LISA System Design

S.W. Ellingson*

September 15, 2002

Contents

1 Introduction

The L-band Interference Surveyor/Analyzer (LISA) instrument was developed as a means to observe sources of radio frequency interference (RFI) to passive microwave radiometry in the region 1200–1800 MHz. Data gathered from LISA will be used to characterize RFI and to provide coherently-sampled waveform data for the development of signal processing countermeasures to be implemented in a fully-digital radiometer currently under development at the Ohio State University ElectroScience Laboratory (ESL). LISA consists of a single rack of equipment plus a small antenna unit, making it easily transportable and suitable for use in a variety of field environments, including NASA's P3-B aircraft. This report serves to document the

*ElectroScience Laboratory, The Ohio State University, 1320 Kinnear Rd., Columbus, OH 43212; Voice: (614) 292-7981, Fax: (614) 292-7297, E-mail: ellingson.1@osu.edu.

design and construction of the LISA instrument, which occurred at ESL over the period March–August 2002. Separate documents describe validation testing of the completed instrument at ESL, and guidance for the installation of LISA on NASA's P3-B.

2 LISA Overview

A conceptual block diagram of the instrument is shown in Figure 1. Physically, LISA consists of a small antenna / front-end unit (AFEU) and an equipment rack, separated by up to several hundred feet of coaxial cable. A brief description is provided below; for additional detail, consult the following sections of this report.

The AFEU uses a planar spiral antenna backed by a ground plane. A noise generator (capable of being switched on or off) is available for calibration purposes via a directional coupler. Also, the input can be switched to an ambient-temperature matched load for calibration or diagnostic purposes. The switch output is delivered to a low-noise amplifier (LNA) followed by a line amplifier which drives the coaxial cable and also limits bandwidth to the 1200-1800 MHz range.

At the equipment rack, the signal flow is as follows. First, a tunable calibration tone is injected. This tone is mainly to facilitate diagnostics on the coherent sampling subsystem, and can be switched on and off as needed. The signal is then filtered (once again) to 1200-1800 MHz, and a portion of the signal power is redirected to a spectrum analyzer. The spectrum analyzer is under the control of a PC; control and data are exchanged via a 115.2 kb/s serial connection. The remainder of the signal is delivered to the coherent sampling subsystem. This subsystem uses a direct-conversion receiver to tune (under PC control) anywhere between 1200 MHz and 1700 MHz. "I" and "Q" components at baseband are low-pass filtered with 8 MHz cutoff and sampled at 20 MSPS, yielding a digitized bandwidth of 16 MHz. The output samples are queued in a 256K-sample-long first-in-first-out (FIFO) buffer, allowing up to 13 ms of contiguous signal capture. The FIFO contents are acquired by the PC by means of the PC parallel port. Although the receiver runs continuously, samples are allowed to enter the FIFO only when an acquisition is triggered by the PC.

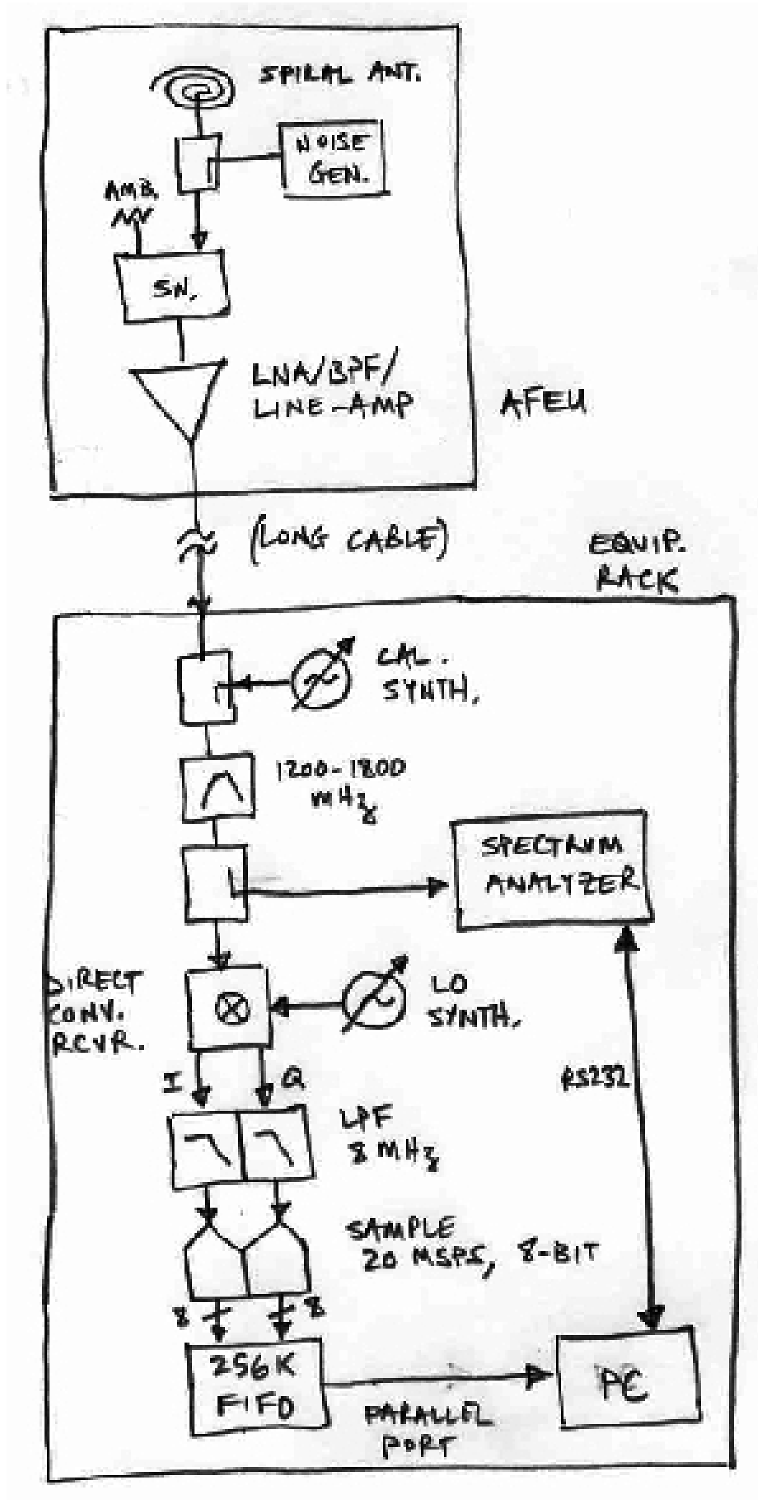

Figure 1: Conceptual block diagram of the LISA instrument.

The general concept of operation is as follows. The instrument is under the control of the PC, via a C-language program running under Windows 98. The control software accepts a command script (an ASCII text file) which describes the sequence of operations requested by the user. The script includes commands for controlling the AFEU, configuring and aquiring data from the spectrum analyzer, tuning the calibration synthesizer and direct conversion receiver, triggering and acquiring data from the coherent sampling subsystem, as well as a few commands for various other system functions. A common user strategy will be to use the spectrum analyzer to obtain rapid measurements of power spectral density over large frequency ranges, identify sources of interest from those measurements, and then tune the coherent sampling subsystem to frequencies of interest to obtain waveform data. However, the script language is very flexible and many other RFI observation strategies are possible.

The equipment rack is shown in it's operational state in Figure 2. Note that a pull-out keyboard/monitor is used. The entire LISA instrument is powered from a single 115VAC outlet, from which the internal uninterruptable power supply (UPS) is powered. All other equipment in the rack is powered via 115VAC outputs from the UPS. Figures 3 and 4 show the LISA equipment rack as it appears in the "stowed" configuration; e.g., keyboard/monitor unit retracted, rack ready to be moved.

3 Description of Instrument Components

In this section, a more detailed description of the instrument components and their specifications are provided.

3.1 AFEU

The AFEU is shown in Figure 5. It is a rectangular aluminum box of dimensions 12-in $\times$ 17-in $\times$ 3-in. The antenna is a wideband planar right-hand circularly-polarized spiral, placed in a circular aperture on one side of the AEFU enclosure. The spiral is backed by a ground plane 2-in away ($\lambda/4$ at 1420 MHz). The spiral itself is rendered in copper flow on a 12-in $\times$ 12-in piece of FR-4 circuit board material. A tiny surface-mount 4:1 transformer is used as a balun to interface the spiral's natural

Figure 2: The LISA equipment rack, as it appears when the system is running.

Figure 3: The front of the LISA equipment rack, as it appears when the system is stowed. From top to bottom: Spectrum Analyzer, LISA electronics box, 1U keyboard/monitor unit, computer, DC power supply, UPS.

Figure 4: The rear of the LISA equipment rack, as it appears when the system is stowed.

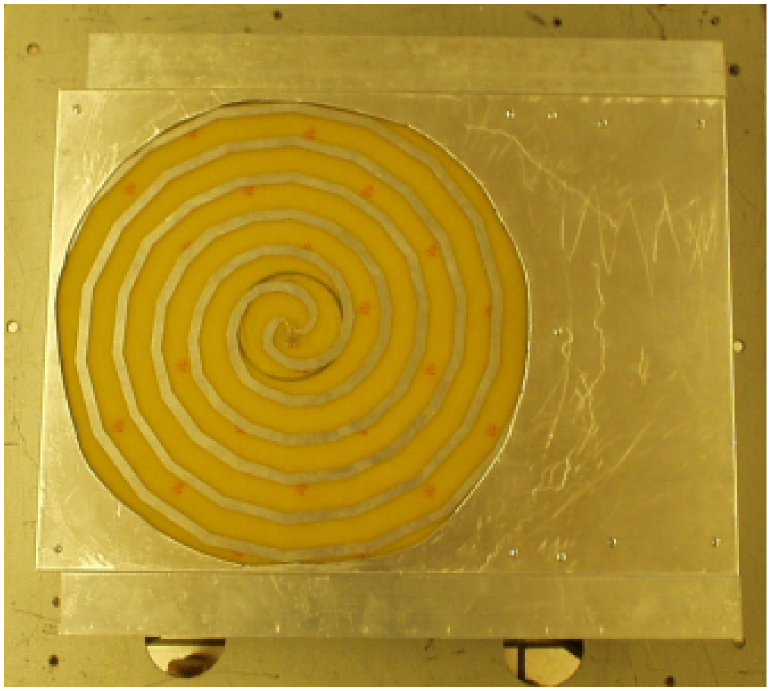

Figure 5: The antenna side of the AEFU. Note mounting L-brackets on top and bottom (with respect to orientation in this picture).

200Ω, unbalanced output to a 50Ω unbalanced input for coaxial cable. The S11 measured at the balun output is shown in Figure 6.

Figure 7 shows the inside of the AFEU. A schematic is shown in Figure 8. No heating or cooling is employed. Note that the interface between the AFEU is via 3 coaxial cable connections, labeled J1–J3:

- J1 provides DC power for the AFEU's RF electronics. It also carries a binary control signal from the equipment rack to the AEFU, by means of a small change in the level of the DC voltage, which is used to control the state of the antenna switch.

- J2 provides DC power for the AFEU's noise generator. It also carries a binary control signal from the the equipment rack to the AFEU, by means of a small change in the level of the DC voltage, which is used to control the noise generator.

- J3 carries the RF output of the AFEU back to the equipment rack.

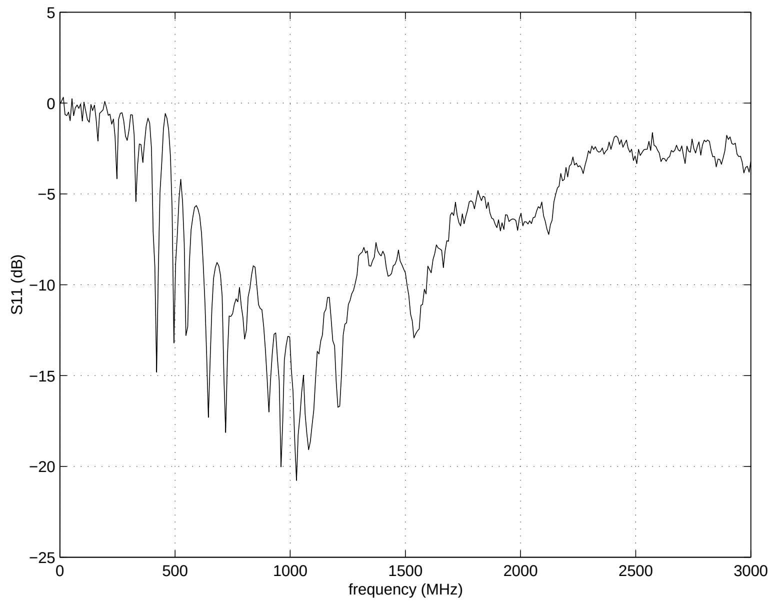

Figure 6: Measured S11 of the AEFU antenna.

In the AFEU, J1 and J2 use identical receiver circuits that are explained in detail in Section 3.4. The LNA is a 15 dB gain, 1.5 dB noise figure (estimated maximum) custom design based in the Agilent ATF-34143 PHEMT MMIC, and is documented in [1]. The LNA is connected to a custom line amplifier documented in [2]. The line amplifier provides about 20 dB additional gain, and includes a stripline bandpass filter with cutoffs around 1200 MHz and 1800 MHz. Figure 9 shows the measured response of the LNA and line amplifier.

The three coaxial cables that connect the AFEU to the equipment rack may be of any type as long as they are 50Ω with less than 10 dB or so attenuation. RG-223 is recommended although RG-58 will suffice. The cables must end in SMA male connectors at both ends, and there must be no DC blocks (e.g., series capacitors) anywhere between the AEFU and the equipment rack, as this would interfere with the operation of the J1/J2 power and control circuits.

3.2 Equipment Rack

A block diagram of the equipment rack is shown is Figure 10. As shown here and in Figures 3 and 4, the equipment rack includes the following items:

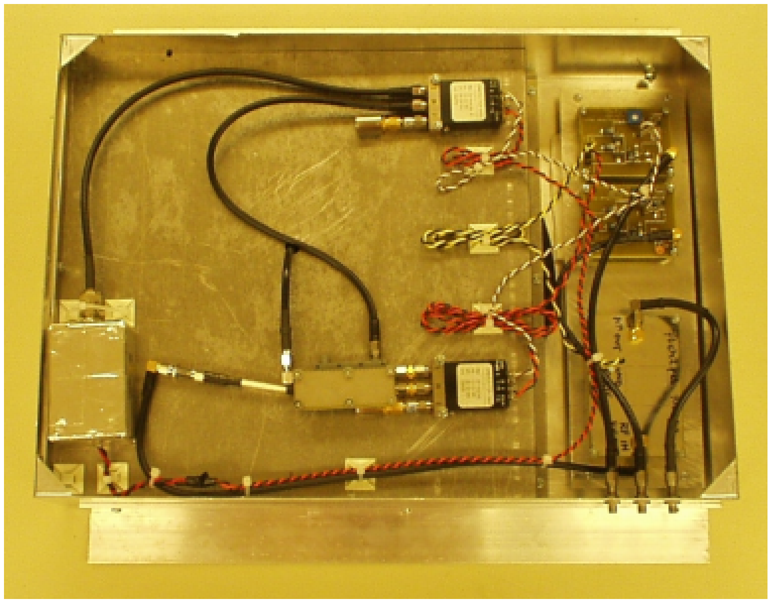

Figure 7: AEFU, cover removed. Antenna is facing away from the observer in this picture. The silver box at the far left is the noise generator. The black components with white labels are the RF switches associated with the noise generator (top) and calibration load (bottom). The LNA is the small silver component to the left of the calibration load / antenna switch. At the far right, top to bottom, are the control receiver for the noise generator, control receiver for the antenna switch, and the line amplifier. The 3 SMA jacks that are used to connect the AFEU to the equipment rack are visible at the bottom right.

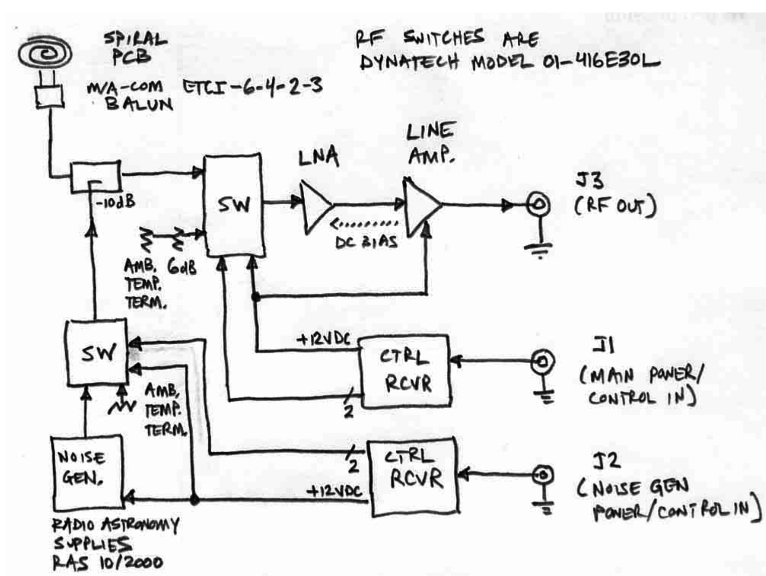

Figure 8: AFEU schematic.

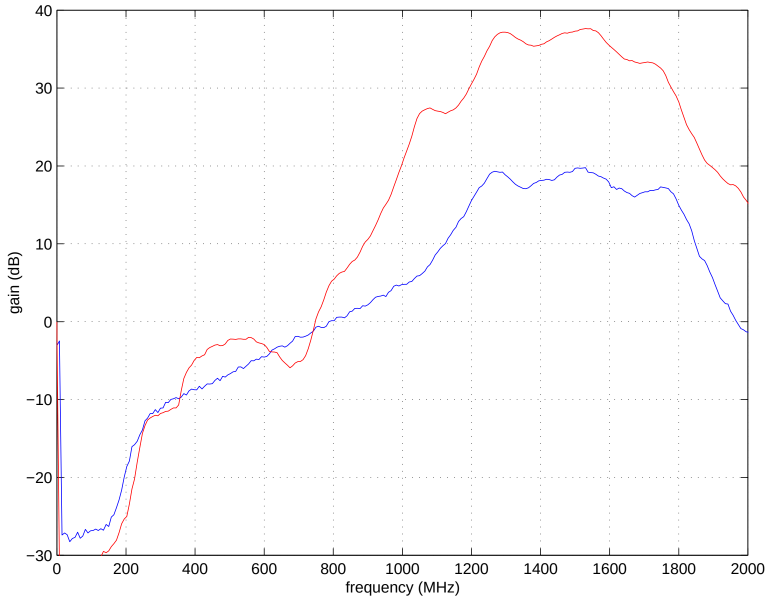

Figure 9: Measured frequency response of the AFEU electronics. *Top:* Antenna terminals to J3. *Bottom:* Line amplifier alone.

- Spectrum analyzer, Agilent Model E4407B. The spectrum analyzer is interfaced to a PC via RS-232 at 115.2 kb/s. The PC-based system control software commands the spectrum analyzer and collects data using the techniques described in [3].
- Electronics box, documented in Section 3.3.
- 1U retractable keyboard/monitor unit, CyberResearch Model GFA1510.
- Personal computer, documented in Section 3.5.
- DC power supply, Xantrex Model XFR 40-30.
- UPS, APC Model SU1000RM2U.

3.3 Electronics Box

The electronics box contains RF, power, and control distribution circuits, as well as the coherent sampling subsystem. A view of box from the rear is shown in Figure 11. Another view of the box revealing the inside is shown in Figure 12. A block diagram

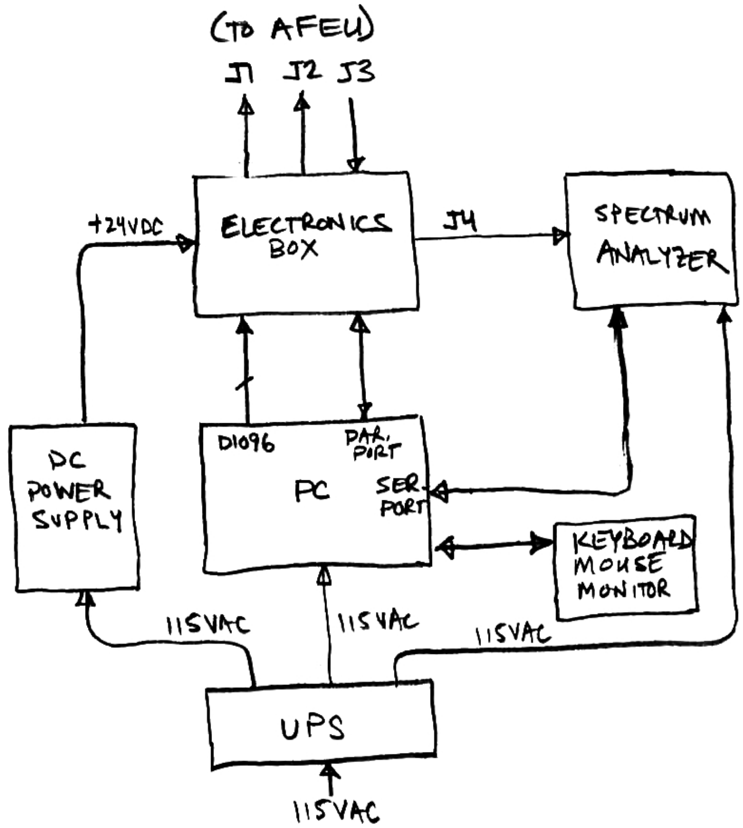

Figure 10: Block diagram of the equipment rack.

Figure 11: Outside of the electronics box, viewed from rear.

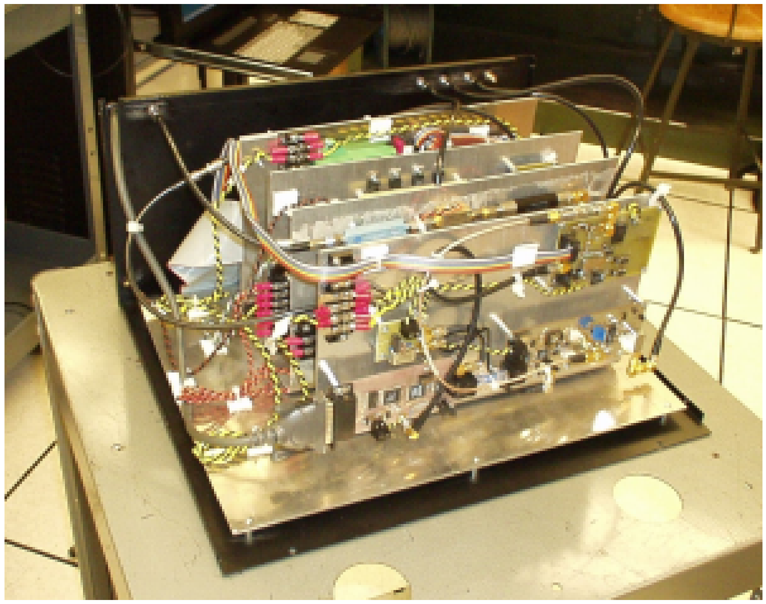

Figure 12: Inside of the electronics box viewed from front.

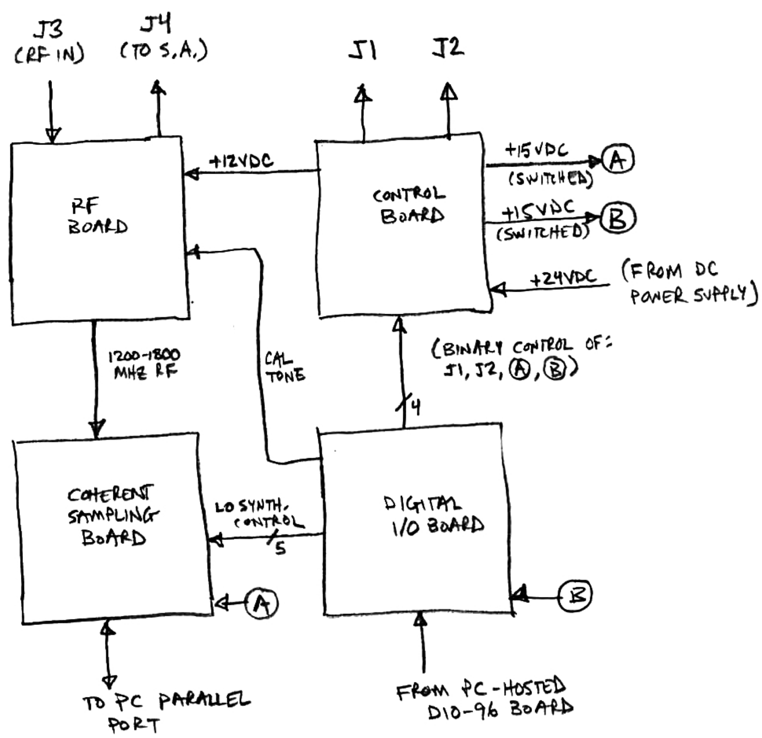

Figure 13: Block diagram of the electronics box.

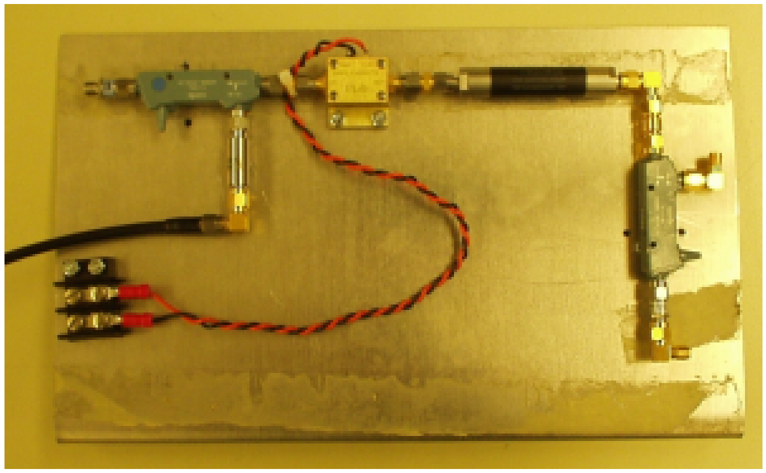

Figure 14: RF Board.

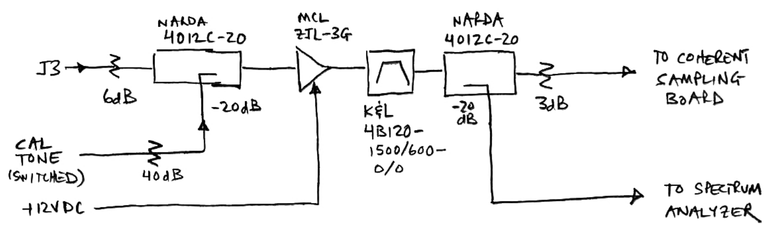

Figure 15: RF Board schematic.

is shown in Figure 13. As shown in this figure, the electronics box consists of 4 subassemblies as follows:

- The RF Board, shown in Figures 14 (picture) and 15 (schematic). The frequency response of RF board is shown in Figure 16.

- The Coherent Sampling Board, shown in Figure 17 (picture) and 18 (schematic). This board uses a custom direct conversion receiver [4]* and FIFO buffer [5] developed at ESL. The direct conversion receiver includes a considerable amount of RF gain, such that −37 dBm at the input (about −77 dBm at the antenna terminals) causes clipping of the digitizer outputs.

- The Control Board, shown in Figure 19 (picture) and 20 (schematic).

- The Digital IO Board, shown in Figure 21 (picture) and 22 (schematic). This board also contains the calibration synthesizer. The tone level out of this syn-

*The gain control voltage is set to +2.4 V.

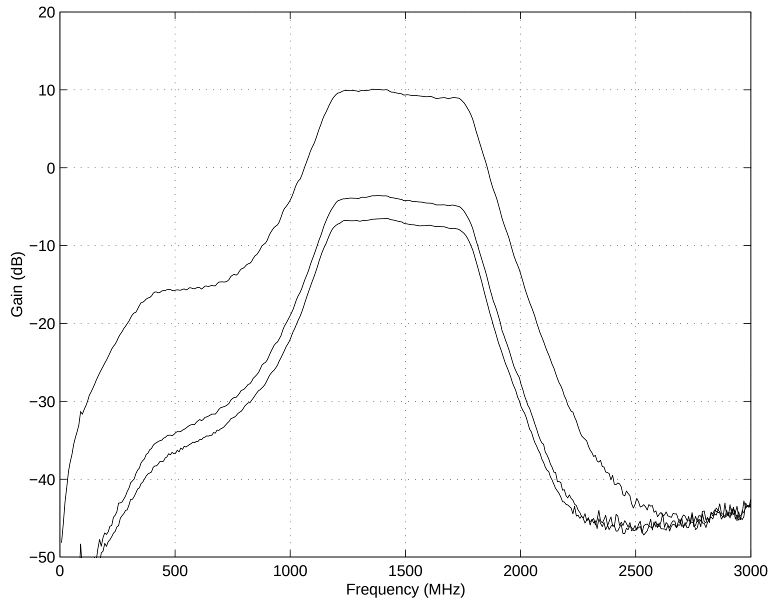

Figure 16: Measured frequency response of the RF board. *Top:* Primary input (from AFEU) to primary output (to Coherent Sampling System). *Middle:* Coupled input (from Calibration Synthesizer) to primary output. *Bottom:* Primary input to coupled output (to Spectrum Analyzer).

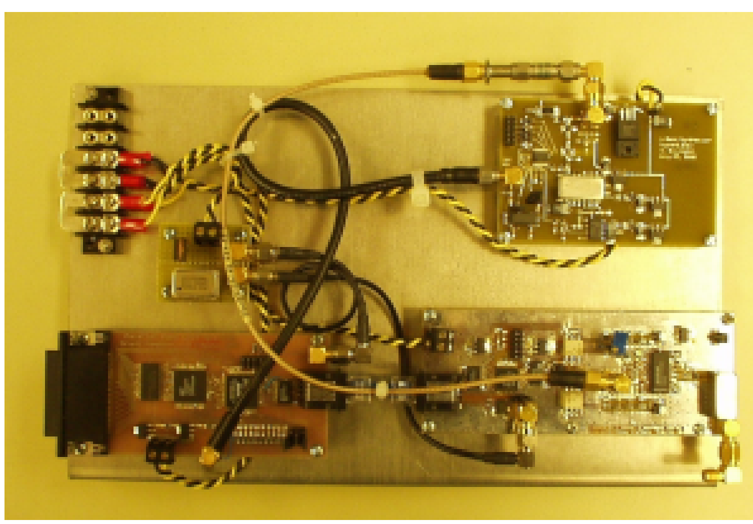

Figure 17: Coherent Sampling Board.

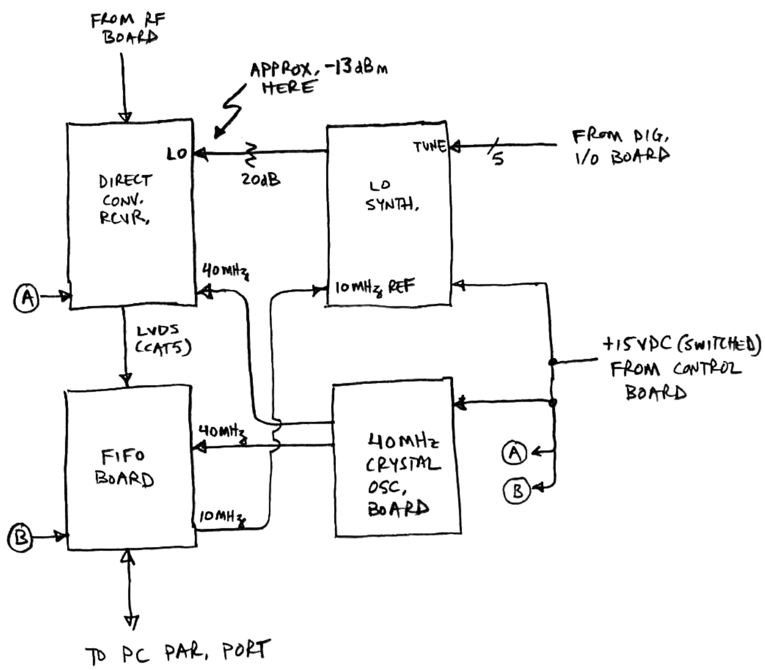

Figure 18: Coherent Sampling Board schematic.

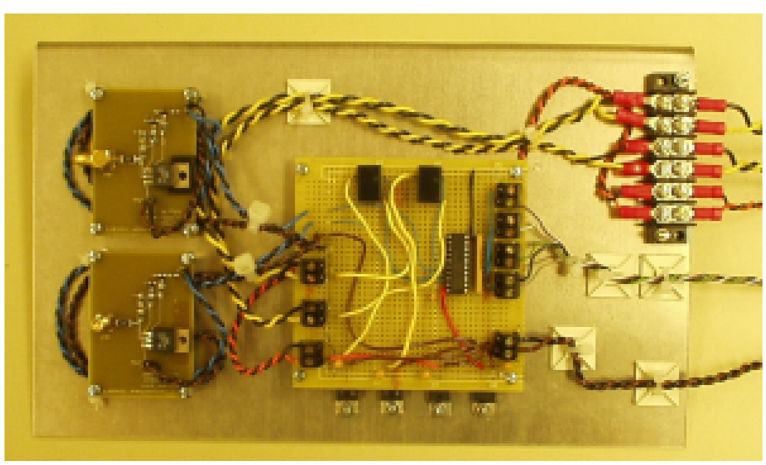

Figure 19: Control board.

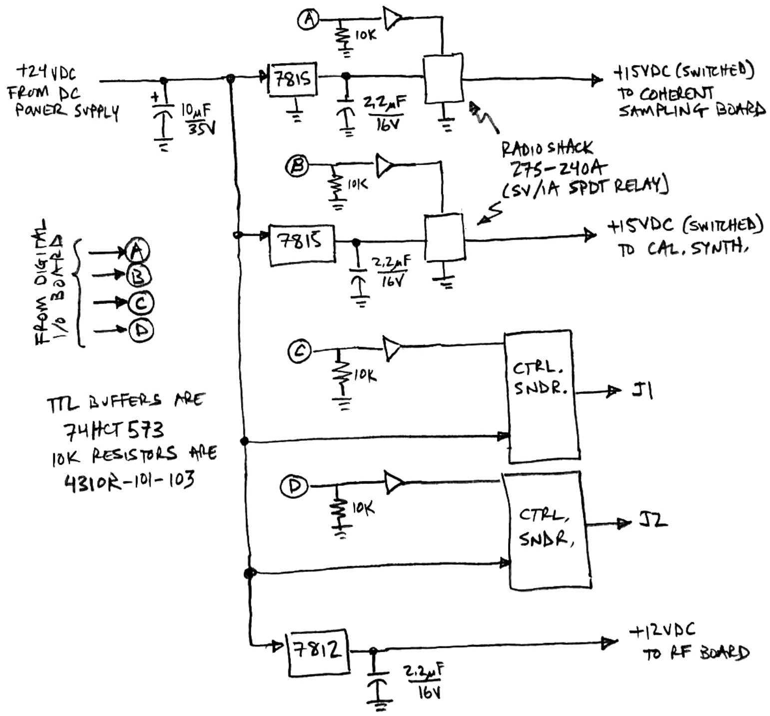

Figure 20: Control board schematic.

thesizer is +6.7 dBm, and appears at the input of the coherent sampling board at −41 dBm.

The calibration and LO synthesizers use the same, custom ESL design, and are not currenly documented (except as a few pages in the author's stack of illegible design notes!). It should be noted that the calibration synthesizer currently uses it's own on-board crystal oscillator and is *not* slaved to the same timebase as the coherent sampling subsystem.

The gain from the J3 input to the electronics box to the input of the coherent sampling subsystem is about 40 dB. For the overall frequency response, see Figure 23.

The electronics box consumes about 0.2 A at +24 VDC when coherent sampling and tone calibration are powered down. Coherent sampling consumes an additional 1 A when turned on. The calibration synthesizer consumes an additional 0.1 A (approx) when turned on.

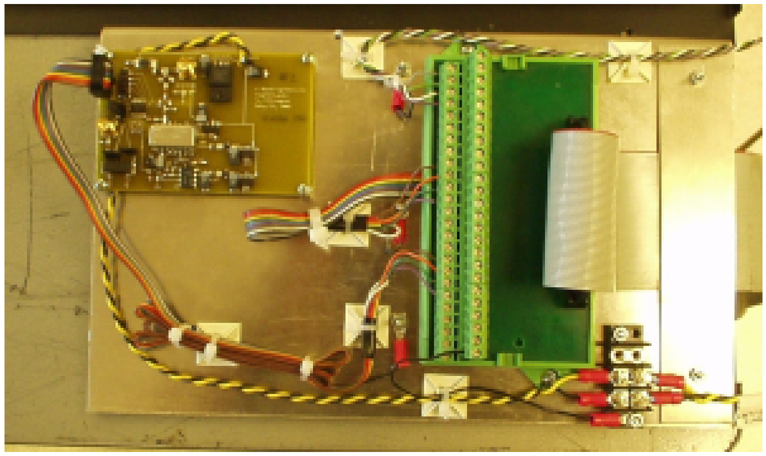

Figure 21: Digital IO board.

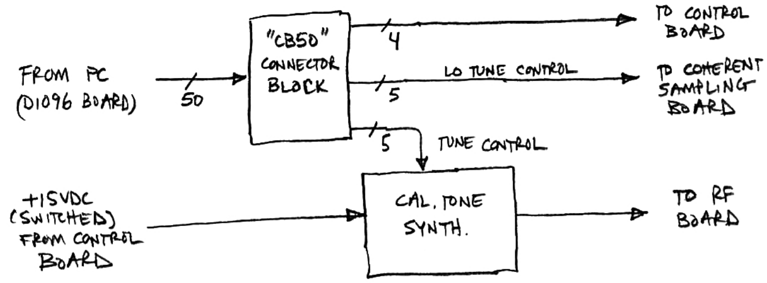

Figure 22: Digital IO board schematic.

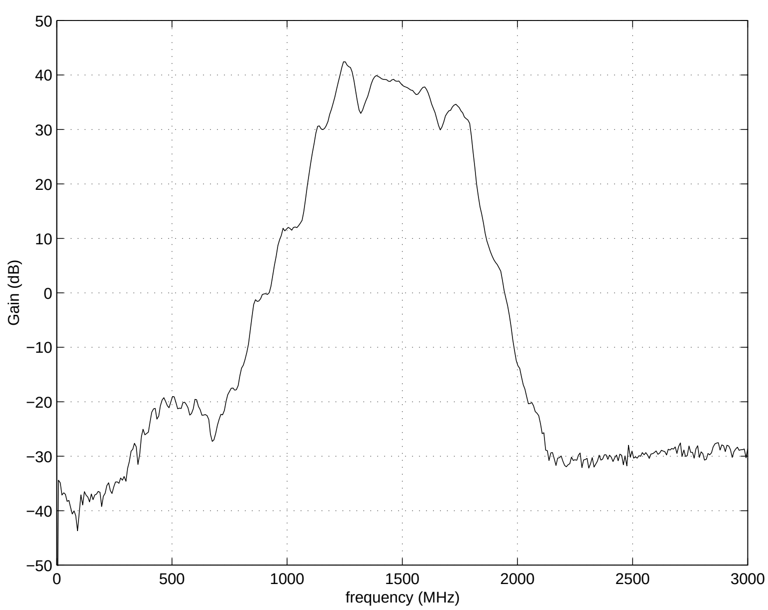

Figure 23: System frequency response as measured from the J3 input of the electronics box to the coherent sampling system (video averaging of 100 traces with 30 kHz resolution bandwidth).

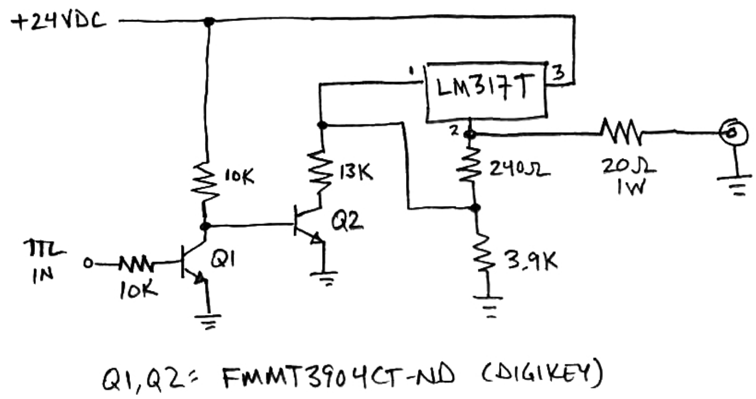

Figure 24: Control Sender Circuit.

3.4 Remote Control/Power Circuit

As mentioned previously, the J1 and J2 connections between the AFEU and the equipment rack are used to convey power and a binary control signal over a single coaxial cable connection.† The J1 and J2 circuits are identical, and are described here. In each case, the control sender (located on the control board of the electronic box) accepts +24 VDC power and a TTL control signal from the PC, via the DIO-96 board. The control sender board (see schematic, Figure 24), applies a DC voltage to the output cable which varies slightly according to the state of the digital input signal. At the control receiver board (see schematic, Figure 25), regulated +12 VDC power is obtained from the cable and the digital signal is recovered by means of a comparison to a regulated reference voltage.

Note that the control receiver generates both the desired signal and it's complement. This is to facilitate the RF switches used in this design, which require dual complementary TTL signals for control.

3.5 PC

At present, LISA is equipped with a 133 MHz Pentium PC with a 3 GB hard drive, running Windows 98. The PC is fitted with a National Instruments DIO-96 card, which provides the interface to the LISA electronics box (specifically, the Digital IO

†The inspiration for this design comes from a similar circuit devised for MIT Haystack Observatory's "Small Radio Telescope" (SRT); see http://web.haystack.mit.edu/SRT/index.html.

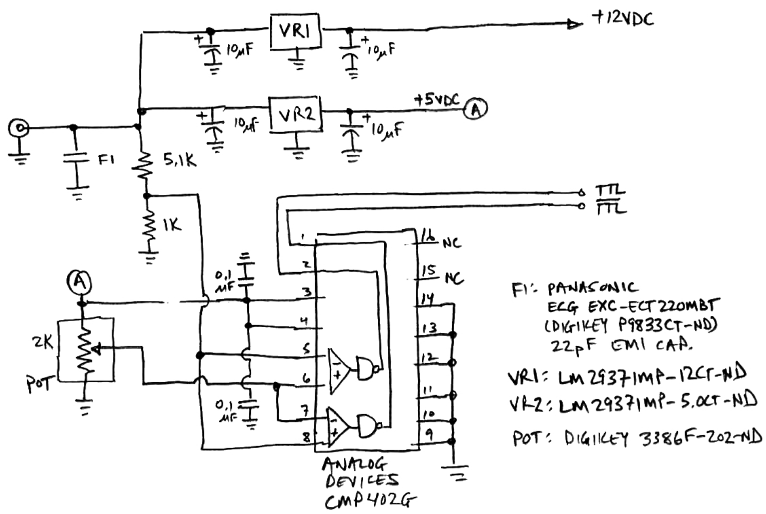

Figure 25: Control Receiver Circuit.

board). Over this interface, 5 lines are dedicated to the control of the Calibration Synthesizer, 5 lines are dedicated to the control of the LO Synthesizer, and one line each is dedicated to the following four functions: Coherent Sampling Board Power On/Off, Calibration Synthesizer On/Off, AFEU Noise Generator On/Off, AFEU Antenna/Matched Load Select.

System control is via a C-language program developed using National Instrument's LabWindows/CVI development environment. A snapshot of the GUI is shown in Figure 26.

A script language was developed to allow simple, flexible control of experiments using LISA. An example of a simple script is provided in Appendix A. To provide a brief orientation as to the use of the script, an explanation of the first few lines of this script is provided below.

```
// 0-3 GHz
```

Text following a "//" at the beginning of a line is ignored, and available for comments.

```
CD 1                                    # Display 1
```

"CD" stands for "change display". In this case, the program is instructed to display subsequent results to display no. 1 (the top left panel of the GUI) during execution.

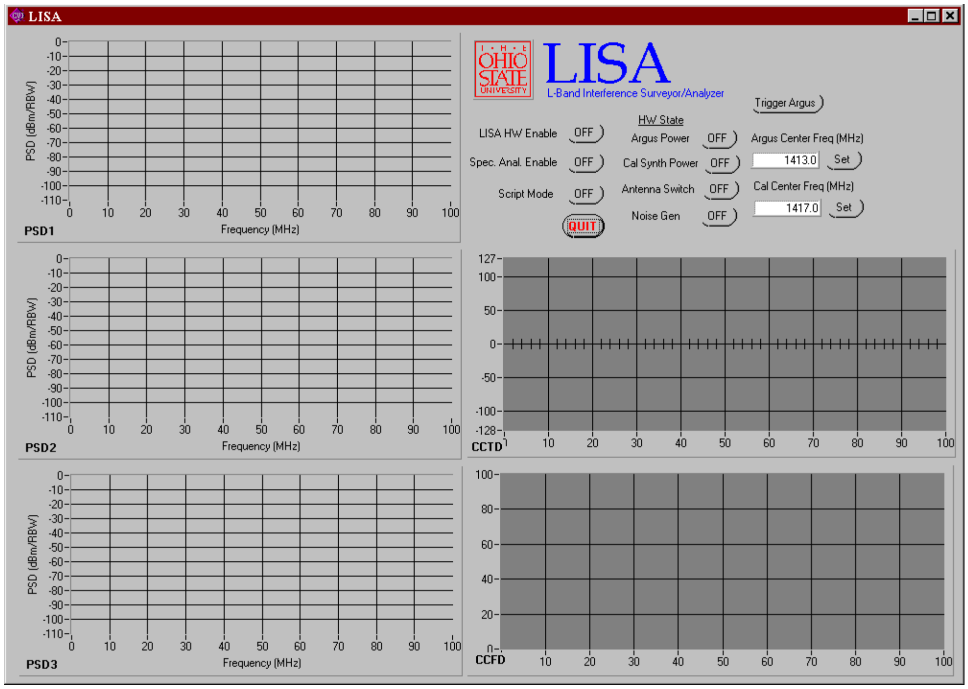

Figure 26: GUI. Note that the GUI uses the term "Argus" to refer to the coherent sampling subsystem.

A number sign is used to indicate that additional characters on that line are to be ignored (i.e., used for comments).

```
IN 1                                        # Toggle to antenna
```

"IN" tells the computer to toggle the AFEU's antenna switch such that the input is either the antenna (1) or the matched load (0).

```
FN 0.0e+0 3.0e+9 1.0e+6 3001 1 100 0 1 # Max hold
```

"FN" is a request to obtain a multiple sweeps from the spectrum analyzer. The parameters are the start frequency (0 GHz), stop frequency (3 GHz), RBW (1 MHz), number of points per sweep (3001), enable max hold (1; 0 would mean enable averaging instead), number of sweeps (100), measurement ID number (0), and display color (1). "Max hold" means that the result will be a single trace in which each point is the maximum value for that frequency across all sweeps. "Averaging" means the average of the traces in linear power units (e.g., mW). A "measurement ID number" is a unique number that identifies the requested measurement and is also used to label data files associated with that measurement. The "display color" is a code indicating the color of the trace used on the GUI.

The control program executes the script from beginning to end, and then returns to the beginning, following an endless loop until the program is manually terminated. Data files associated with each requested measurement are saved to disk using the measurement ID, iteration number, and date/time to construct a unique filename.

Additional script commands currently implemented include the following (please refer to the source code for guidance on how to use these commands):

- `CC`: Trigger an acquisition from the coherent sampling subsystem.
- `FC`: Similar to `FN`, except `CC`'s are triggered one after another until the spectrum analyzer is finished. This allows the PC to perform `CC`'s when it would otherwise be waiting for an `FN` command to complete.
- `NG`: Turn AFEU's noise generator on/off.
- `PA`: Turn power to coherent sampling subsystem on/off.
- `PC`: Turn power to calibration synthesizer on/off.
- `SA`: Tune LO synthesizer (must be turned on first).
- `SC`: Tune calibration synthesizer (must be turned on first).

In the near future we anticipate adding additional commands to allow spectrum analyzer output to be analyzed and tuning of the coherent sampling system in response to detected signals.

Acknowledgments

This work was performed under NASA ESTO Project NAS5-02001, entitled "Digital Receiver with Interference Suppression for Microwave Radiometry." The spiral antenna unit, LNA, line amplifier, and coherent sampling subsystem were previously

developed under ESL's Argus Radio Telescope project, which is funded primary by the SETI Institute.

References

[1] S.W. Ellingson, "A 1-GHz Highpass PHEMT Low-Noise Amplifier", Informal Report, July 2002, available via http://esl.eng.ohio-state.edu/∼swe/argus/docserv.html.

[2] S.W. Ellingson, "A Low-Cost L-Band Line Amplifier", Informal Memo, September 2002, available via http://esl.eng.ohio-state.edu/∼swe/argus/docserv.html.

[3] S.W. Ellingson, "Agilent Spectrum Analyzer Computer Control Demo", IIP Memo 20, June 6, 2002.

[4] G.A. Hampson, "Phase 8: Low Cost 900-2100MHz Complex Receiver", Sep 10, 2001, http://esl.eng.ohio-state.edu/∼gah/phase8.html.

[5] G.A. Hampson, "Phase 6: Generic Low-Bandwidth LVDS-Parallel Port Receiver", Augst 14, 2001, http://esl.eng.ohio-state.edu/∼gah/phase6.html.

A Example of an Experiment Script

```
// 0-3 GHz
CD 1                                    # Display 1
IN 1                                    # Toggle to antenna
FN 0.0e+0 3.0e+9 1.0e+6 3001 1 100 0 1 # Max hold
FN 0.0e+0 3.0e+9 1.0e+6 3001 0 100 1 2 # Average
IN 0                                    # Toggle to terminator
FN 0.0e+0 3.0e+9 1.0e+6 3001 0 100 2 3 # Average

// 1200-1800 MHz
CD 2                                    # Display 2
IN 1                                    # Toggle to antenna
FN 1.2e+9 1.8e+9 1.0e+6 601 1 100 3 1  # Max hold
FN 1.2e+9 1.8e+9 1.0e+6 601 0 100 4 2  # Average
IN 0                                    # Toggle to terminator
FN 1.2e+9 1.8e+9 1.0e+6 601 0 100 5 3  # Average

// Detection span (1413+/-10 MHz)
CD 3                                         # Display 3
IN 1                                         # Toggle to antenna
FN 1.403e+9 1.423e+9 10.0e+3 2001 1 100 6 1 # Max hold
FN 1.403e+9 1.423e+9 10.0e+3 2001 0 100 7 2 # Average
IN 0                                         # Toggle to terminator
FN 1.403e+9 1.423e+9 10.0e+3 2001 0 100 8 3 # Average

// End of script
EN
```