

**VLA Electronics Memo # 244**

*Fiber Optic Transmitter/Receiver  
Duplication for the Pie Town Link*

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***Abstract:*** In this National Radio Astronomy Observatory Co-op project, completed during the summer of 2002, two spare modules were constructed for the Very Large Array Pie Town link. The Pie Town Optic link combines astronomy data from the Very Long Baseline Array with the VLA to give increased resolution. An optical transmitter and receiver pair were constructed to provide support to the existing modules. The transmission system uses a 50 mW laser and an external modulator to transmit four IF signals a distance of 104 km. In this report module design is covered along with artwork, drawings, and schematics used in the construction. Troubleshooting setups and methods are discussed. Finally, a detailed list of parts and prices are included along with datasheets.

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## **1. Introduction**

This section describes the function of the entire Pie Town (PT) to Very Large Array (VLA) link as well as how the transmitting and receiving is accomplished.

### **1.1 Pie Town to VLA Fiber Optic Link**

The purpose of the Pie Town optic link was to combine the astronomy data of Very Long Baseline Array (VLBA) with data from the VLA. The present resolution in the VLA was increased to provide astronomers with a sharper image. It should be noted that Pie Town link is only functional when the VLA is in an "A" configuration. In other words, the VLA antennas are positioned to the max distance on each arm (27 km). This link adds 27 Baselines to the array, keeping the origin at the center of the VLA.

There are four IF signals generated in VLBA format (between 500 MHz – 1000 MHz) at the Pie Town Antenna. These signals are converted, at Pie Town, to a 50 MHz wide VLA signal. The four signals are multiplexed and then modulated onto a single laser. The signal is transmitted over 104 km of fiber to the VLA site. Once the signal arrives at the site, it is received and converted back into an RF signal. The final RF signal is sent to the existing backend of the VLA.

A block diagram illustrating the PT to VLA link can be seen below in *Figure 1*.

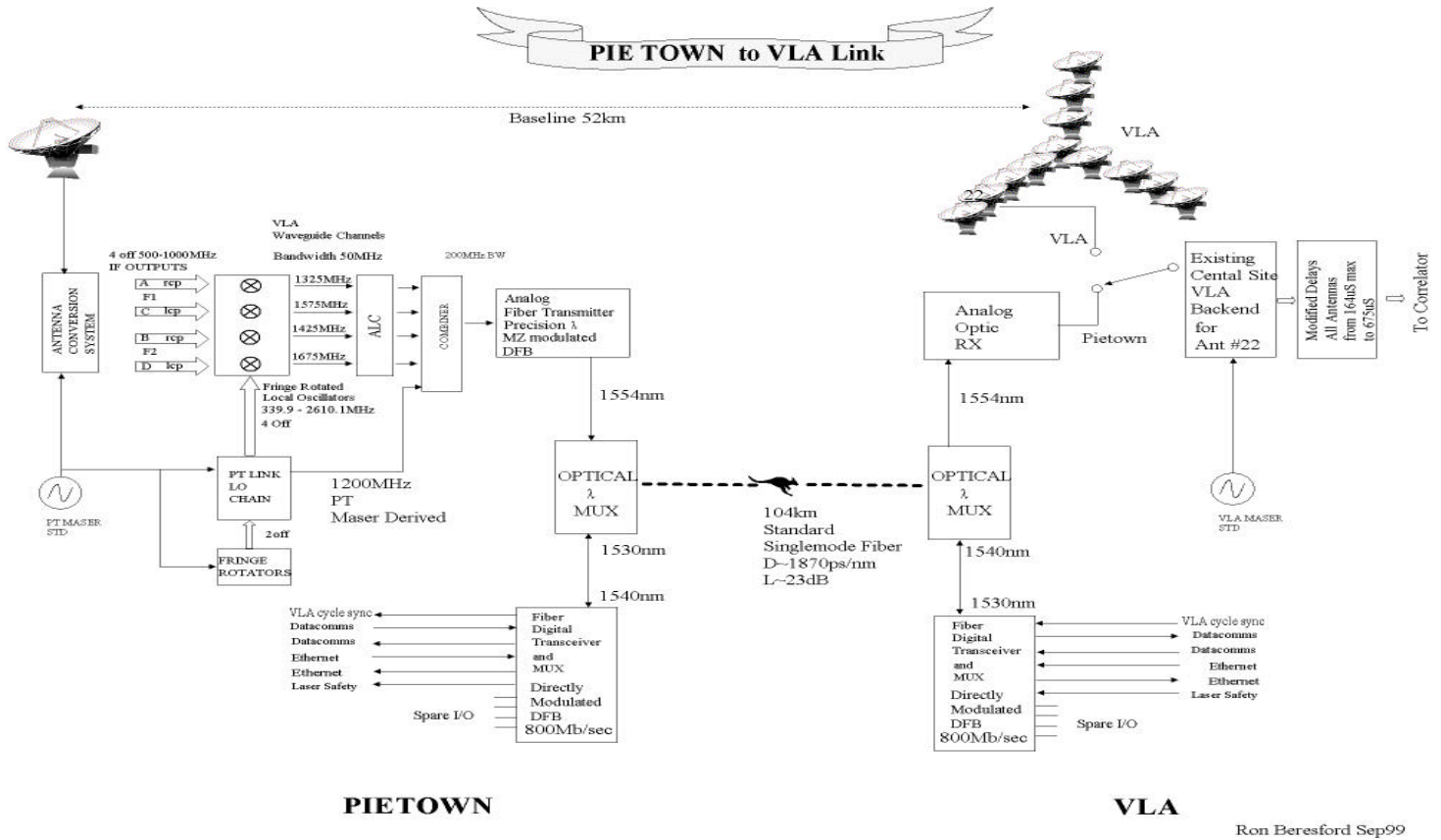
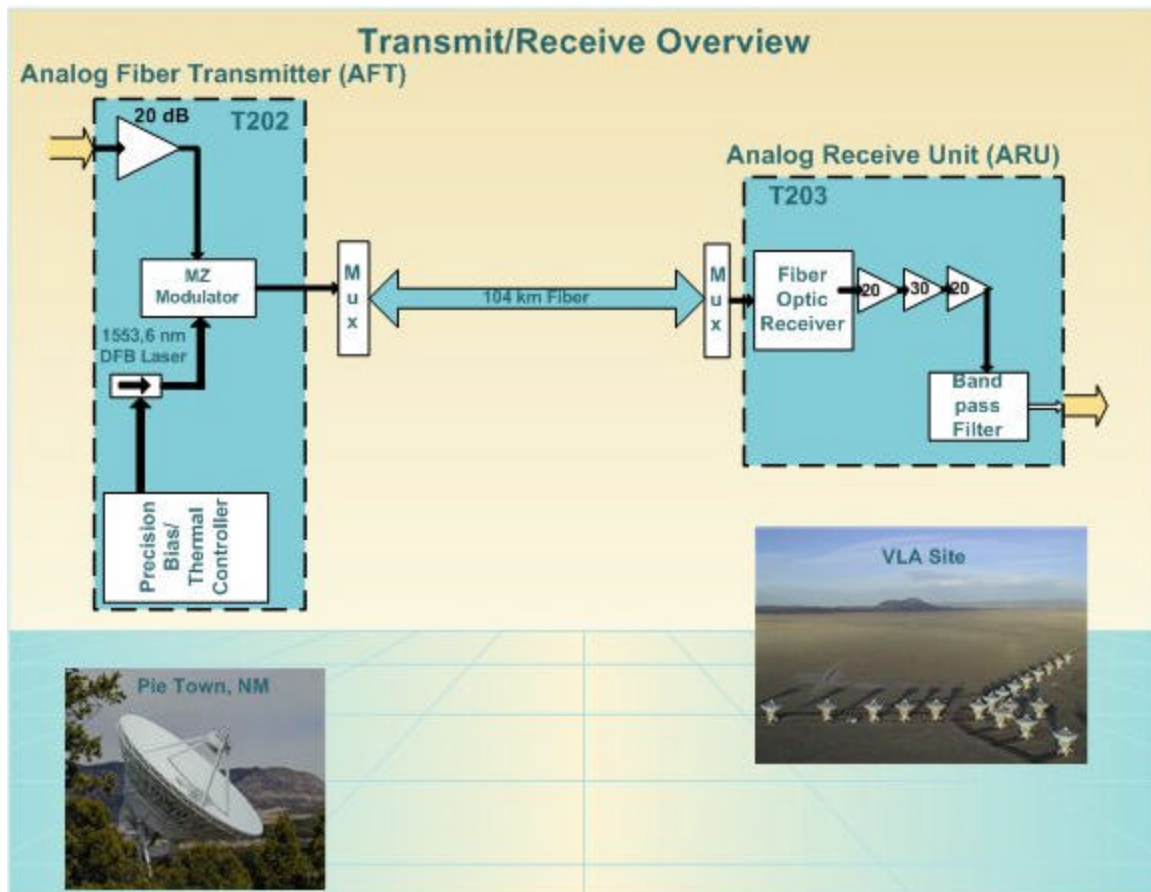


Figure 1: Pie Town To VLA Block Diagram

## 1.2 Pie Town Link: Transmit and Receiver Modules

An essential part of the Pie Town Link is the Fiber Optic Transmitter and Receiver Modules. The purpose of these modules is to take an Analog multiplexed signal (Converted from VLBA format to VLA format) and externally modulate the signal on to a laser (using DWDM). The laser operates at a wavelength of 1555 nm, which can be tuned using a thermal controller. The signal is then sent over 104 km of fiber, using fiber from Western New Mexico Telephone Company (WNMT), to the VLA site.

Once the signal arrives at the site, the signal is received using a fiber optic receiver and is converted back into an analog signal. The received RF signal is amplified back up and a filter is used to clean up the signal before sending it on to the backend receiver. The transmission process is illustrated in *Figure 2*.



**Figure 2: Transmit and Receive Overview**

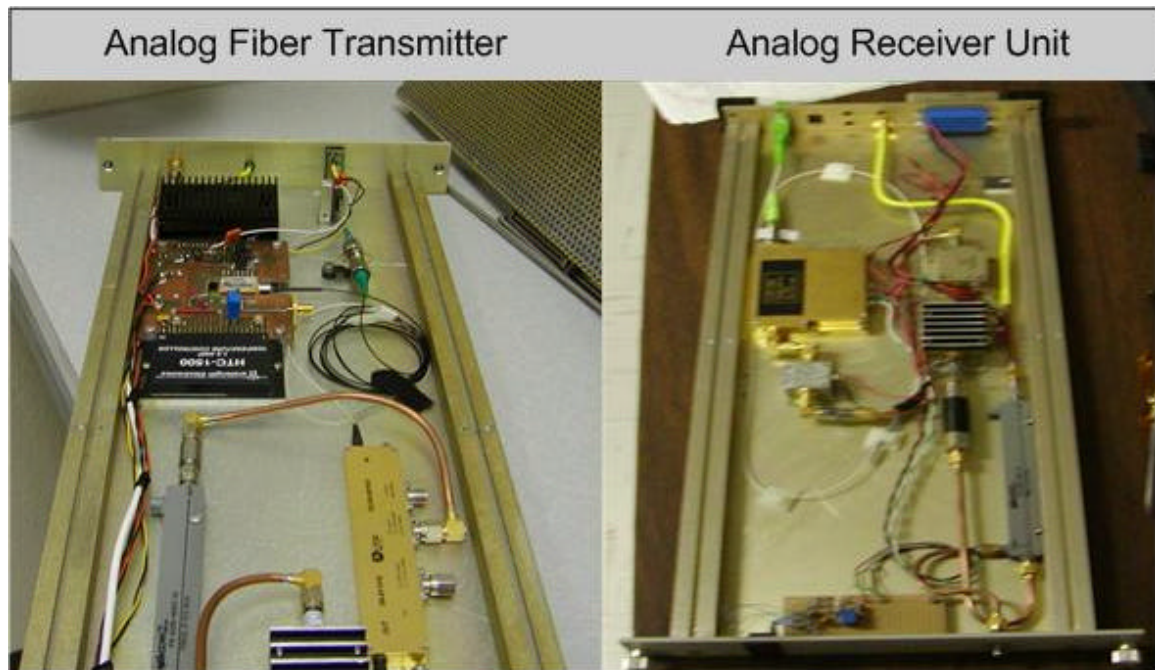
The Transmitter Module is commonly referred to as the Analog Fiber Transmitter (AFT) or T202 module, and the receiver module is known as the Analog Receive Unit (ARU) or T203. Only two modules were originally constructed for use in the Pie Town Link.

## 2. Co-Op Project

This section describes the project assigned and some of the required tasks and project goals.

### 2.1. Project Description

The Pie Town link only has a single T202 and T203 module. Since there are no spares for these modules, in the event of a failure in either module, the entire PT link is shut down. Due to demand for less downtime, a spare for both modules was required. Along with creating duplicate modules, documentation for each part along with detailed schematics and pricing was required. *Figure 3* shows a picture of the insides of the T202 and T203.



*Figure 3: Current Transmit/Receive pair at the site.*



## **2.2. Tasks and Goals**

In order to get the most out of the project, the following set of tasks was defined: improvements, time restraints, and budgeting issues. Also, there are certain goals that must be completed. Therefore, a set of objectives was made and divided up in to required tasks and project goals:

### **I. Required Tasks**

- Use in-house parts to reduce costs.
- Spare must fit in a singlewide module slot.
- Provide documentation and testing procedures.
- Spares must be identical to the original modules.
- Order more replacement parts.
- Build both modules before the end of July 2002.

### **II. Project Goals**

- Improve upon the existing design.
- Reduce future problems by extensive testing.
- Continual use of both spares after construction.

### 3. Module Design

This section describes how the original modules were designed. The choice of components and a characterizing of the current Pie Town Link Signals are included in this section. The engineer in charge of this design was Ron Beresford.<sup>†</sup>

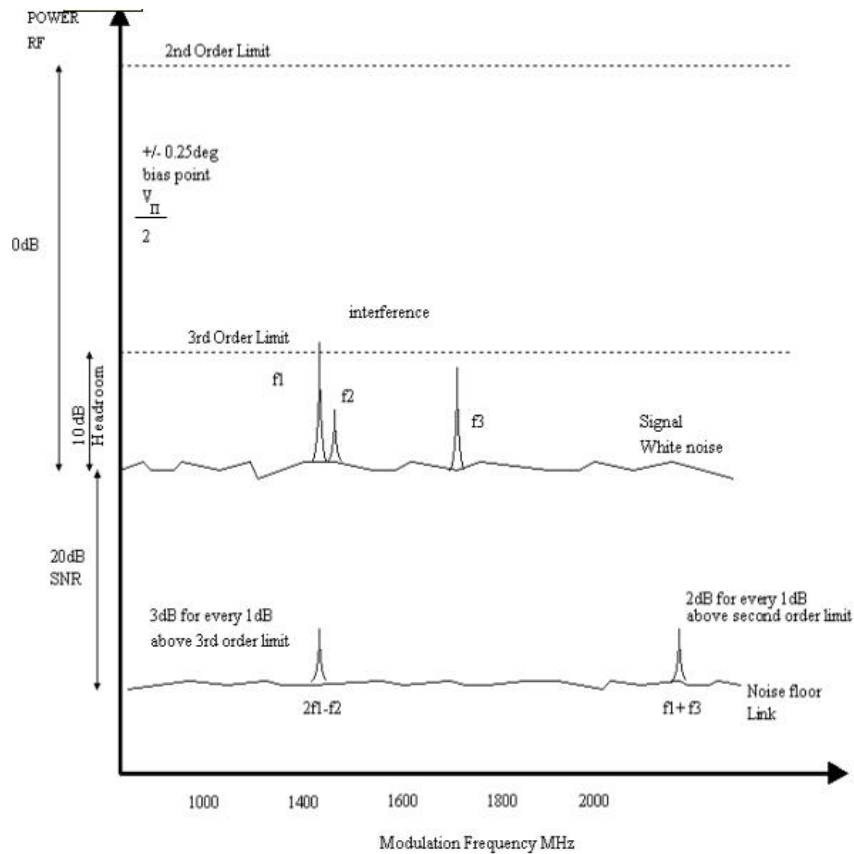
#### 3.1. Analog Fiber Transmitter

The Optical Transmitter is designed to transmit four externally generated IF signals over 104km of fiber. The method of external modulation with a high power CW laser was chosen over direct modulation. “By externally modulating an ultra-stable CW laser with an MZ modulator wavelength chirping is eliminated. Increasing CW laser power will reduce the link noise figure”<sup>†</sup>. A problem with using external modulation is there is a high insertion loss (around 5 dB or greater). Initial tests were done with a 90 mW laser to provide sufficient drive. Testing determined that a minimum power output from the transmitter is 8.8 dBm.

Choosing a dynamic range is an important factor in the design of the transmitter. The signal to noise ratio (SNR) is around 20 dB, since this is “adequate for digitization and good astronomy”<sup>†</sup>. Also, headroom of 10 dB was chosen to make “Dynamic Range as large as reasonable achievable”<sup>†</sup>. This gives a required dynamic range of 30 dB (20 dB SNR + 10 dB headroom). A graph showing the design of dynamic range is found in *Figure 4*.

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<sup>†</sup> Information quoted in this essay comes from Ron Beresford’s report “RF Fiber Optic Link” found in the Pie Town Hand Book.



**Figure 4: Determining the Dynamic Range**

Another important design issue was the effects of the Stimulated Brillouin Scatter (SBS). This effect, which is non-linear, happens in narrow line width, high power systems over long distances. The forward wave interacts with vibrating molecules in the glass causing a backward traveling wave, which causes power losses and decreases the SNR. *Figure 5* on the following page shows the required launch power as a function of distance. Based on this plot, a launch power of 8 dB was needed to ignore the effects of SBS. A 50 mW DFB laser was bought with a Hybrid Temperature Controller (HTC) to stabilize and adjust the frequency. Also, a PLD-500 was bought to control laser bias.

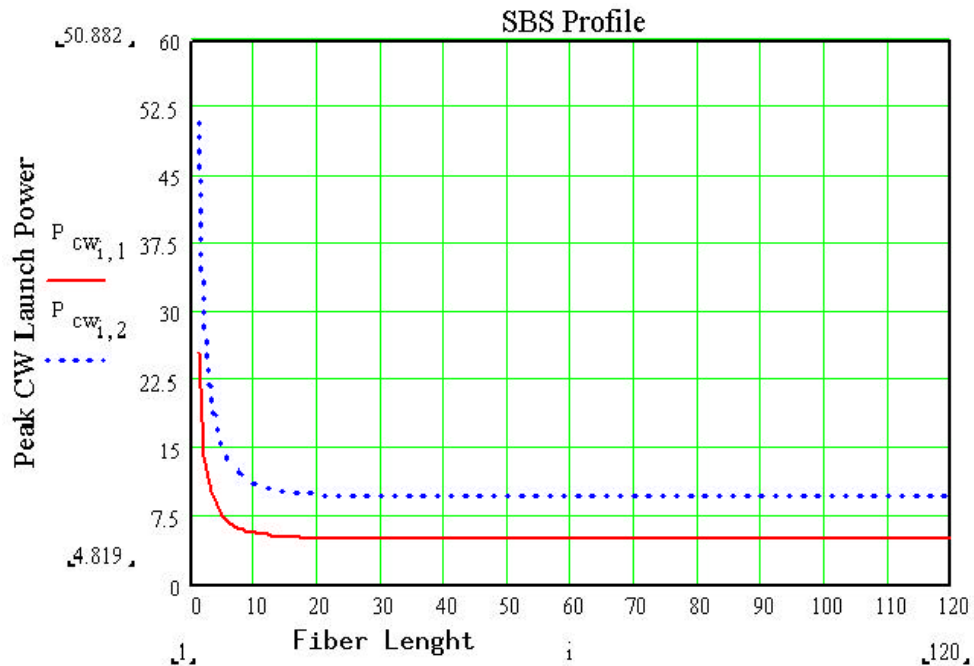


Figure 5: SBS Launch Power

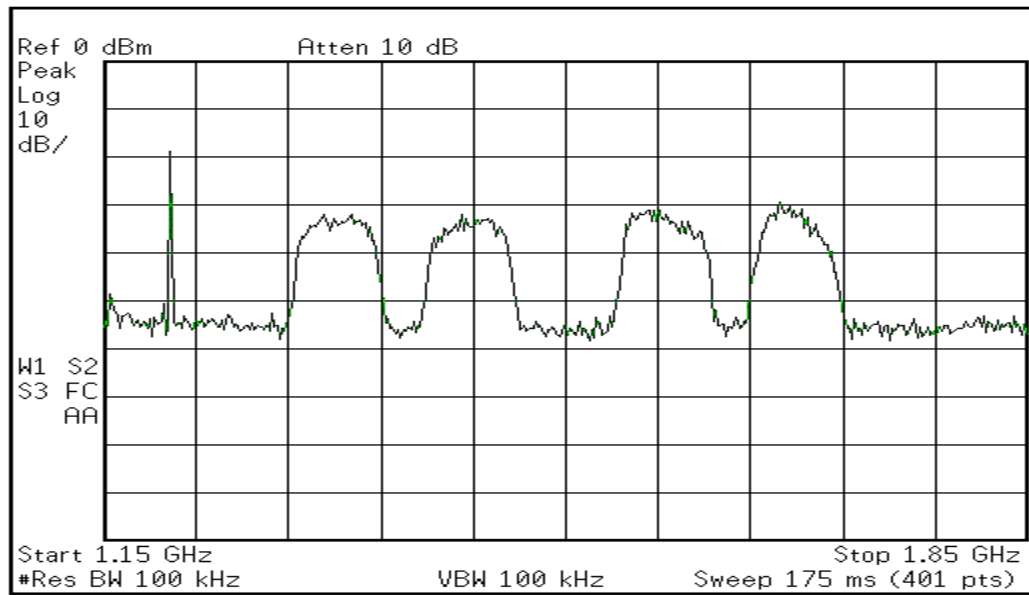
### 3.2. Analog Receiver Unit

Two important design considerations are low noise and receiver sensitivity. In order to keep the SNR down, the first amplifier must always be a low noise amplifier. “CAD modeling revealed that there is a one for one relationship between the noise figure of the amplifier immediately preceding the PIN detector and the noise floor of the link”<sup>†</sup>. The first stage amplifier was chosen to be a low noise amplifier from Mini-Circuits. The max power received in the link is determined by the sensitivity of the photodiode. The receiver that is currently used in Pie Town has a sensitivity of 0.8 mA/mW.

A problem in the original design was impedance matching. The output impedance of the photo-detector was 500  $\Omega$ , which was matched with a 50  $\Omega$

input on the amplifier. This impedance mismatch might cause reflections and losses. A solution would be to build a low-loss broadband transformer, but “Vector analysis of the mismatched configuration revealed excellent 50 MHz pass bands for A, B, C, and D channels. Resistive matching was not required”†.

A good received signal at the VLA site contains the proper phase delay and amplitude. All four bands including the 1200 MHz syncing tone should be received at levels around -25 dBm. The signal was found by characterizing the receiver at the VLA site. Also, some tweaking of the L6 oscillators at Pie Town was required. A spectrum capture a good of a Pie Town Transmitter/Receiver signal is shown in *Figure 6*.



*Figure 6: Typical Received VLA Signal*

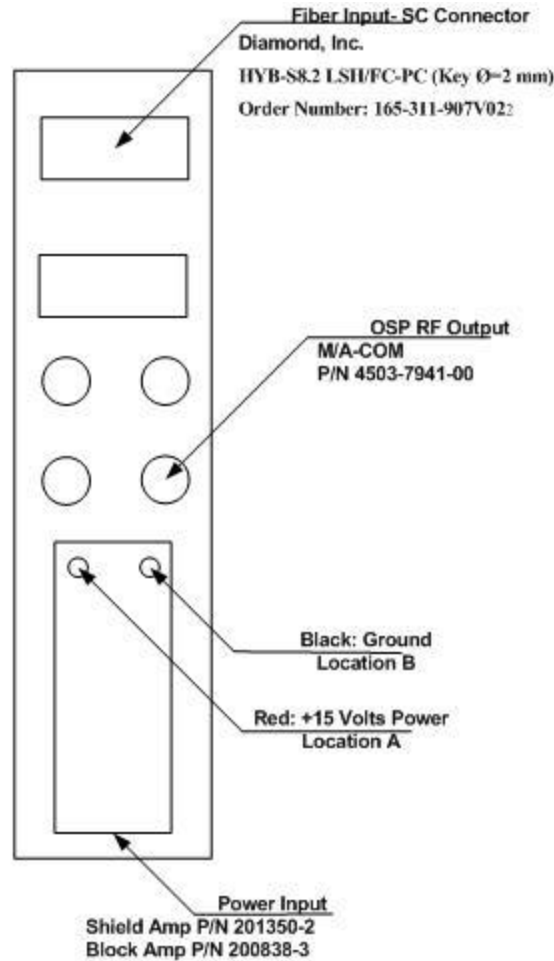
## 4. Module Construction

This section describes the construction of a two modules based on the current design in use at Pie Town. Details on the construction and design choices involved are included.

### 4.1. Building the T203

A trip to the VLA and Pie Town was required to get information on how both modules were built, and to acquire parts for building spares. Both modules were designed for a singlewide VLA slot, with OSP RF connectors on the back for simple connection. The hardware for building singlewide modules such as the chassis and the railing was found at the VLA. Finally, a front panel for both modules had to be drawn and sent to the machine shop.

The first module to be built was the T203. The chassis was assembled using parts from the site and the Array Operations Center (AOC). A pin-out of the back panel of the T203 chassis showing both connectors and wires can be found in *Figure 7*. Once a chassis was built, a layout of components was developed. *Appendix B, Figure 1* shows component arrangement. A 20 dB, low-noise, and a 30 dB amplifier (all manufactured by *Mini-Circuits*) were taken to build this module. Since these were the last amplifiers, an order for extras was placed. Also, a different receiver was used in this project. A Small Integrated Receiver Unit (SIRU) SIRU 2300 from JDS Uniphase was used instead of the SIRU 1114. The receiver has a sensitivity of .85 A/W compared to .8 A/W in the original module. A problem presented by using the SIRU 2300 was it was a bit bigger than the unit used in the original.



*Figure 7: T203 Pins and Connections*

A front panel had to be constructed to hold a Digital Panel Meter (DPM) a power LED, and a SMA test point. Both modules had the same setup; therefore the front panel design was used for both modules. The lead-time on the front panel construction was between two and three weeks. *Appendix B, Figure 2* shows the final drawing used for the front panel.

The choice to use a terminal strip to power the amplifiers and the receiver was made. A terminal strip can be easily modified if something fails. The panel meter, which monitors the power received, requires a circuit card that controls a

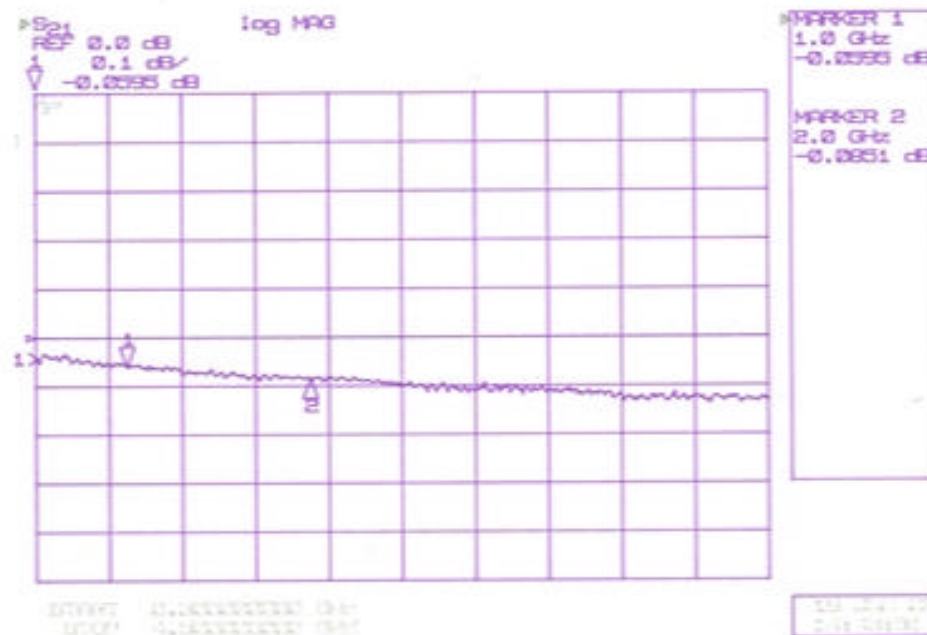
DPM and the full-scale value. A  $22\text{k}\Omega$  POT was used to adjust the full-scale reading. The panel measures the voltage of the receiver monitor pin which, based on the data sheet, is the microwatts of power (The voltage is roughly 85% of the total power received). A circuit schematic used in the T203 module can be found in *Appendix A, Figure 3*.

There were a few mechanical issues involved in the design as well. Since the module has to fit neatly into a singlewide VLA slot, no screws from the components mounted down to the chassis could stick out. A set of taps was used to tap out holes for a 4-40 screws. Short screws were used so that the amplifiers and other components could be mounted to the chassis and the screws would not stick out the other side. The front panel needed some slight adjusting so that it would not hit the modules in the adjacent spaces.

After components were mounted to the chassis and the DPM circuit card was tested and completed, the task of building Rigid Coax connecting the components arose. The process of building coax requires special tools: a tool to cut and strip the copper, another for bending, a special soldering tip, and a mount to keep the melting semiconductor from spilling out. A small nick in the copper can cause suck-outs (a high frequency point of high losses and reflections over the line). When adding a connector end, a bad solder re-flow can cause suck-outs that tend to move around the desired band of frequency. In order to keep the losses over these cables as low as possible, all cables were



tested for losses on the network analyzer. The frequencies used in this project range from 1 GHz to 2 GHz, but the cables were swept from 2-18 GHz for assurance. A graph showing typical loss over a cable made can be found in *Figure 8*.



*Figure 8: Typical Losses for Coax*

#### **4.2. Building the T202**

The construction of the T202 Module required that the 50mW Laser and Modulator be used for testing in the EVLA project. Therefore, a two-week deadline was imposed. The laser card was already etched and built. The circuit schematic and board artwork can be found in *Appendix A, Figure 4 and Figure 5*. For this module, the CQF938/50 Laser was chosen as the laser diode. Laser power and current are controlled using a Laser Diode Driver, which is a PLD-500, purchased from Wavelength Electronics. Adjusting two labeled POTs on the side of the PLD-500 can change the output power and a power limit. Also

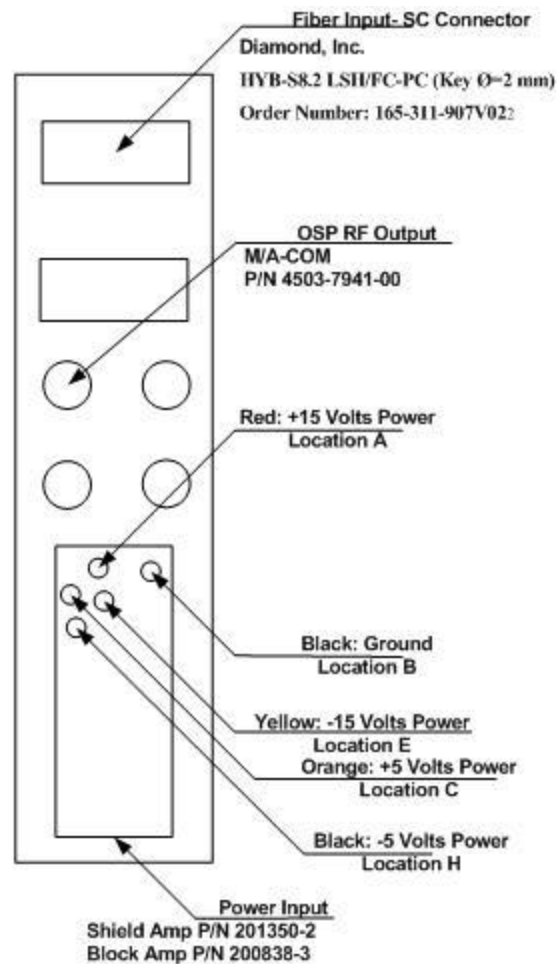
laser wavelength can be monitored and controlled using a Hybrid Temperature Controller (HTC). An HTC-1500, also purchased from Wavelength Electronics, was used to provide the laser with temperature stability. The HTC also provided a POT to fine tune the frequency to the desired wavelength. A wavelength of around 1554 nm was required, since there is less dispersion but more power losses at this wavelength. The typical laser power output in the original T202 was measured to be around 9 dBm.

The laser diode was directly mounted to the chassis with thermal grease to insure temperature stability. The Modulator used in this project was in OC-192 modulator from JDS Uniphase. The modulator was mounted to a small plate for easy access to the RF input for EVLA testing. The -10dB coupler and 20 dB amplifier were also mounted down to the chassis. Space was left for winding the fiber so that losses caused from bends would be kept to a minimum. The final component layout for the T202 module is found in *Appendix B, Figure 6*.

A second DPM controller card needed to be built. The measured point was the power monitor pin of the PLD-500 (pin 8). This pin out puts a voltage between 0 and 2.5 Volts based on the current/power being consumed by the laser. The main differences between the circuit cards are the full-scale reading and the reference voltage. The monitor pin on the T202 module has a full-scale reading of around 2 volts that can be made with fixed resistors instead of a POT. Also, the measurement is referenced to -5 volts as the lowest voltage and ground

being the highest voltage. Schematics for the DPM control circuit are found in *Appendix B, Figure 3*.

After the circuit card and component mounting was complete, the final task was wiring the active components. The voltages used in this module are +15 V, +5 V, -15 V, -5 V, and ground. The laser runs off of +5 V, -5 V, and ground. +15 and -15 volts are used for the amplifier and circuit card respectively. The picture showing the backplane pins and connectors is found below in *Figure 9*.



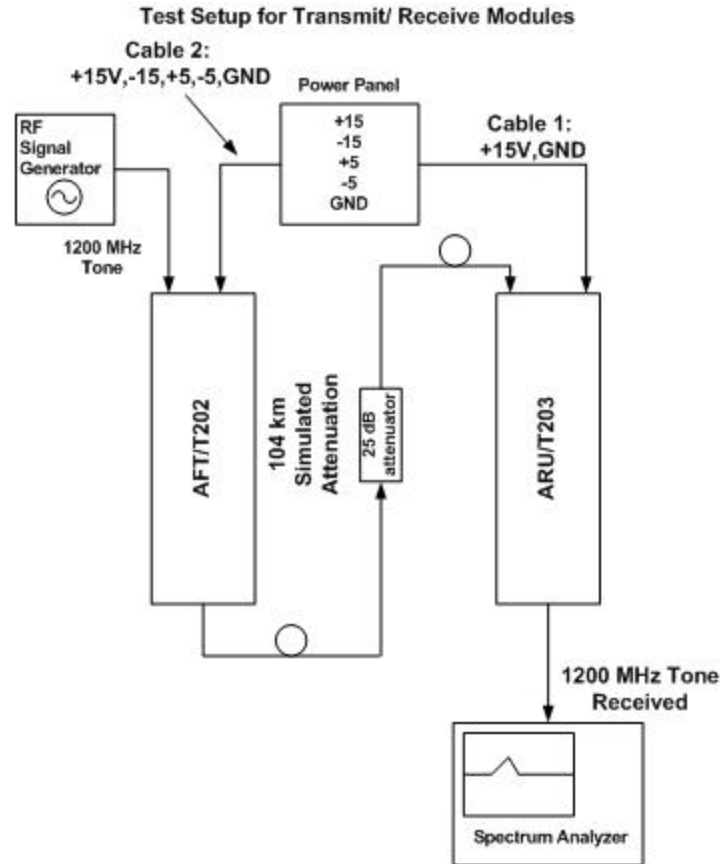
*Figure 9: T202 Pins and Connections*

## **5. Testing**

This section describes, in detail, the testing process after creating the two modules. Bench tests as well as field tests are described as well as some of the problems that occurred in the design process.

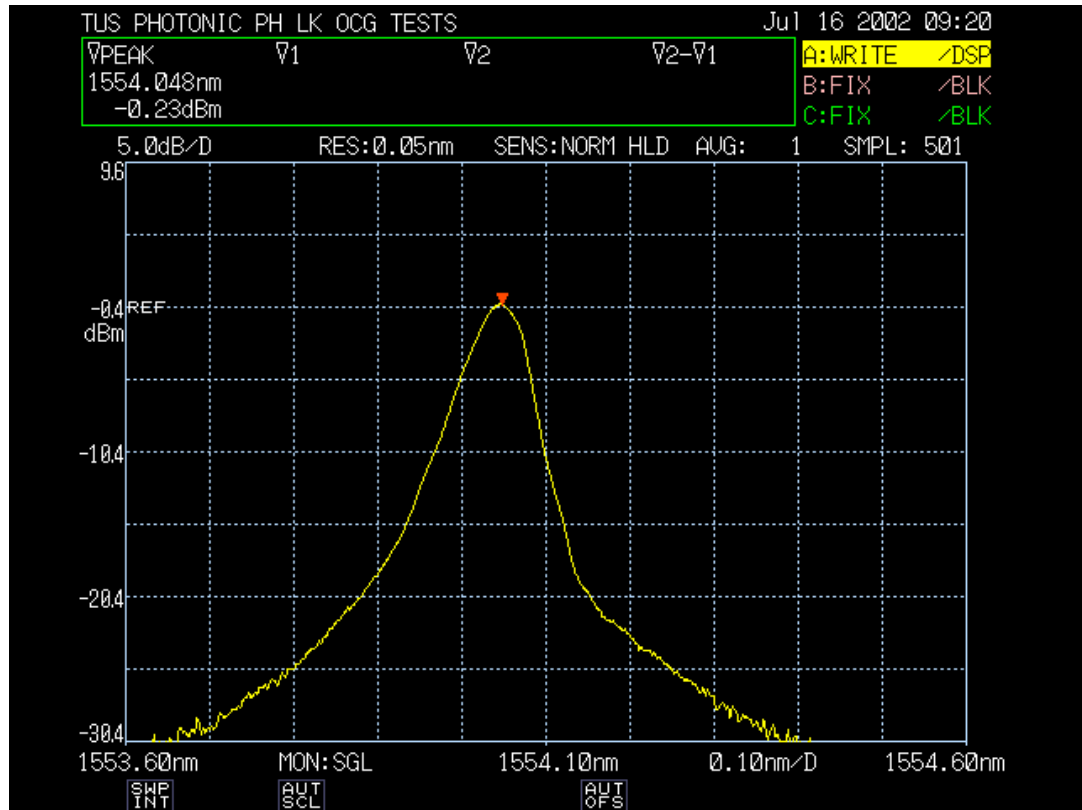
### **5.1. Bench Tests**

In order to see how well the modules will perform out in the field, several tests were performed on both modules. Questions such as: How long can the modules operate? How hot do the modules get? How much power can the modules handle? All these questions must be investigated before tests can be done in the field. Also, a lot of issues can be dealt with in the lab. Before testing could begin, two custom cables were made for each unit to provide easy plug functionality. The cables are color-coded and labeled for each module. A RF signal generator was used to provide a 1200 MHz tone input to the transmitter. A spectrum analyzer was used to monitor the received tone. A 25 dB attenuator was used to simulate the loss caused by 104km of fiber between the VLA and Pie Town. The setup for this test is illustrated below in *Figure 10*.



*Figure 10: Test Setup Diagram.*

After the units were set up, there were a few things that needed to be checked. The laser output was hooked up to an optical spectrum analyzer to test for both wavelength and power. The modules were left to run overnight to test for durability in the field, heat problems, and wavelength drifting. The laser was monitored overnight and maintained a constant wavelength of 1554.04 nm. A capture of the optical wavelength can be seen in *Figure 11*.



*Figure 11: Laser Wavelength and Power.*

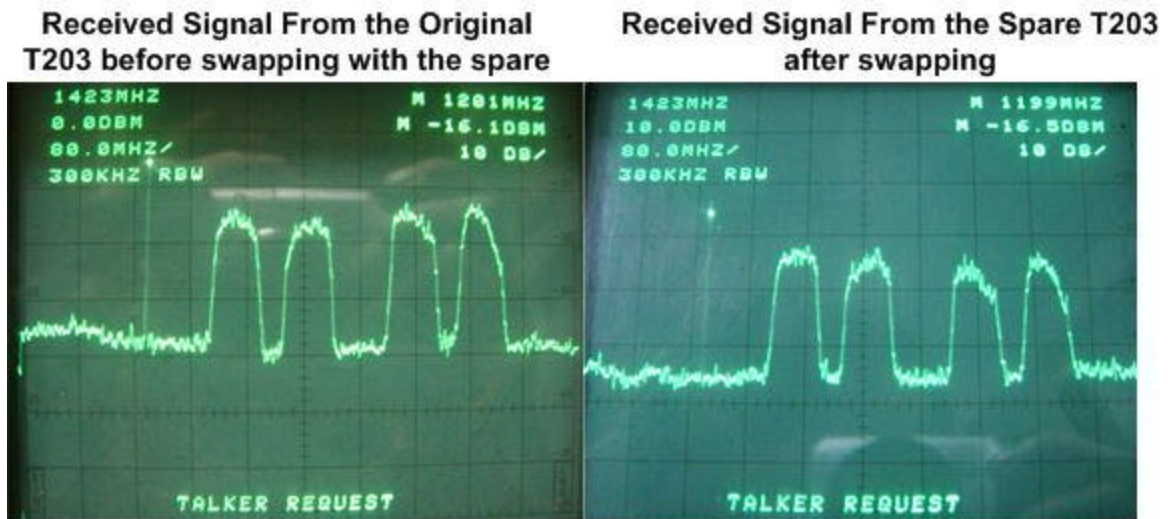
Problems with overheating occurred in the second-stage amplification in the T203 module. The amplifier became noticeably hot, but the module did continue to function. To solve this problem, the amplifier was remounted to the chassis and thermal grease was added. Also, the attenuator was increased to 12 dB to insure that the input was not being overdriven. The wavelength of the laser did remain constant at around 1554.04 nm. The output power of the T202 was tested with an optical power meter and measured 6.54 dBm. This did not meet the requirement of 8.8 dBm drive power. The problem was dealt with at a later time and is explained in the field test section.

Another problem that occurred during testing was that both LCD panel meters failed to read the desired voltages. At first, the boards were assumed to be the problem, but it was later determined that super glue had gotten into between the pads on the PCB of the panel meter. The LCD meters were soaked over night in a bath of 91% rubbing alcohol. This removed the glue and the DPM were re-assembled. The DPM proved to work and was mounted to the front panel.

## **5.2. Field Tests**

After the bench test issues were resolved, further testing at both the VLA and Pie Town was required. Modules would be tested for signal to noise ratio (SNR) and compared to the characterized signal of the original modules. A technician stayed behind at the VLA to record the received signal while the module was switched at Pie Town.

First, the receiver was tested at the VLA site. The original module was hooked up to a spectrum analyzer to monitor the signal. The signal was monitored under the same settings on the spectrum analyzer. The spare module actually had a higher dB level than the original. This level was adjusted by increasing the attenuation in the module. The final resulting signal captures can be seen in *Figure 12*.



*Figure 12: Received Signal Comparison.*

Once the receiver signal was matched up, the laser in Pie Town had to be tested. For this test, output power and external modulation are important. To test the output power, an optical power meter was used to measure the power on the output of the laser. Proper modulation would manifest itself in the received signal at the VLA site. The original laser outputs about 9.3 dBm, but the power output by the spare was around 6.5 dBm. This measurement was made after the output current POT on the PLD-500 was adjusted until the power would not get any higher. It was later determined that half of the power (~ 3 dBm) was lost due to cracks in the fiber core on both the input and output of the modulator. A new modulator was acquired and the old modulator was sent back to the manufacture for repairs.



To test the module, the received signal was monitored at the VLA. The signal looked correct, but the power level was down due to the problems mentioned above. Once these power level issues were dealt with, the modulator worked as expected.

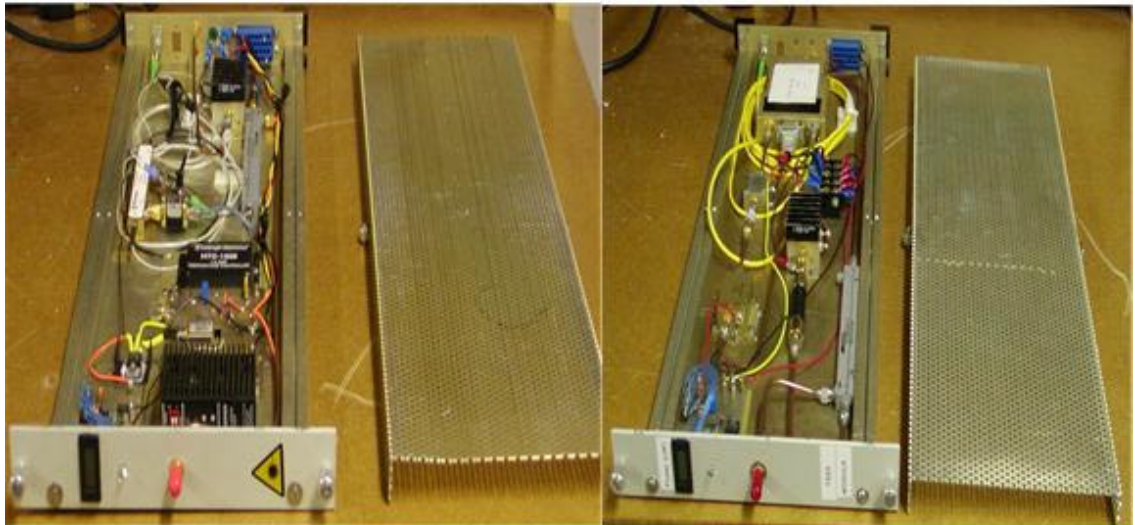
## **6. Conclusions**

This section describes the final status of the project and provides a brief summary of the project.

### **6.1. Final Results**

After testing the project on the bench and in the field it is apparent that both modules function correctly and can be used as spares. The final status of the modules at the end of this project is working spares. It is recommended that further testing into signal timing should be done if these modules are to be used during observing. These modules should be periodically swapped out with the originals in order to test functionality and part reliability. The modules should be stored in a stable environment and handled with care. Also, the proper safety equipment should be used when working with the laser, as lasers can cause serious injuries. If any more modules are to be built or extra parts needed, a cost summary for each module can be found in *Appendix A, Figures 1 and Figure 2*. Spare parts are kept near where the modules are stored. Any information on parts such as data sheets or purchase orders can be found in *Appendix C* or on the CD, which is included with this paper.

A picture showing off the spare modules is seen below on *Figure 13*.



*Figure 13: Constructed Spares.*

## **6.2. Comments**

This project has been successful, since all the required tasks have been completed. If this project could be attempted again, more time would be spent looking into adding additional options that were not attempted due to time constraints. A feature that was not included was an optional adjustment to the bias control on the modulator.



**2. Expense Summary for the Analog Fiber Transmitter**

**Part List for the T202 Module**

8/8/02 8:19 AM

Part Number	Description	Qty.	Manufacturer	Cost
CQF938/50	1550nm DFB laser w/ PMF fiber	1	JDS Uniphase	\$1,650.00
ZFL-2500VH	Broad-Band Amplifier 20dB	1	Mini Circuits	\$264.95
HCT-15000	Hybrid Temperature Controller	1	Wavelength Electronics	\$99.00
PLD-500	5 Volt Laser Diode Driver	1	Wavelength Electronics	\$272.00
26111;26112	Blue Polarization Main. Fiber	1	Wave Optics	
DPM 1S	LCD Display	1	Martel Electronics	\$58.36
FP-87	6 dBm Pad 8 GHz	1	Texscan	-----
2025-6002-10	-10 dBm Coupler	1	M/A-Com	\$236.55
MC7905	5 volt Regulator	1	Motorola	-----
10150-002171	OC-192 External Modulator	1	JDS Uniphase	\$3,836.00
			<b>Cost to construct</b>	<b>\$6,416.86</b>

Key	
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## Appendix B: Schematics and Diagrams

This appendix provides all the technical details of the project: this includes circuit schematics, block diagrams, spectrum analyzer captures, and testing information.

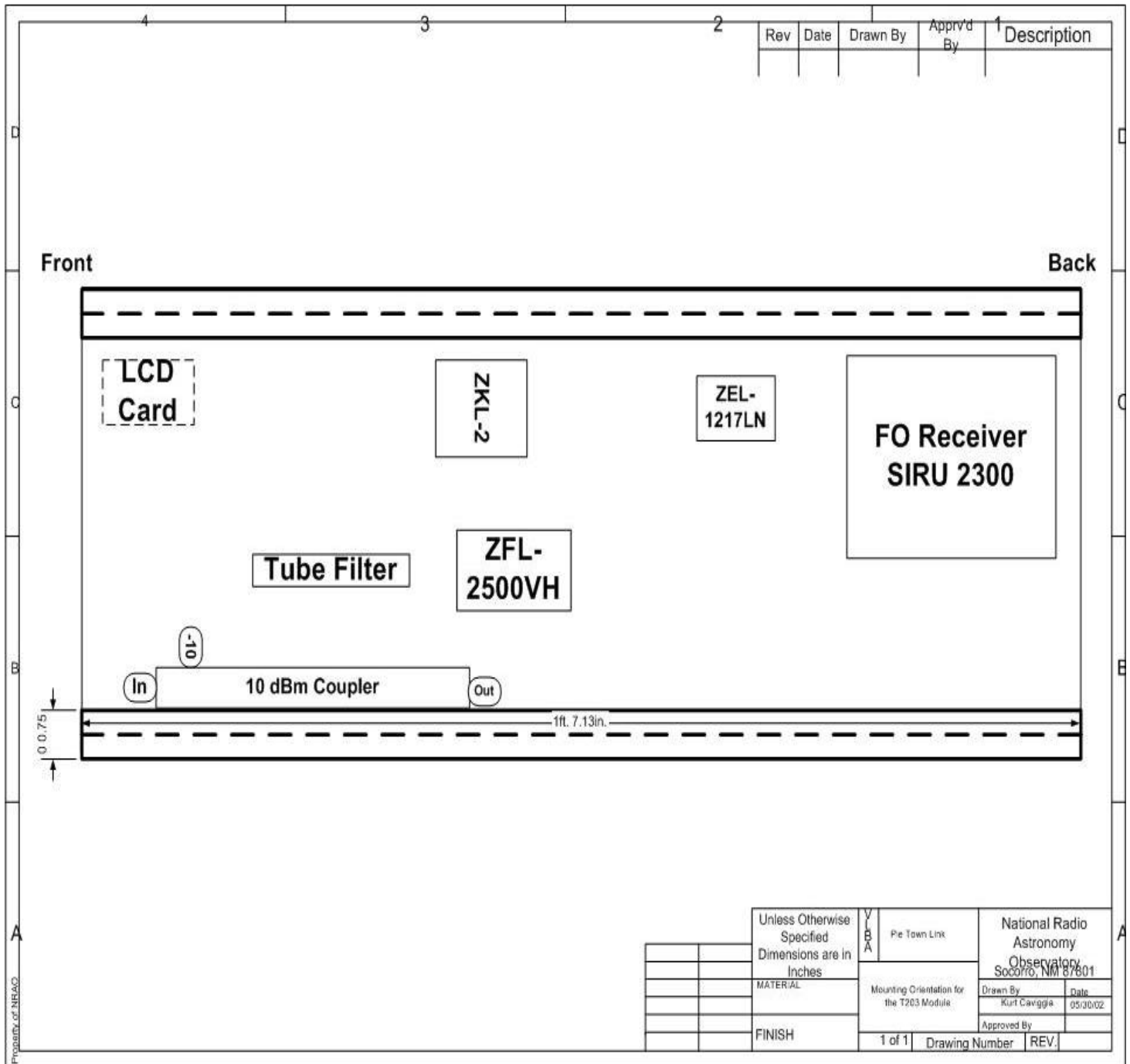


Figure 1: Component Layout

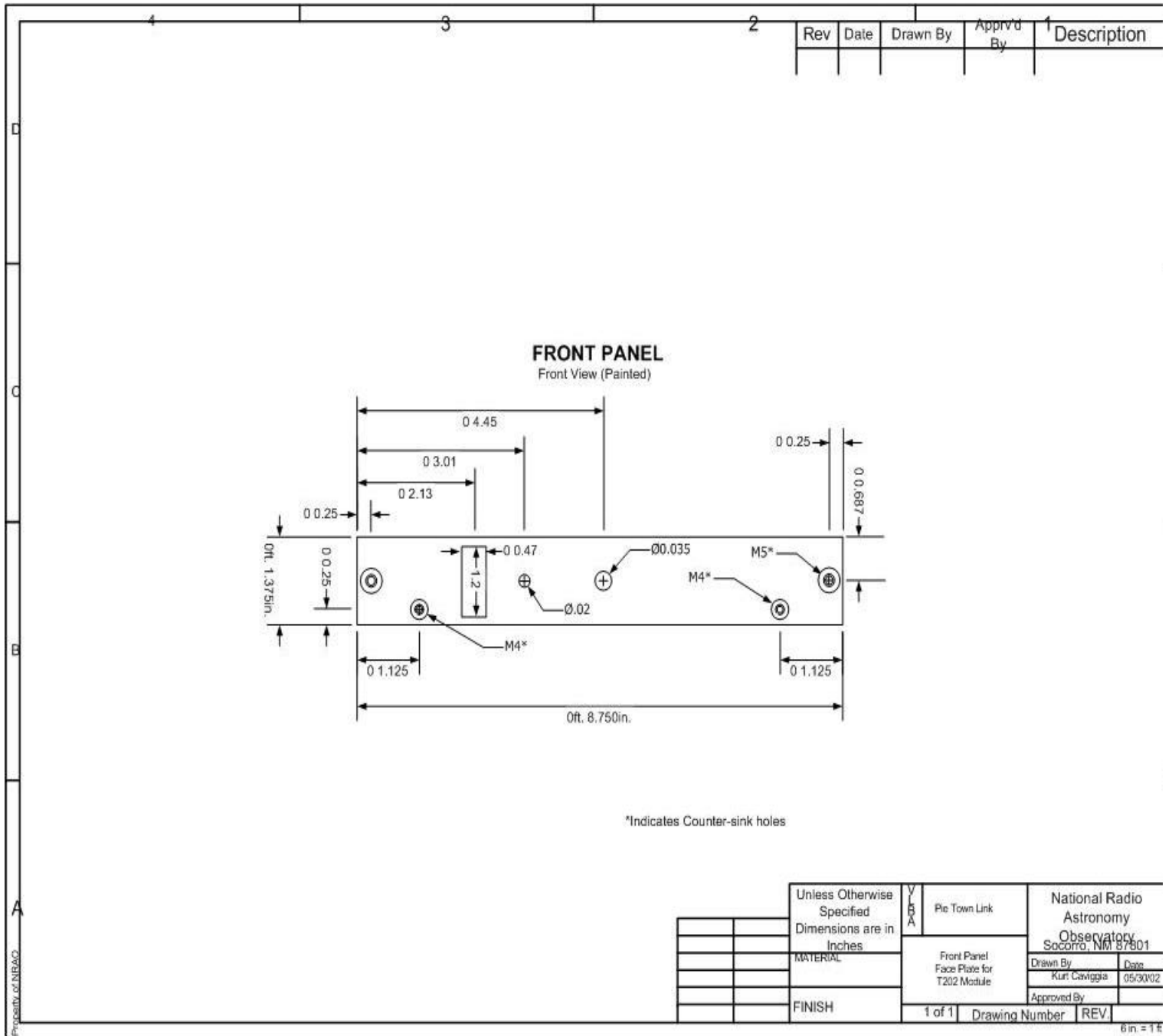
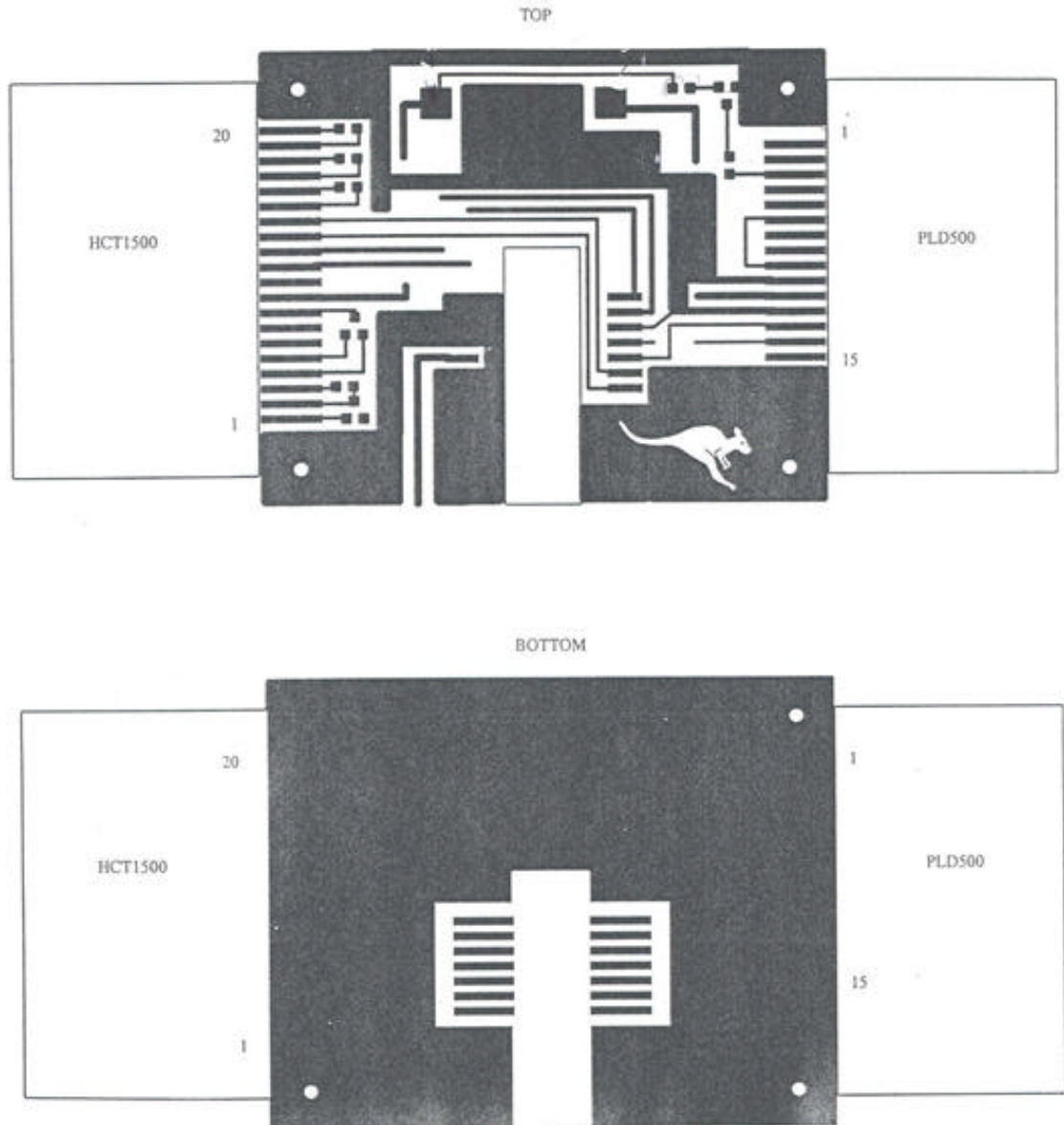


Figure 2: Front Panel drawing for the T202





**Figure 4: DFB laser Board Artwork.**



