1020. We plan to cool the feed horns, circular-to-square transitions, OMTs, magic tee, and the first LNA to 20 Kelvins. All other receiver components will be at room temperature.

3.6 Calibration

Amplitude calibration of astronomical data will be performed by means of an ambient blackbody load mounted on a chopper wheel. There is a concern about the possibility of saturating the receiver's second LNA, which is believed to have an output 1 dB compression point of approximately -10 dB. Our receiver calls for approximately 60 dB of pre-detection gain. With a 375 Kelvin input in a 22 GHz bandwidth, the output power from the final amplifier stage is -9.5 dBm. We desire an amplifier with a P1dB at least 20 dB higher than this.

Gain compression tests will be performed on September 28, 2001. If the compression point of the LNAs is not high enough, we will pursue the use of amplifiers from the ALMA LO group, or else use semi-transparent vanes for amplitude calibration.

VLBI phase cal injection will be at IF.

3.7 LO System

The LO system will be designed to allow for frequency-switching observing modes. The LO system will be phase stable, as required for VLBI at 86 GHz [12]-[14]. The favored system configuration is shown in figure 3. It consist of the existing GBT LO1 as its base, followed by frequency multiplication, filtering and amplification. The multipliers and amplifiers were designed for the ALMA project and tested [15]. The most significant contributors to the total phase noise on the first LO will be the maser and the HP synthesizer. Expressed in units of time, the rms jitter on the synthesizer and hydrogen maser is 0.75 and 0.20 psec respectively. The ALMA frequency multiplier module contributes only 63 fsec.

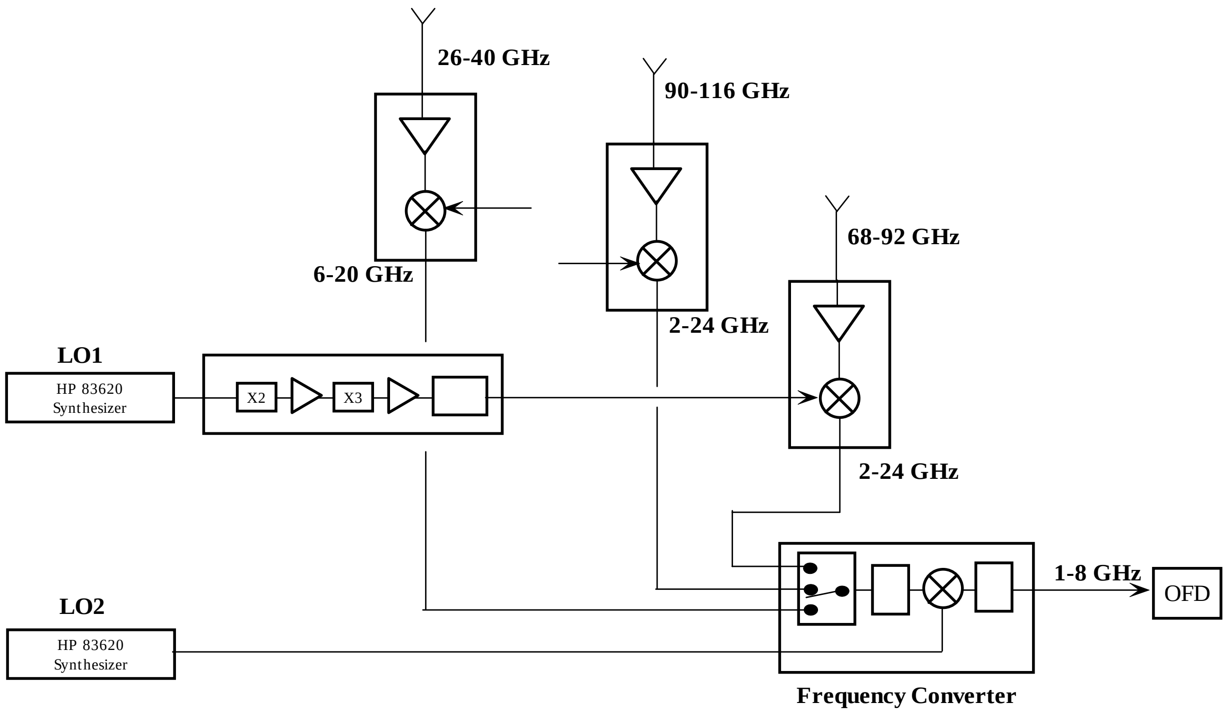


Figure 3. Concept of a mm-wave LO system using a shared multiplier and a shared frequency converter.

The proposed LO system requires a second frequency conversion in the Gregorian receiver room, using the LO1B synthesizer as a tunable source. Use of the LO1B synthesizer as a tunable LO source precludes its use as a test-tone generator. A fixed-frequency test-tone source may be added the receiver at a later date. The required range for the second LO is 11 GHz to 18 GHz. It is envisioned that this LO will be part of a shared frequency converter unit, comprising a mixer, a filter bank, and and amplifier.

3.8 Gain stability

HFET amplifier gain fluctuations become significant when detection bandwidths become large. A pseudo-correlation receiver architecture was chosen as best solution to this otherwise limiting influence on radiometer sensitivity.. The use of a temperature-controlled plate (for ambient temp components) is being considered. The receiver front-end will be constructed as a tightly-integrated package to provide long thermal time constants. Thermal isolation of each arm of the differencing assembly may be desirable to reduce correlated gain fluctuations. Mechanical isolation of the cooled receiver components will minimize refrigerator induced modulations.

3.9 Array receivers

No effort will be made to allow for future expansion of the number of pixels in each module of this initial 3mm receiver.

3.10 Infrastructure

Turret: The 3mm receiver will be designed to fit in one of the existing holes in the turret, and it will occupy minimal space in the Gregorian cabin.

Cryogenics: The receiver will use the existing GBT helium compressor system
Tertiary reflector system: A tertiary system, as it was envisioned in recent years [16]-[19], will not be designed as part of this project, however, the 3mm receiver system will be designed with the expectation that a tertiary system may be added later. This constraint will lead to the following choice of architecture: either (a) the top surface of the turret must be kept clear and free of optics used for receiver calibration, or (b) if calibration optics are placed above the turret (as part of this Module 1 development project), they will have to be adapted (in the future) to the additional functionality desired. Such a system will then need to serve all functions of amplitude calibration, beam switching, and structure distortion correction. The choice may have an effect on feed horn design, although axial offsets could be taken out by translation of the subreflector, or by the addition of focussing elements.

4.0 Resolution of open technical issues or design alternatives discussed at the CoDR:

1. *Consider merits of shifting the frequency coverage to a single module of ~85-115 GHz. Some observatories, notably UMass, have traditionally opted to cover only the high end*

of the band (as much as 80-115 GHz). This covers the majority of important spectral lines including all CO isotopes, CN, CS, HCN, HCO+, SiO, and many others, but forfeits some important species such DCN and DCO+ that lie below 75 GHz. A receiver covering ~80-115 GHz would cover the best continuum window, which is ~80-100 GHz.

The idea of separating module 1 into two modules was considered. Rather than having a single module that served all functions of spectral line and continuum observing, the merits of separating the functions into separate modules were evaluated. In such a scheme, one module would cover 68-92 GHz and be optimized for spectral line work. The other module would be optimized for continuum detection in the 80-100 GHz band. It was decided that the benefits of two-module plan were small compared to the added cost and complexity. We intend to continue with our original plan and not pursue the separating of spectral line and continuum functions. Both capabilities will be served by a common receiver front-end, called module 1.

2. *Consider a 20 GHz wide IF.*

This capability has been added to the design.

3. *The biphase modulator from Pacific Millimeter may not be able to cover Module 1's full 30% bandwidth. The best that PM has done for the MAP project is 26%. In addition PM does not have an existing design that is centered on our band. Other sources are being considered.*

PM is willing to create a new modulator design for this project without additional cost or schedule impact. There's a small risk that there will be some degradation at the band edges.

4. *Placement of both LNAs ahead of the biphase modulator to reduce Trx.*

This has been done.

5. *Using higher switch rates, and placement of the second LNA outside the second tee.*

We plan to increase the switching rate from 2.5 kHz to 10 kHz. The placement of the second LNA is still under discussion.

6. *How best to create circular polarization for VLBI?*

We plan to use a removable quarter-wave plate.

7. *Continuum detection and baseband processing*.

The use of CalTech's baseband processing design is under negotioation..

8. *Vacuum window technology*.

Crystalline quartz with matching layers is preferred [20].

9. *Segmenting the RF continuum path*.

The band has been divided into three parts.

10. *Design of a tertiary reflector and chopping system*.

The initial outfitting will not include tertiary reflectors, but will include a “chopping” wheel capable of a variety of rotational modes.

5. Frequency Conversion

The initial proposal for this receiver called for a dual conversion; a variable first LO would convert any portion of the RF band to an IF in the range 18-26 GHz. A fixed-frequency second LO would further convert the sky frequency to 6 GHz with 4 GHz bandwidth. This scheme is shown below in figure 4.

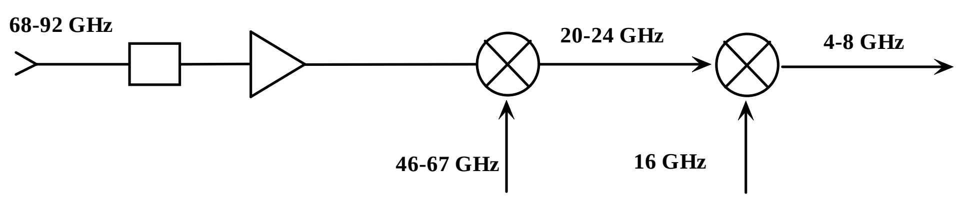


Figure 4. Frequency conversion scheme originally proposed.

A change to this scheme was proposed, to allow for the future use of wideband spectrometers. We have opted for a new approach that uses an essentially fixed first LO at 66 GHz to convert the entire RF band to an IF range of 2 GHz to 22 GHz. This first IF will not be transmitted off the telescope. As shown in figure 5, a variable second LO will produce a second IF in the range 4-8 GHz to be transmitted over single-mode fiber to the Equipment Room where the IF signals can be input to a variety of back ends. Future processing of wide-band IFs will need to be done in the Gregorian receiver room. To allow for this capability, the 2-22 GHz IF channels will be made available as coaxial outputs on the *common frequency converter* unit.

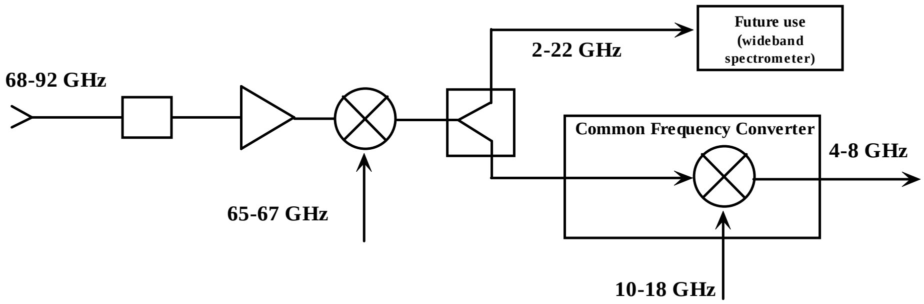


Figure 5. Recommended frequency conversion for wideband IF.

The GBT Spectrometer incorporates eight 1.6 GHz samplers enabling users to analyze up to eight 800 MHz wide spectra simultaneously. With the GBT common IF/LO system, the user can stagger-tune four pairs of these and cover 3.2 GHz of instantaneous bandwidth on two polarizations, with 391 kHz frequency resolution. This observing mode will provide an excellent

means to obtain velocity-resolved spectra of galaxies in the 3mm band. However, there is scientific interest in covering 3 to 5 times this instantaneous bandwidth for galaxy redshift searches in both the 3mm and 26-50 GHz regions. We were asked at the CoDR to investigate this possibility so that the receiver spectral channels could perhaps be designed to work with higher bandwidth spectrometers.

The driving specification for spectrometers intended for redshift searches is the required frequency (velocity) resolution and the desire to cover as much instantaneous bandwidth as can be afforded. The frequency resolution in the 3mm band should be approximately 30 MHz or better, and in the 26-50 GHz band 10 MHz or better.

A wideband analog lag correlator (WASP2) has been designed and built [1],covering 3.7 GHz of instantaneous bandwidth with 33 MHz frequency resolution. This machine accepts a 4-8 GHz IF and provides 128 lags. Informal discussions with the WASP2 developer, Andy Harris of University of Maryland, indicate it is technically feasible to stack ten of the WASP2 correlators, add some configuration switching, and provide 2 X 18.5 GHz bandwidth with 33 MHz resolution for 3mm work, or 2 X 6.2 GHz bandwidth with 11 MHz resolution for 26-50 GHz work. A rough cost estimate is $250K for such a machine. In addition, a converter system for this machine requires 2 X 5 converters to mix contiguous front-end RF bands to the 4-8 GHz or 6.5-8.0 GHz IF bands.

At least two other research teams are working to develop analog lag elements with up to 20 GHz instantaneous bandwidths. However, it is not clear that even if developed they could be economically practical, because of the number required to provide sufficient frequency resolution for the GBT application. At the moment, the WASP technology seems to be most feasible, although we will continue to monitor developments.

It is clear that the spectral channels of the 3mm receiver must send atleast 4 GHz of bandwidth, tunable over the full front-end frequency coverage, over the GBT fiber IF to the Equipment Room for use with the GBT Spectrometer, VLBA DAR, and other backends. A final decision on how to configure the receiver converters can wait 2-3 months to gather further information about wideband spectrometers, but the following describes a feasible scheme that could interface with a 10 X WASP2 correlator.

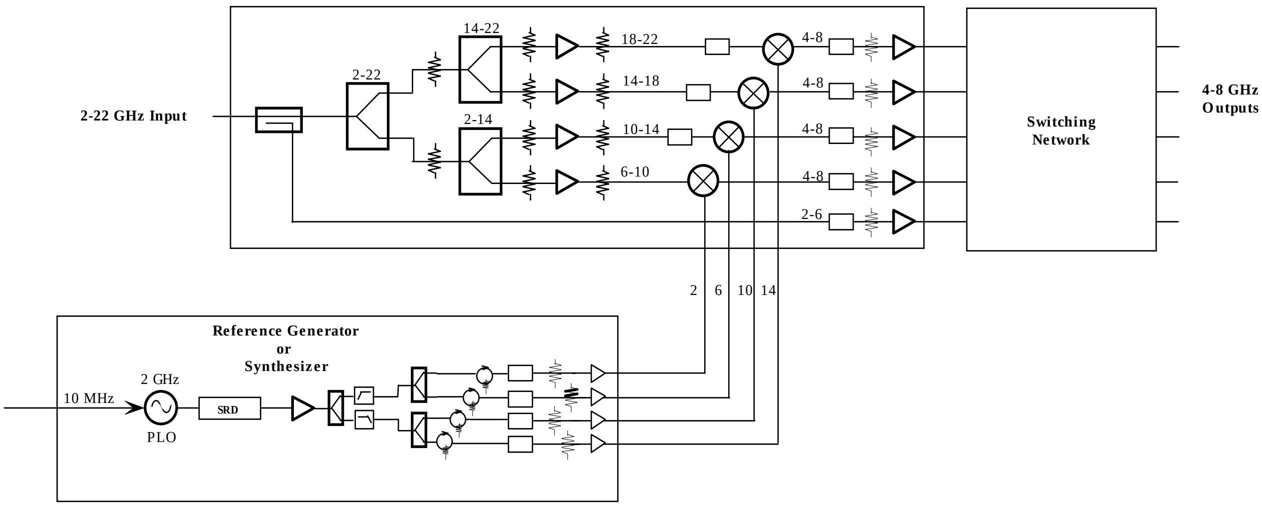


Figure 6. A scheme for segmenting and frequency converting the 2-22 GHz IF band to provide complete instantaneous coverage for a 10 X WASP2 correlator.

For this new frequency conversion scheme, a mixer spurious analysis was performed. Results are given in appendix B.

It is possible to achieve 40 dB of image rejection in the conversion of the 68-92 GHz RF band to an IF of 2-24 GHz.

The HP 83620's frequency switching characteristics are as follows:

Switching time:	For steps within a frequency band: 15 ms + 5 ms/GHz step size Maximum, or across band switch points: 50 ms. Step or list modes within a frequency band: 5ms + 5 ms/GHz step size.
Frequency Bands:	10 MHz to 2 GHz 2 GHz to 7 GHz 7 GHz to 13.5 GHz 13.5 GHz to 20 GHz

6. Optics

Analysis of the Gregorian optics of the GBT has been reported by Norrod and Srikanth [21], [22]. The use of tertiary optical systems has been suggested, as a means for removing feed-arm motion, and for rapid beam switching on the sky. Such a tertiary system is not given explicit treatment here, but the addition of optics for thermal calibration purposed are now being considered. The complete design of thermal calibration optics may not be completed by the time of outfitting the GBT with the first 3mm receiver, however, the receiver will be designed with the expectation that fast beam-switching and structure deformation correction capabilities may be added later. These added features may take the form of additional optics, or perhaps we will use the existing thermal calibration optics by adding the necessary servo control circuitry to facilitate the beam-switching and deformation correction. Using a single set of mirrors to accomplish all functions (calibration, beam switching, structure correction) is preferred, to minimize system noise contribution and beam distortion.

Proposed functions of the optics system:

(A) To select the desired feeds.
(B) To steer the feed illumination onto various blackbody calibrators
(C) To terminate one feed (of a closely-spaced pair of feeds) in a thermal load when observing in certain spectral line modes.
(D) Beam switching on the sky.
(E) Removal of feed arm motion.

The desired beam separation on the sky calls for a very small lateral separation of the two feed horns (3 cm). Such close spacing of makes it very difficult to optically terminate just one of the beams in a thermal load. The switching could be done in waveguide, but with a significant noise penalty.

Figure 7 shows a possible mechanical layout of receiver electronics and optics. The feeds and a cold thermal calibrator are selectively illuminated by an arrangement of flat mirrors. The chopper wheels will hold an ambient calibrator, a quarter-wave plate, and other grids and filters.

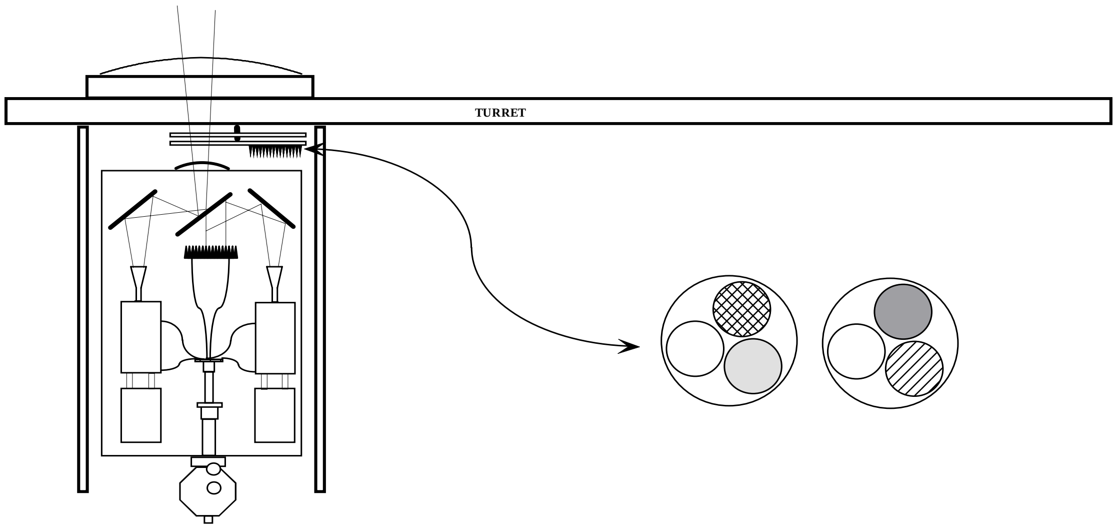


Figure 7. Proposed mechanical layout of optics and electronics.

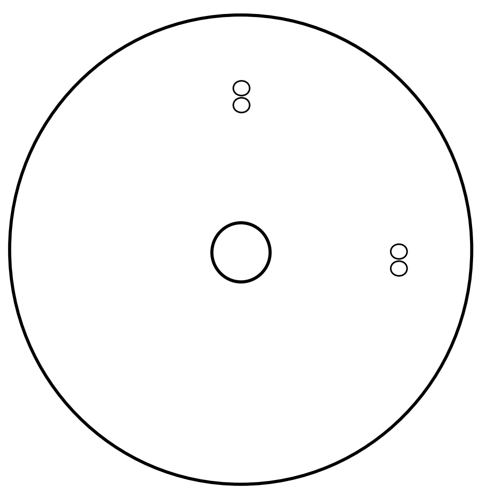


Figure 8. Relative size of 36 inch turret opening, a 1 inch diameter feed aperture, and a 4.5 inch vacuum window.

7. Monitor and Control

An asynchronous YGOR Manager, written in C++, will be created for the 3mm receiver. This Manager will use the Monitor and Control Bus (MCB) to communicate with the receiver hardware, which will contain a single VLBA MCB Standard Interface Board (SIB). Control of the receiver will be accomplished by writing a code to a specified relative address on the SIB. This data is latched and may be verified by a read to the same address. Monitoring of the receiver will be accomplished in a similar fashion by reading specific relative addresses. Monitor points may be either analog or digital.

The 3mm receiver Manager will have two graphical user interfaces (GUIs). The first GUI will be written in Tcl/Tk and Visual Tcl as part of the Control Library for Operators and Engineers (CLEO) interface. The GUI will be a simplified schematic representing the receiver electronics and IF path with a combination of text fields, buttons, and icons that provide complete access to the monitor and control functionality of the Manager. The second GUI will be part of GBT Observe (GO), which is the observers interface. None of the GBT's receivers currently has a GO interface, therefore the GUI representation for 3mm receiver is unknown at this time.

8. Components

8.1 Radome

If later we find that a radome is required, we will use a thin expanded PTFE sheet material, either Gore-Tex RA7956 or an equivalent Zitex product. At the present time however, we plan to have our vacuum windows (see next section for description) aligned with the top surface of the turret, a covered by a protective layer of Eccofoam PP (closed cell polyethylene foam from E&C). It has very low loss and is available with K = 1.03, 1.06, and 1.1.

8.2 Vacuum Window(s)

Crystaline quartz with anti-reflection coatings: either X-PTFE/HDPE/Z-quartz/HDPE/X-PTFE or PTFE/Z-quartz/PTFE. Expected performance:

insertion loss	$\le$ 0.05 dB
return loss	$\ge$ 22 dB

8.3 Feed Horns

Srikanth tested the GBT 12-15 GHz feed horn on 8/22/01 and found it to be a good candidate for scaling to 80 GHz. Return loss of 25 dB and cross-polarization of 25 dB is expected over the 68-92 GHz band. The scaled 12-15 GHz design is expected to give excellent performance over a 1.39 frequency ratio (upper/lower freq). The feed will illuminate the entire primary reflector, with a 12 db edge taper.

8.5 Circular-to-Square Waveguide

This will be designed by Sri, as a scaled version of the existing Ka-band design.

8.6 OMT

We plan to use an orthomode wavegude junction, similar to that described in Wollack [4]. ALMA band 3 production units are in test at the time of this writing. Pending the results of the tests (Taiwan, CSIRO), we will decide whether to use the ALMA band 3 design (W-band) or to scale it lower in frequency. Desired performance over the 68-92 frequency range:

insertion loss	< 0.2 dB
return loss	> 20 dB
isolation	> 40 dB

Data for one of the W-band prototypes is shown in figure 9.

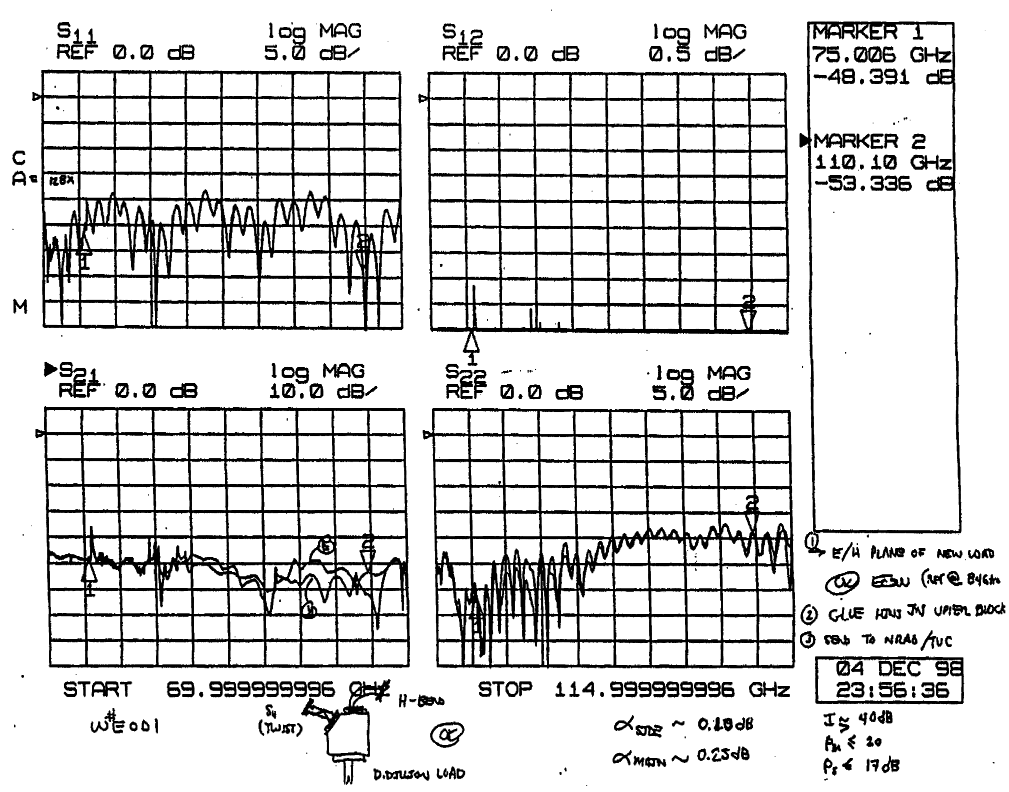
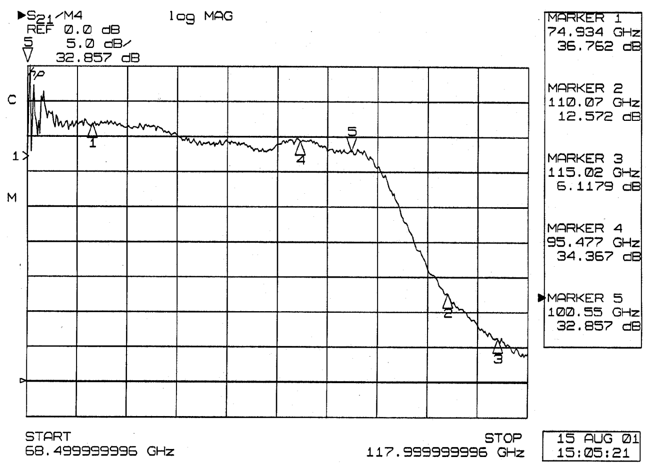


Figure 9. Performance of a prototype W-band OMT.

8.7 LNAs

Amplifiers for the receiver front-end will be produced by the CDL. The several variations of the W-band design are now being evaluated by CDL. Typical performance data is given below in figure 10. Note that the data includes the effects of a mylar vacuum window, feed horn, and copper waveguide. Desired performance:

Gain	35±2 dB
Te	< 50 K



13:00.6 09/28/97 THOT=297 TCOLD=78 MW63

F,MHZ	TRCVR	TOFF	TX	NDB	GAIN
84000	45.2	82.3	0.0	-60.00	2.17
85000	54.1	78.5	0.0	-60.00	2.21
86000	53.8	78.5	0.0	-60.00	3.26
87000	54.4	78.3	0.0	-60.00	6.86
88000	55.0	78.3	0.0	-60.00	10.55
89000	57.3	78.5	0.0	-60.00	7.15
90000	56.3	78.6	0.0	-60.00	7.70
91000	57.8	78.4	0.0	-60.00	8.15
92000	60.5	78.6	0.0	-60.00	5.20
93000	60.0	78.4	0.0	-60.00	9.71
94000	62.7	78.7	0.0	-60.00	8.30
95000	61.5	78.9	0.0	-60.00	6.67
96000	57.9	78.9	0.0	-60.00	4.89
97000	55.6	78.9	0.0	-60.00	2.57
98000	55.6	78.9	0.0	-60.00	2.87
99000	57.5	79.2	0.0	-60.00	2.51
1000*	58.7	79.2	0.0	-60.00	1.00
1010*	63.9	78.8	0.0	-60.00	0.49
1020*	81.3	79.1	0.0	-60.00	0.27
1030*	127.6	81.0	0.0	-60.00	0.11
1040*	151.4	80.5	0.0	-60.00	0.04

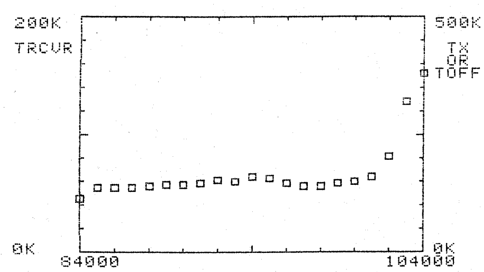


Figure 10. Typical performance data for a CDL W-band amplifier.

8.8 Biphase Modulators

Modulators must have reasonably low loss (so as not to add to the receiver noise temperature), excellent amplitude balance, and a very flat phase response. Performance goals:

Amplitude balance	< 1 dB
Phase difference	180 ± 2 degrees
Carrier suppression	> 15 dB

8.9 Detector Readout Electronics

We are currently evaluating options, including a preliminary design by Steve Padin.

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