

120-205 MHz Receiver for PAPER: Precision Array to Probe the Epoch of Reionization

Chaitali R. Parashare

Department of Electrical and Computer Engineering, University of Virginia, Charlottesville, VA 22903

Richard F. Bradley

NRAO Technology Center (NTC), 1180 Boxwood Estate Road Charlottesville, VA 22903

Abstract. This report represents the design and construction details of the receiver designed to use for PAPER: Precision Array to Probe the Epoch of Reionization.

1. Introduction

A dual-polarization radio frequency processor (120-205 MHz) was developed for PAPER: Precision Array to Probe the Epoch of Reionization. The design consists of four amplification stages using Hittite HMC476MP86 mmic amplifier, an effective 120-205 bandpass filter and some 3 dB attenuators for interstage isolations. The 75 Ω coaxial cables from antenna elements terminate on receiver boards hence the 75-50 Ω impedance matching module as described in [] is also a part of the receiver board with F-type connectors at the input side.

The assembly of all the boards together in an RFI enclosure box is also described in this report.

2. Design Details

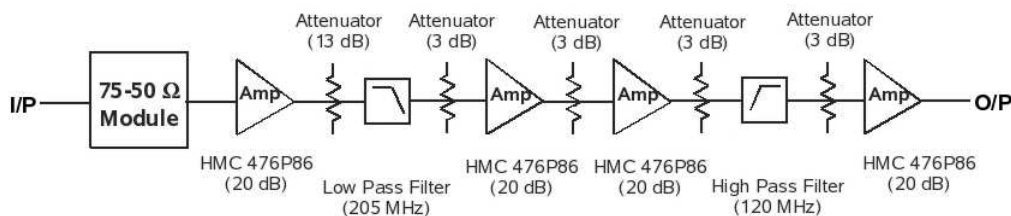


Figure 1. Block Diagram of the Receiver Design

Figure 1 shows a block diagram of the receiver design. The 75-50 Ω impedance matching network is followed by an amplification stage using Hittite HMC476P86 which is followed by a low pass filter, two HMC476P86 amplifiers, a high pass

filter and another HMC476P86 amplifier. 3 dB attenuator are included between the components for isolation purpose. All the components were designed using Agilent Advanced Design System (ADS).

2.1. Amplifier Biasing Circuit Design

As mentioned earlier the amplification stage consists of a Hittite HMC476P86 which has a gain of 20 dB. The biasing circuit is given in Figure 2. The biasing voltage is +5V with a bias resistor value of $33\ \Omega$ ($1/8\ W$). The $0.1\ \mu f$ capacitors at input and output sides act as DC coupling capacitors.

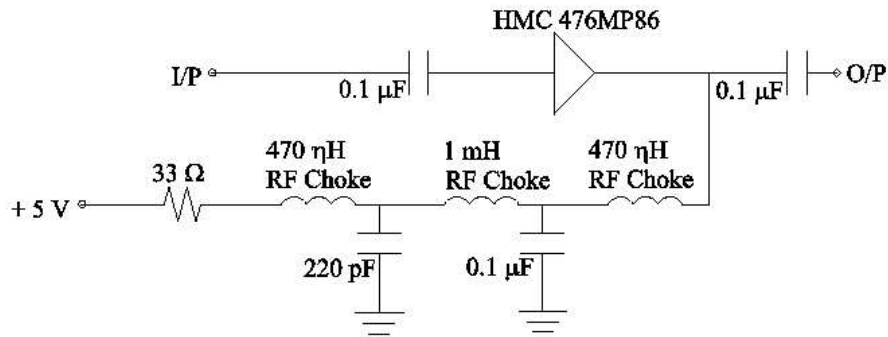


Figure 2. schematic of Hittite HMC476P86 Biasing Circuit

2.2. Low Pass Filter Design

Figure 3 illustrates the low pass filter design with 13 elements. The filter cutoff frequency is 205 MHz. The inductors are constructed by winding a 28 AWG magnet wire with the air core diameter of 0.064 inch. The inductors are wound in such a way that the polarizations of two inductors next to each other are opposite to each other. Also, to minimize the mutual coupling of inductors, they are connected in right angle to each other rather than in a straight line. Parallel combinations of capacitors are used to obtain the desired values.

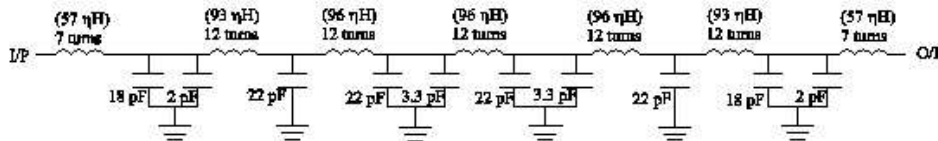


Figure 3. Schematic of the Low pass Filter (Cutoff Frequency 205 MHz)

2.3. High Pass Filter Design

Figure 4 illustrates the high pass filter design with 11 elements. The filter cutoff frequency is 120 MHz. Same as the low pass filter, the inductors are constructed with a 28 AWG magnet wire and air core diameter of 0.0064 inch.

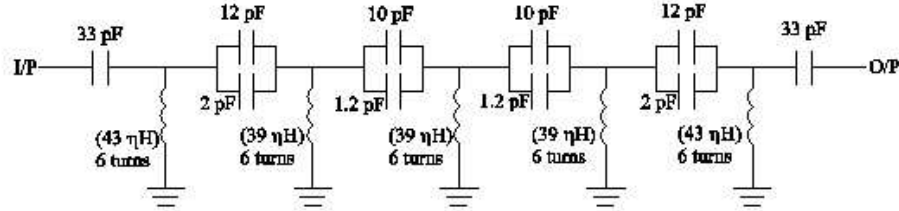


Figure 4. Schematic of the High pass Filter (Cutoff Frequency 120 MHz)

2.4. Attenuator Design

Figure 5 shows the schematic of 3 dB attenuator. Later as a modification, a 10 dB attenuator was added in the design to achieve a better input match and minimize the reflections in the system. To do so, the 3 dB attenuator between the first amplification stage and the low pass filter was replaced by a 13 dB attenuator. The schematic of 13 dB attenuator is also shown in Figure.5.

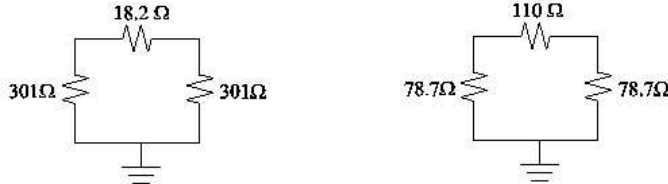


Figure 5. Schematic of a) 3 dB Attenuator b) 13 dB Attenuator

A photograph of the dual-polarization receiver board consisting 75-50 Ω impedance transformation, gain and filter stages is shown in Figure 6. The connectors at input and output side are F-type and SMA respectively. The +5V (for HMC476P86) and +12V (for the amplifier stage in the impedance matching module) supply line are connected from the back side of the board.

3. Receiver Response Measurement

Figure 7 shows the measured response of the receiver which includes response due to four stages of HMC476P86 amplifier, the low pass filter, high pass filters

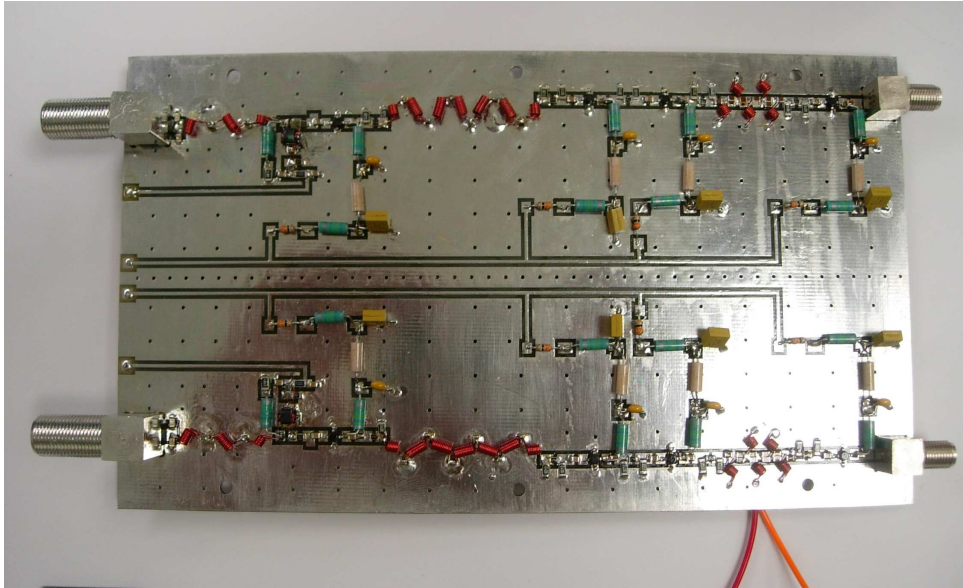


Figure 6. Photograph of the Dual-Polarization Receiver Board

and the attenuators included in the design. Since the receiver board includes the $75\text{-}50\ \Omega$ impedance transformation module at the input side, the receiver response was measured together with the $50\text{-}75\ \Omega$ impedance transformation module and a 25 cm $75\ \Omega$ RG-6 (5789) cable. In addition to this, the response of the transmission system including a 25 cm $75\ \Omega$ RG-6 cable and the impedance matching modules was measured separately. The gain of this measurement was subtracted from that of the previous measurement to obtain the results as shown in Figure 7. The receiver gain is 53 dB over the frequency range of 120-205 MHz.

Figure 8 shows the response of the receiver connected together with the transmission system consisting of a 150 m $75\ \Omega$ RG-6 (5789) cable and impedance matching modules. The gain of the amplifier stages in the impedance matching modules (total 15 dB) and the cable loss (6.72dB/100 meter) adds a gain of ~ 4 dB with a slope of -0.034 dB/MHz.

4. Temperature Stability Measurement

The gain versus temperature was measured using the HP 8753D VNA with the receiver and the $75\ \Omega$ transmission system including a 25 cm $75\ \Omega$ RG-6 cable and the impedance matching modules kept inside the environmentally controlled chamber (Thunder Scientific Corp., Model 2500S) The temperature was varied over the range of $0\text{-}50^\circ\text{C}$ in steps of 10°C allowing 2 hours between gain readings to ensure thermal equilibrium. A plot of the gain versus temperature at several

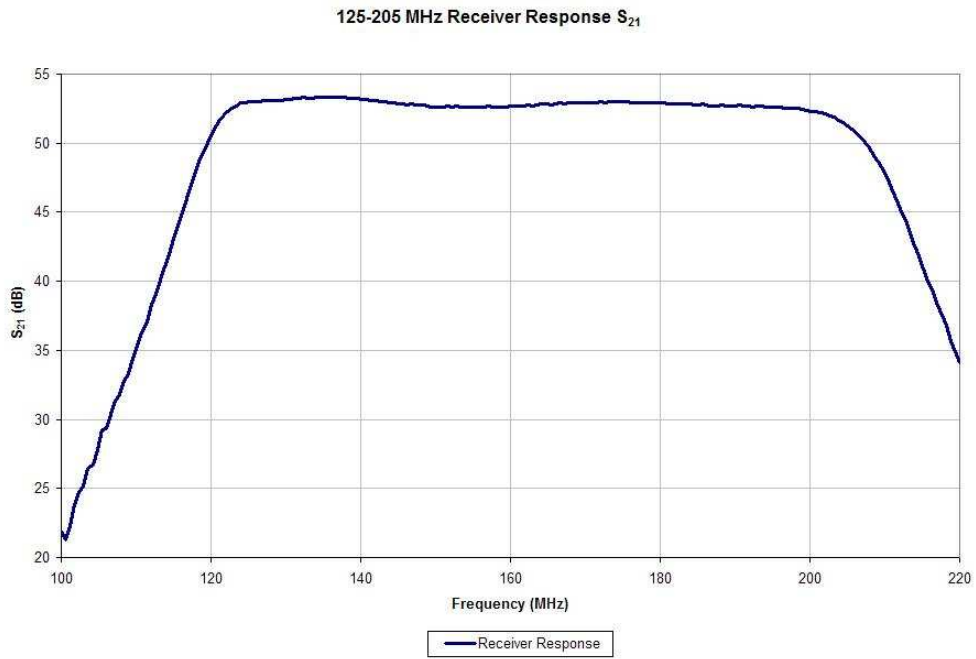


Figure 7. 120-205 MHz Receiver Response

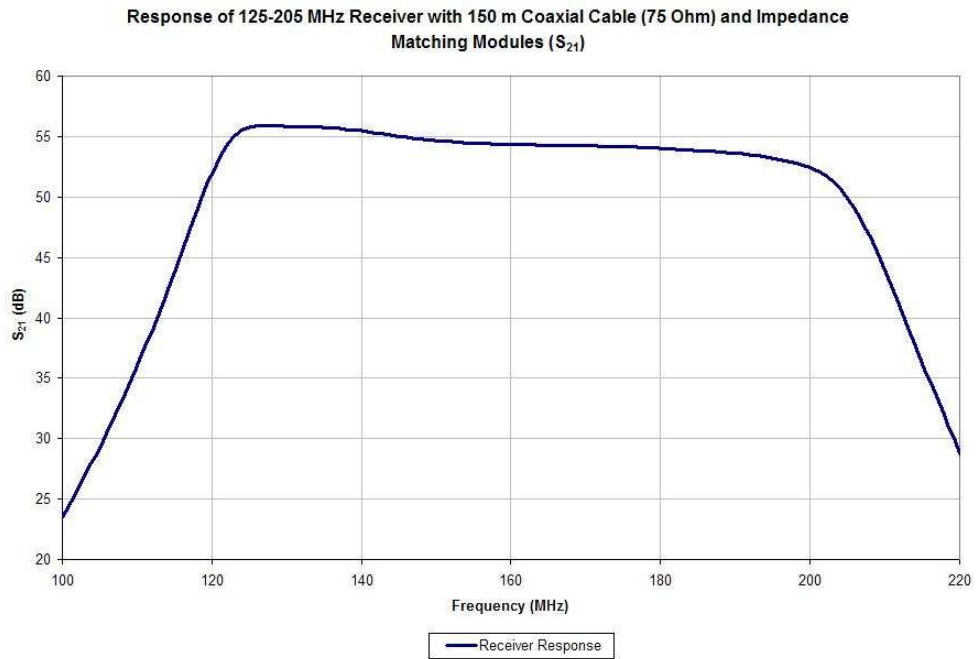


Figure 8. Response of 125-205 MHz Receiver with 150 m 75 Ω RG-6 (5789) and Impedance Matching Modules

operating frequencies is shown in Figure 9. The total gain includes 15 dB gain of the amplifiers in the impedance matching networks and the receiver gain of 63 dB which is 10 dB higher because the test was performed before the modification of adding a 10 dB attenuator. The gain sensitivity with temperature is approximately $-0.06 \text{ dB}/^{\circ}\text{C}$.

The electrical delay though the entire system was also measured during this test and found to be insensitive to temperature over the $0\text{-}50^{\circ}\text{C}$ range.

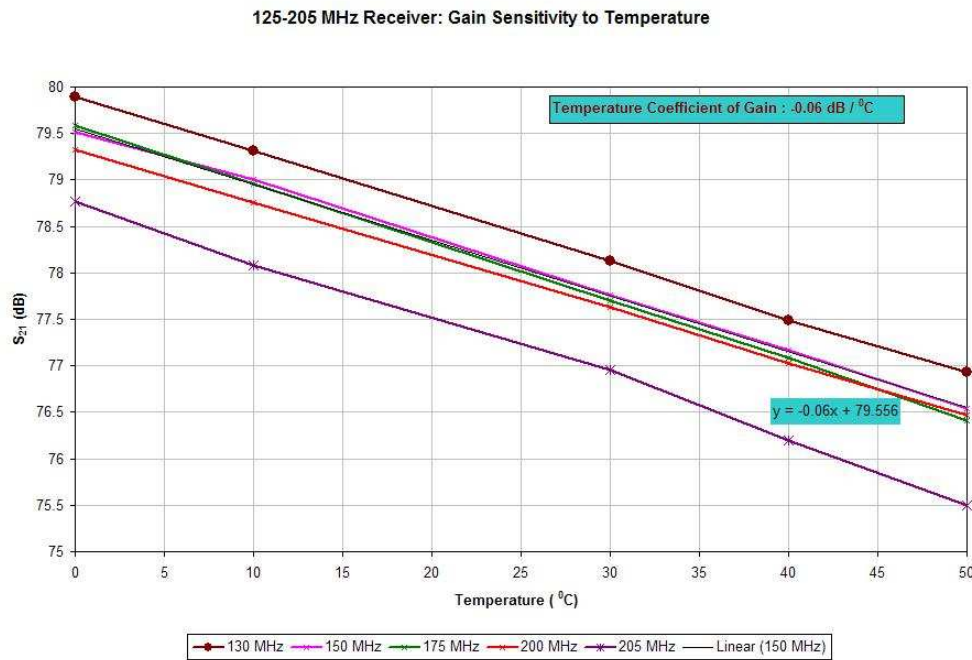


Figure 9. Graph showing the gain of the 120-205 MHz receiver with the transmission system (25 cm cable) as a function of ambient temperature at several operating frequencies.

5. Assembly of the Receivers in a RFI Shielded Enclosure

Initially, total eight receivers were mounted in a box of aluminum. When RFI measurement of the entire system consisting a sleeve dipole antenna, 75Ω transmission system and the receiver box, was conducted in the NRAO Green Bank anechoic chamber, it was observed that the receiver box assembly was causing regenerative feedback producing unwanted harmonics. To solve this problem, the receivers were mounted in a RFI shielded enclosure which will prevent such emissions from becoming RFI. The shielding is accomplished by bronze insect screening attached to a sturdy wooden framework and detachable lid. Copper

gauze was used between all seams to improve the electrical conductivity within the interface regions. A detailed information on the RF shielding enclosure design is given in[].

The inside dimensions of the enclosure are $29 \times 29 \times 29$ inches which were chosen to accommodate the power supplies as well. Two bulkheads, each having an effective area of 18×24 inches, were included on both sides of the enclosure for cabling. One of the bulkheads was designed for F connectors and the other for SMA connectors. This enclosure was designed to accommodate total 32 receiver boards. The arrangement of the receiver boards is such that the boards are mounted in two rows each containing total 16 boards. The assembly structure was simulated using AutoDesk Inventor.

Two mounting plates were designed, as shown in Figure 10, to mount the receiver boards vertically. The plate was made out of 22×12 inches sheet. An L-shaped bracket was constructed to secure the board firmly on the mounting plate. The L-bracket is fastened to the board as shown in Figure.10 and the bottom side of the bracket is fastened to the mounting plate. The F connectors of the boards go directly to the F connector bulkhead. Thus, with the help of L-bracket from one side and the tightening the F connectors to the bulkhead secure the boards in place. The mounting plates are fastened to the bulkhead for F connectors. From the 22×12 inch area of the sheet, the boards are mounted in 20×7 inch of area. The most of remaining 20×4 accommodates the power terminations to supply $+12 V$ and $+5 V$ DC power to the receiver boards. To have a sufficient room for power supplies and to avoid a physical contact of the coaxial cables (from the SMA connectors to the other bulkhead) to the DC connections, the area of plate containing the power terminations is bent in 150° angle as shown.

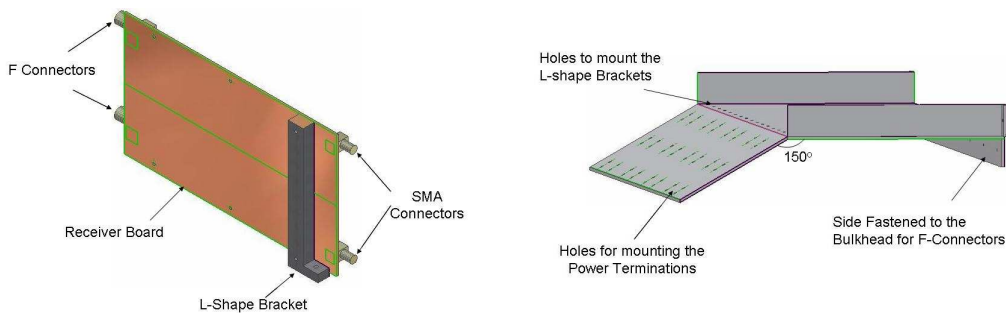


Figure 10. a) L-shape bracket attached to the receiver board b) mounting plate to hold the receivers

Figure 11 illustrates the entire assembly. It consists of the bulkhead for F connectors. Two mounting plates are fastened to it. The boards are mounted on the plates with the help of L-shape brackets. The F connectors of the receiver

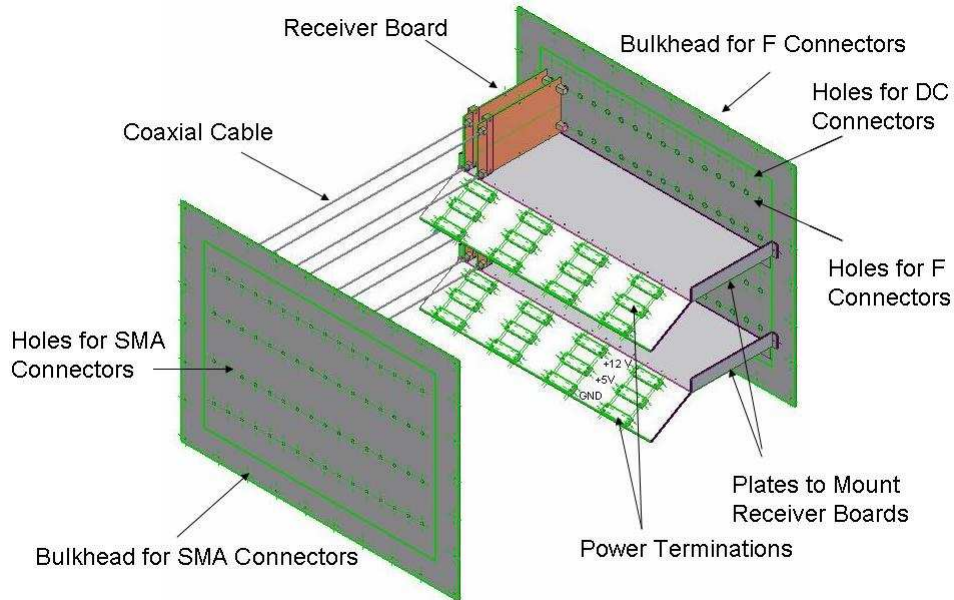


Figure 11. Illustration of the receiver boards assembly

directly go to the bulkhead. The SMA connectors of the board are connected to the other bulkhead through SMA/SMA 36" RG-58 cable. The mounting plate consists of three rows of power terminations, for +12 V, +5 V and ground connection, and four columns with each column connecting to four boards. The bulkhead for F connectors also includes DC connectors to supply +12 V DC power to the baluns situated at the antenna elements. The 75 Ω dual RG-6 (5789) terminates at the F connectors on the bulkhead and the third wire, which is used for bringing DC power to the balun situated at antenna, is connected to the DC connector.

Figure 12 shows photographs of the assembly of eight receivers with the front door of the enclosure removed. The power supplies are kept inside the enclosure. Absorbing material is inserted at the top to reduce the enhanced radiation caused by the cavity resonance effect.

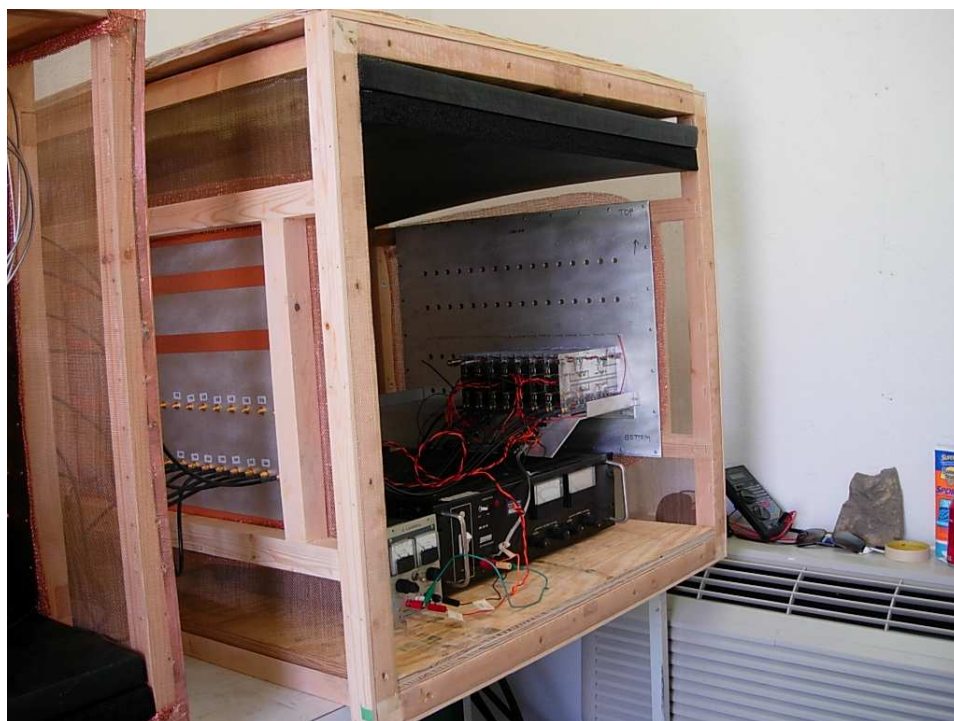
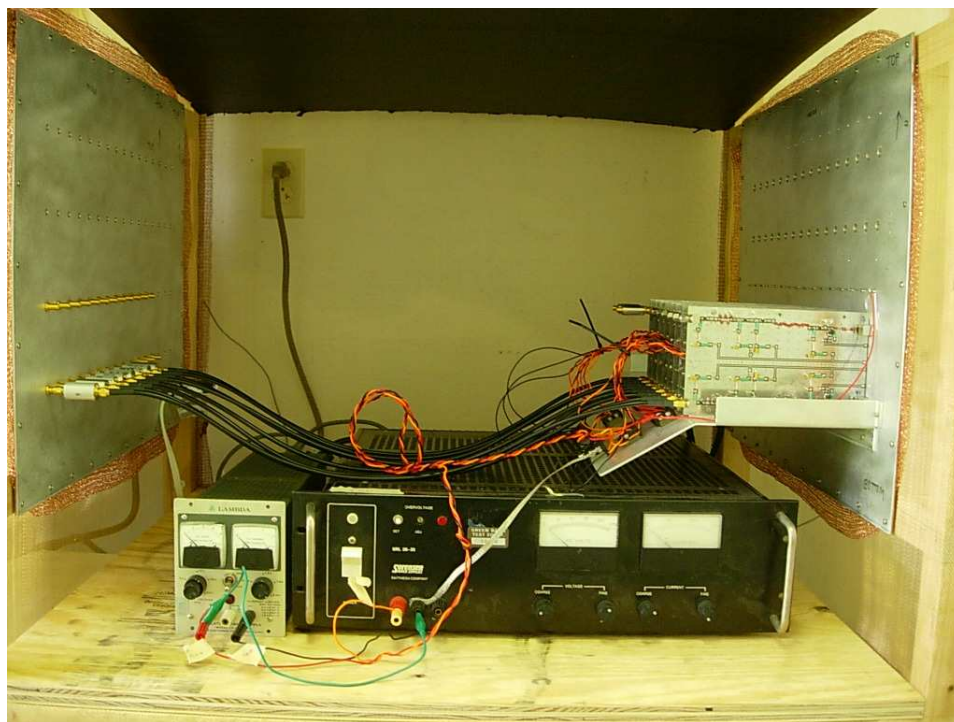


Figure 12. Photographs showing receiver boards assembly