Stability tests on the warm CTT IF amplifier: Memo No. 1

Date: 21-Sept-2004, Richard Chamberlin

1 Introduction and summary of result

The CSO heterodyne receiver upgrade program[1] will use new warm IF amplifiers which were acquired from CTT, Inc.: see sample data sheet in Figure 1.

The new warm IF amplifiers were packaged in an enclosure with automatic power level control (ALC) and active temperature control: see schematics in Figures 2 and 3. See photograph of assembled unit in Figure 4.

In this memo we present test results on the stability of the packaged CTT IF amplifier with the active temperature controller on and with it off.

With the active temperature controller on we found the Allan Variance[2] time was about 33 seconds and there was a periodicity in the temperature and the RF output of about 38 minutes. With the temperature controller turned off and the amplifier temperature just drifting, the 38 minute periodicity in the RF power output disappeared and Allan Variance time increased to about 66 seconds. However, because of the drifting temperature the amplitude of RF noise was generally greater except for a few short one or two hour intervals as noted below.

The rest of the memo describes in detail our methods, results, and suggests directions for further improvement.

2 Measurement setup

Throughout these measurements the source of the RF signal was a HP83620B synthesizer putting out a CW tone centered on 6.0000 GHz with output power of -10.0 dBm. Except in the final stability test (described in the next section), the tone from the HP synthesizer was attenuated 30 dB, and then feed to the CTT IF amplifier. The total RF power from the warm IF amplifier was detected with an HP 438A RF power meter using a an HP 8481A detector. The RF total power was also detected by a diode connected to the CTT amplifier monitor output, internal the CSO fabricated enclosure. The signal from this diode was used as input the ALC circuit and to provide a front panel accessible indication of the "RF Level": see Figure 2. The "RF Level" output was monitored with a Fluke 8840A Digital Voltmeter (DVM). This data from the DVM was collected and recorded but is not presented here.

During all tests the CTT IF amplifier was run with the automatic level control (ALC) circuit turned off. Unless otherwise indicated, the room air conditioner system (AC) was turned on stabilizing the room air temperature to approximately 23 deg. C. Tests were also done with the AC turned off in which case the room air temperature could vary between 28 to 34 deg. C. When the IF amplifier active temperature was controller was turned on its set point was 32.5 deg C and never changed during any of the testing.

Data from this setup was acquired and logged in a laboratory PC[1] running the Linux OS[2]. Data from the RF power meter was acquired through the PC's GPIB adapter[3] Temperature measurement in the IF amplifier enclosure was made with the three DS18B20 single wire thermometers interfaced to the PC through a one-wire bus controller attached to one of the PC's standard RS232 serial line ports [3]. Figure 5 shows a block diagram of the test setup. Data from only the DS18B20 mounted directly on the CTT module is reported here.

3 Measurement time series

Figure 6 is the time series showing results from the entire period of testing, about 620 hours. The top panel in the figure is the total RF power acquired from reading the HP438A power meter. The bottom plot is the temperature of the CTT IF amplifier measured by one of the DS18B20's mounted directly on the amplifier enclosure.

The time series involved different kinds of testing which will be described further. Table 1 indicates how the time series is broken up by the different types of testing.

[1]Industrial Computer Source (ICS) chassis with a mixed ISA and PCI passive backplane and ICS single board computer, model SB586T.

[2]Slackware version 8.x; Linux version 2.4.26; gcc version 2.29.3.

[3]National Instruments (NI) GPIB adapter, model TNT for the ISA bus using the NI supplied GPIB driver for Linux version number 0.8.6.

Table 1: How the time series of Figure 6 is broken up

hours	type of testing	Changes/Remarks
0-23	TEC on. AC on.	
23-44	TEC off. AC off.	
44-115	TEC on. AC on.	
115-331	TEC on. AC on.	Pot near U20 turned full CCW.
331-476	TEC off. AC off.	
476-504	TEC on. AC off.	TEC and IF amp power supplies separated.
504-523	TEC on. AC on.	
523-551	TEC on. AC on.	1 db pad on CTT IF amplifier output.
551-618	Output of HP83620B connected directly to RF power meter. (No IF amp.)	

key: TEC is thermoelectric cooler used to regulate IF amplifier temperature.
AC is room air conditioning.

4 Results and some discussion

4.1 Test instrument stability characterization

We start our discussion with the last test in the time series of Figure 6: hours 551-618. This last period is used to characterize the stability of the ensemble of RF test equipment and for this purpose the output of the HP83620B synthesizer was connected directly to the input of the HP8418A detector. No synthesizer settings were changed from previous measurements in the time series. Figure 7 shows this part of the time series in more detail. Betweens hours 580 and 582 are shown in even greater detail in the lower panel. Over this two hour period the response of the system is stable but with apparent slow oscillation which is just resolvable. The amplitude of the oscillation was about ±0.2% of the average value. Fourier analysis on the time series from hours 575 to 615 showed strong peaks in the power spectrum at $2.5\text{Hr}^{-1}, 4.9\text{Hr}^{-1}, \text{and} 7.5\text{Hr}^{-1}$ corresponding to 24, 12, and 8 minute periods. The Allan variance time was about 86 seconds. See Figure 8. In the Allan Variance plot, the peak at about $\tau = 350$ seconds was caused by the periodicity in the time series of Figure 7.

4.2 Warm IF amplifier stability with temperature controller ON: Best results

The total time series reflects different testing conditions. Here in this section we focus on the period of best observed performance with the temperature controller turned on. This period was from hours 504-551. For comparison with the best period with the temperature controller OFF (see next section) after hour 523 we attenuated the output of the CTT IF amplifier (1dB pad) before detection and measurement with the HP438A power meter. We show the best 20 hours of this period in Figure 9. During these measurements the room air conditioning was turned on which was required in order for the temperature controller to function.

Figure 10 shows Fourier analysis and the Allan Variance on the RF power time series. The Allan Variance time was only about 33 seconds and there was a strong peak in the RF power spectrum at 1.6Hr^{-1} corresponding to an oscillation with a period of about 38 minutes.

Figure 11 shows Fourier analysis and the Allan Variance on the temperature data. The Allan Variance time was about 66 seconds and there was a strong peak in the temperature power spectrum at 1.6Hr^{-1} corresponding to an oscillation with a period of about 38 minutes. There is a second strong peak in at 2.8Hr^{-1} which is also slightly present in the RF power spectrum, see Figure 10.

The coincidence of peaks in the temperature and RF power spectra suggests periodicity in the two are related. The main peaks in these power spectra *do not* coincide with the power spectrum of Figure 8 indicating the periodic behavior is not related to the small amplitude periodicity observed in the RF power time series observed in the test equipment, Figure 7.

Figure 12 shows a 2 hour sample from a good part of the time series with the temperature controller on.

4.3 Warm IF amplifier stability with temperature controller OFF

We will now examine the total IF power from the CTT amplifier with the temperature controller turned OFF. The data presented in this section was obtained under a much less favorable environment compared to the results presented in Section 4.2 because the room air conditioning was also turned off. Thus, in the long time series between hours 331 and 476 a strong diurnal variation was clearly present. Figure 13 presents this data in more detail.

For comparison with Figure 10 we computed Fourier analysis and Allan Variance time analysis on a typical 20 hour period in this time series: $390 < \mathrm{Hr} < 410$, see time series in Figure 14. The result is presented in Figure 15 as the dotted line. The time series is less regular and the spectrum from Fourier Analysis is more noisy than observed in Figure 10. Possible components are present at around 0.8Hr^{-1} and 1.4Hr^{-1}. To see help see if these components were spurious (and they apparently were) we also did Fourier Analysis on a 120 hour interval starting at hour 340 (solid line in Figure 15). In the 120 hour analysis the Fourier coefficients are boxcar averaged to make them similar in frequency resolution to the 20 hour case.

In general we observed the RF power was noisier with the temperature controller OFF. However, note that there is a very stable one hour time interval centered on about hour 398.8. A two period including this interval is shown in Figure 16. Please compare with Figure 12.

5 Conclusions

The temperature controller appeared to cause oscillation in RF power and temperature with periods of about 38 minutes and 21 minutes.

Efforts at improving controller performance by temperature controller feedback loop tuning and separating power supplies appeared to yield improvements. Perhaps more can be done in these areas. E.g. more feedback loop tuning; and/or more attention to details like power supplies, grounding, and ground loops.

Overall, the RF total power had better general stability and less noise when the temperature controller was ON - compared to with it OFF.

However, comparison of the best two hour periods (temperature controller ON and OFF) show that CTT IF amplifier noise is lowest when temperature does not change at all. Since the temperature controller as currently configured causes some oscillation, the very best (but short) periods of performance are actually found when the temperature controller is in the OFF state.

6 Possible Future Improvements

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Data acquisition system:

  Reduce measurement cycle time to improve time resolution;

  Measure and record room air temperature;

  Implement analog  thermometry  (e.g. thermister or  AD590) on the
  CTT amplifier module for higher resolution measurements.

RF Source:

    Make measurements on noise source at the summit to characterize
    Allan Variance time, etc.   We can see if this is a more stable
    RF source than the HP8320B.

Warm IF amplifier:
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Temperature stabilize with other methods to investigate stability;

Further investigate existing implementation for ground loops, etc.
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7 Acknowledgments

The CTT fabricated IF amplifier was supplied by Jacob Kooi. The temperature controller was designed by Martin Houde and fabricated by Ed Bufil. The data acquisition computer, OS, drivers, and data acquisition program were configured, installed, and developed by CSO summer intern student Riley Ceria who is a senior majoring in electrical engineering at the University of Hawaii, Manoa.

References

[1] J. Kooi and et al. Heterodyne instrumentation upgrade at the Caltech Submillimeter Observatory. In J. Zmuidzinas, editor, *Astronomical Telescopes and Instrumentation*, SPIE Proceedings Series, Bellingham, WA 98227-0010, 2004. SPIE-The International Society for Optical Engineering. http://www.submm.caltech.edu/cso/receivers/papers/spie_2004.pdf.

[2] D. W. Allan, N. Ashby, and C. C. Hodge. The science of timekeeeping. Application Note 1289 p. 59, Eq. A1, Hewlett Packard, Inc., 1997. http://www.allanstime.com/Publications/DWA/Science_Timekeeping/TheScienceOfTimekeeping.pdf.

[3] R. A. Chamberlin. Temperature measurement on the Leighton Telescope: Surface Memo No.2. CSO Technical Memorandum, Caltech Submillimeter Observatory, Hilo, HI 96720, 2003. http://ulu.submm.caltech.edu/cham/surface/ha5_memo_6may03.pdf.

C T T Inc.

SOLID STATE AMPLIFIER GROUP A TEST DATA S

3005 DEMOCRACY WAY, SANTA CLARA, CA 95054, USA, PHONE (408) 986-8321, FAX (408) 986-9097, WEB SITE: http://www.cttinc.com

CUSTOMER : CALTECH
CUSTOMER PART NO. : N/A
OUTLINE DRAWING NO. : 105013321
OPERATING TEMPERATURE : +30°C

JOB NO. : 20224A
MODEL NO. : SA-0364-266A

PAGE NO. : 1 OF 3

SPECIFICATION		TEMP.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.	S/N NO.
			86461	86462	86463	86464	86465							
FREQUENCY (GHz)	4.000	+30°C	65.08	63.95	64.01	64.24	62.77							
	5.000	+30°C	65.42	64.86	64.41	64.16	63.37							
S/S GAIN 60.0 dB min.	6.000	+30°C	64.31	63.61	63.53	63.76	62.45							
	7.000	+30°C	64.48	64.14	63.95	64.48	62.77							
	8.000	+30°C	65.17	63.45	63.52	64.03	62.57							
GAIN FLATNESS (dB)	+/-1 .0	+30°C	0.81	0.74	0.79	0.79	0.69							
	4.000	+30°C	1.91	2.05	2.05	2.05	2.09							
	5.000	+30°C	2.05	2.05	2.05	2.15	2.18							
NOISE FIGURE(dB) 3.5 dB max.	6.000	+30°C	2.61	2.81	2.61	2.72	2.69							
(with 20 dB atten)	7.000	+30°C	2.53	2.71	2.75	2.78	2.65							
	8.000	+30°C	2.62	2.89	2.66	3.01	2.71							
	4.000	+30°C	14.43	12.37	13.62	13.68	13.25							
	5.000	+30°C	15.59	14.31	14.89	14.81	14.74							
P1dB (dBm) +6.0 dBm min.	6.000	+30°C	15.83	14.27	14.77	14.42	14.14							
	7.000	+30°C	15.68	14.41	14.21	14.31	13.57							
	8.000	+30°C	15.66	14.15	14.62	13.91	12.23							
INPUT VSWR	1.5 : 1	+30°C	1.31	1.34	1.41	1.36	1.38							
OUTPUT VSWR	1.22 : 1	+30°C	1.16	1.19	1.19	1.16	1.19							
VDC +15.0V @ mA(max)	1000 mA	+30°C	251	244	253	253	277							

NOTE: MAX OPERATING TEMP IS +85° C (CASE). OTHERWISE DAMAGE OR DEGRADATION MAY OCCUR

TESTED BY : T 37 DATE : 3/19/03 QA : [stamp] DATE : MAR 20 2003

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Figure 1: Typical CTT amplifier specification including test data.

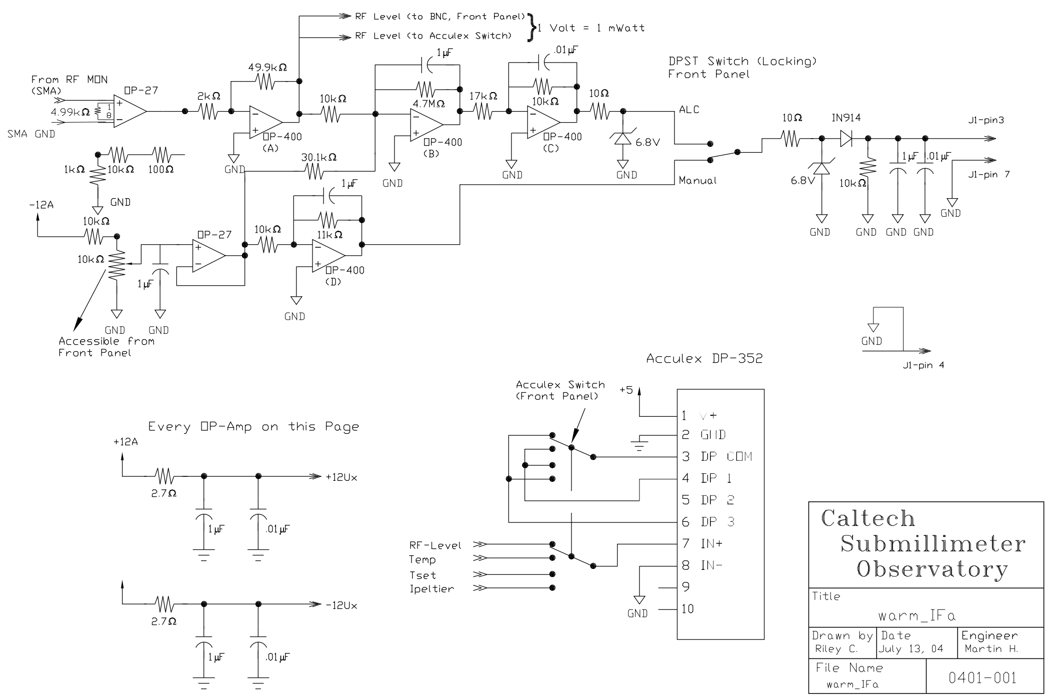

Figure 2: Schematic showing ALC and display circuit.

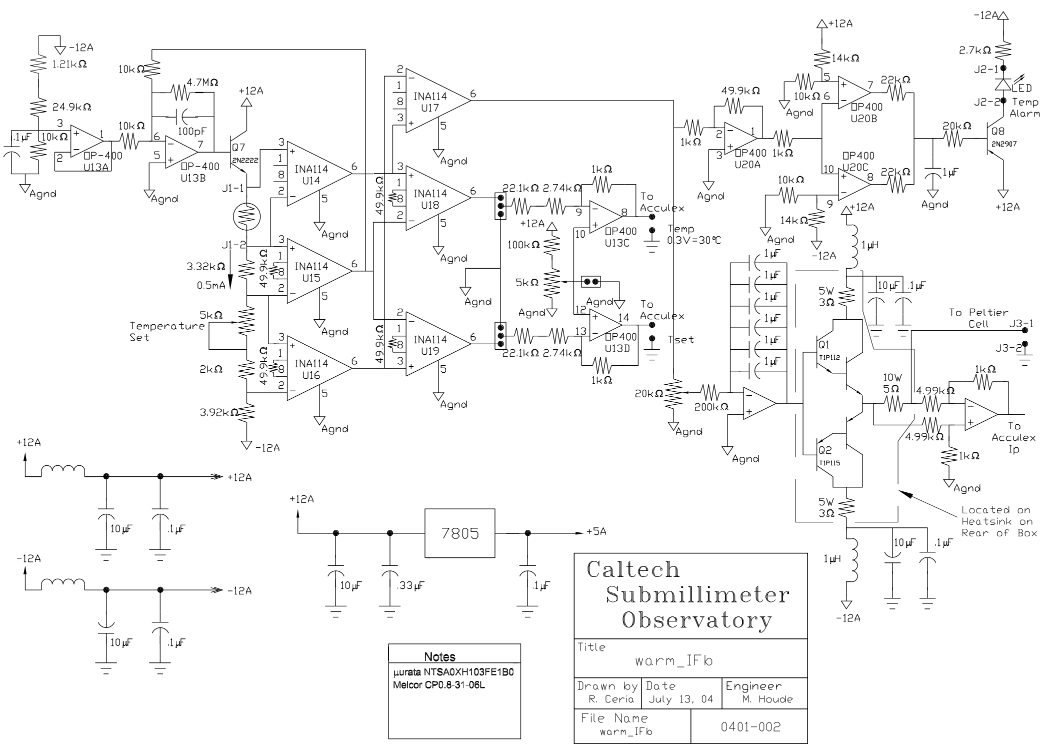

Figure 3: Schematic showing thermal controller circuit.

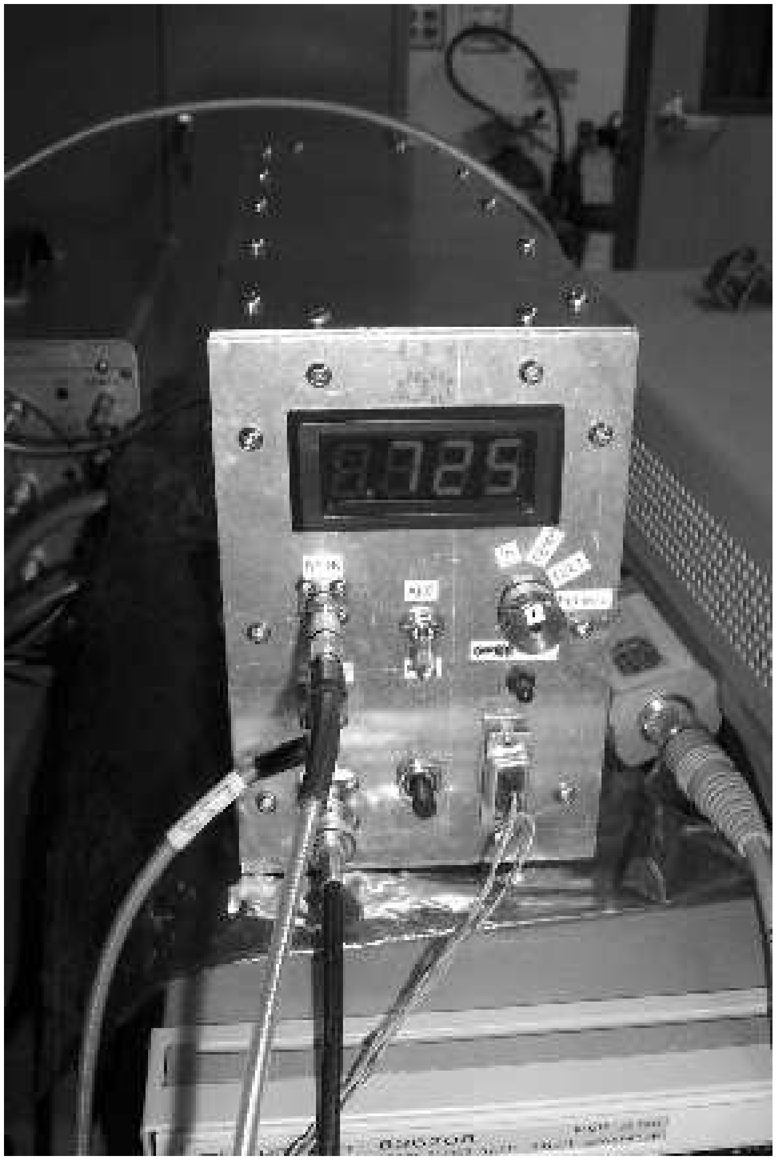

Figure 4: Photograph of assembled IF amplifier module including active temperature controller electronics.

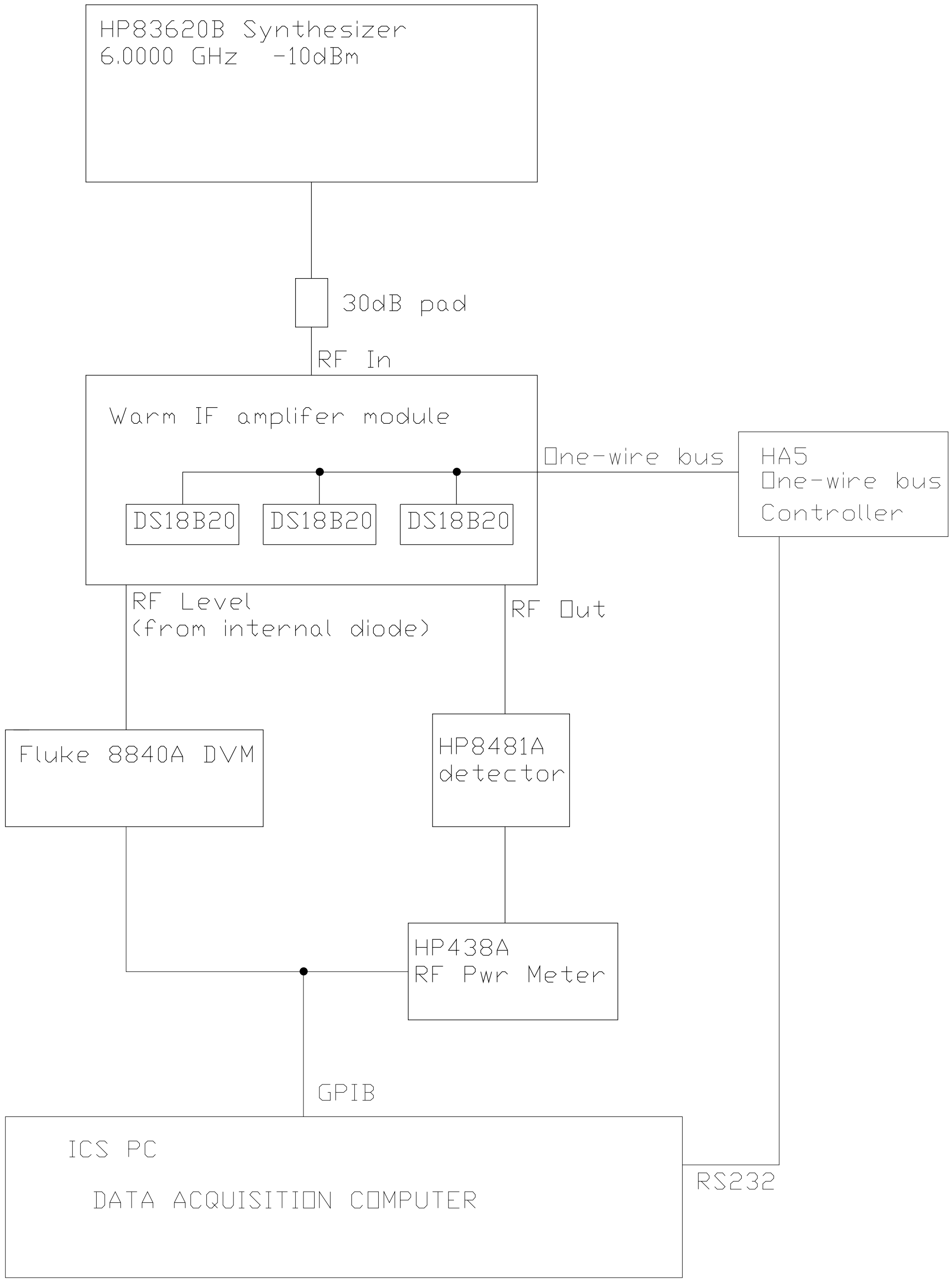

Figure 5: Block diagram of test setup.

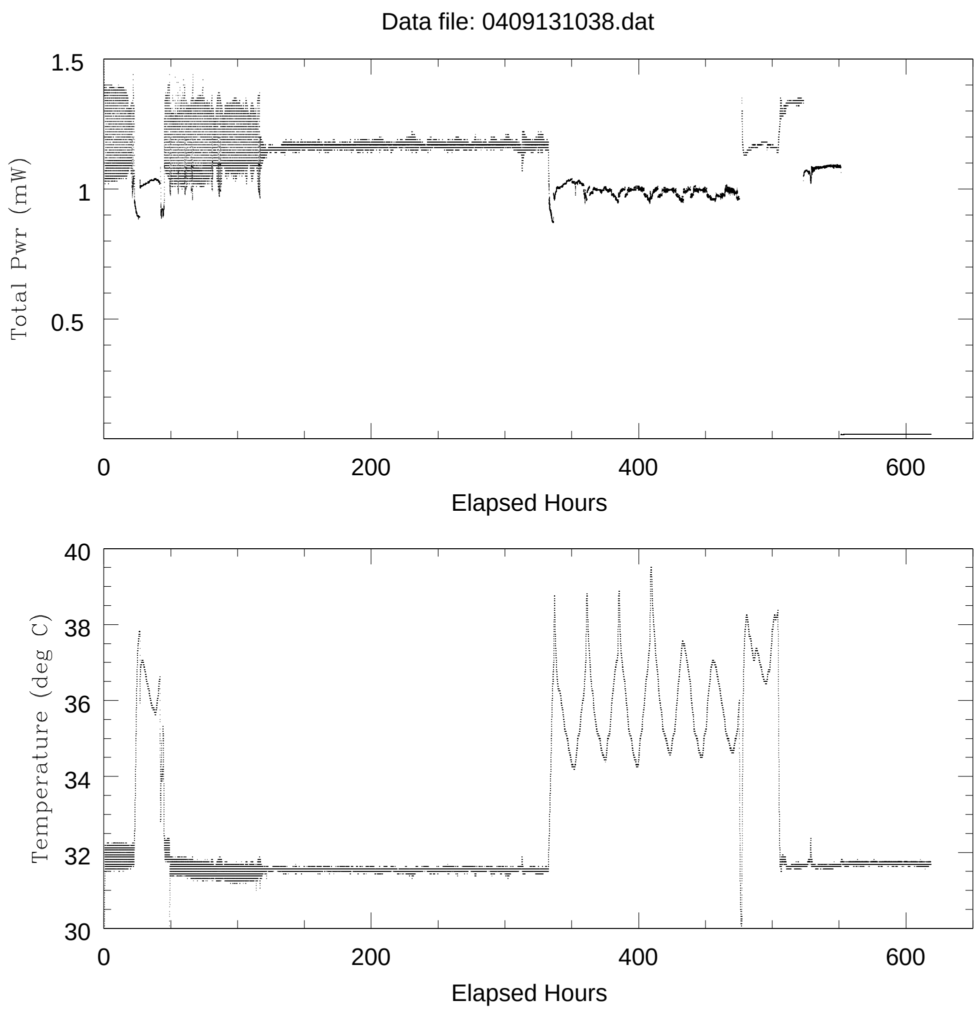

Figure 6: Entire times series of measurements.

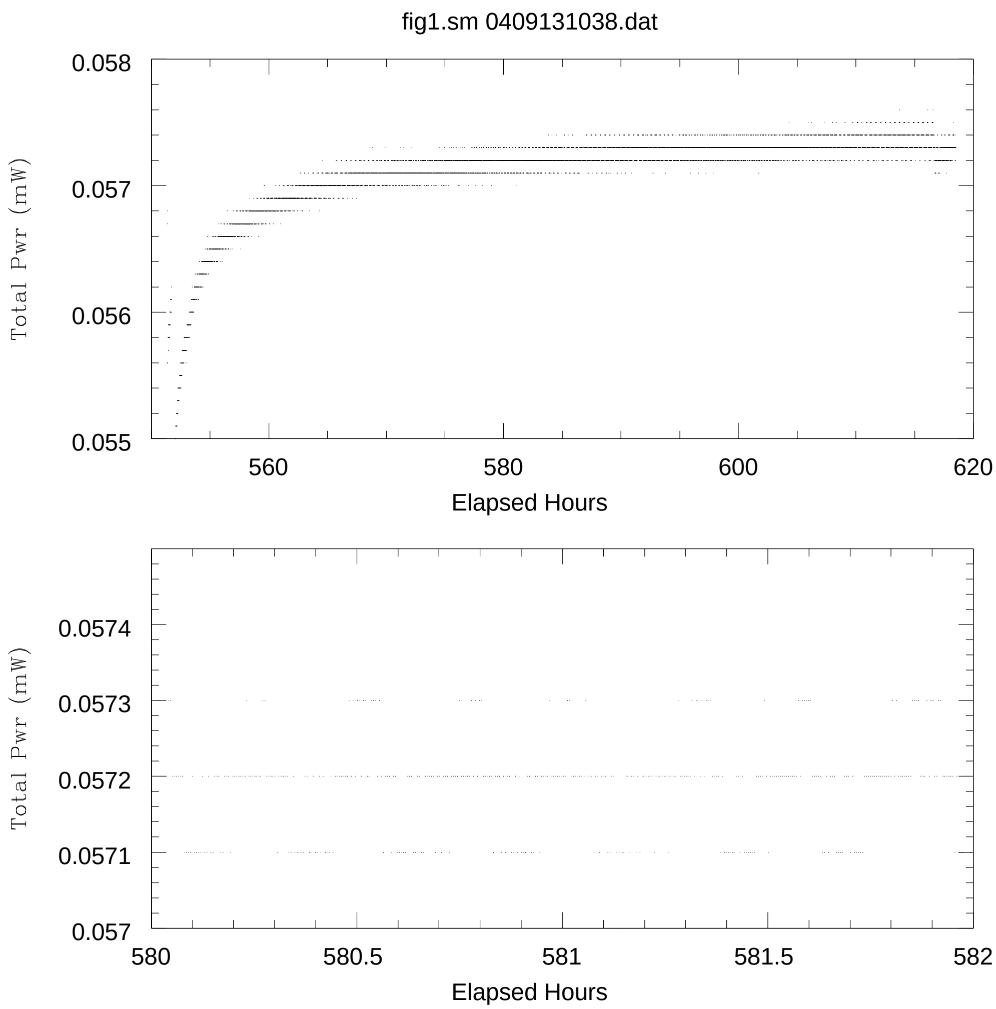

Figure 7: Details from the part of time series used to characterize test instrument stability. Section 4.1.

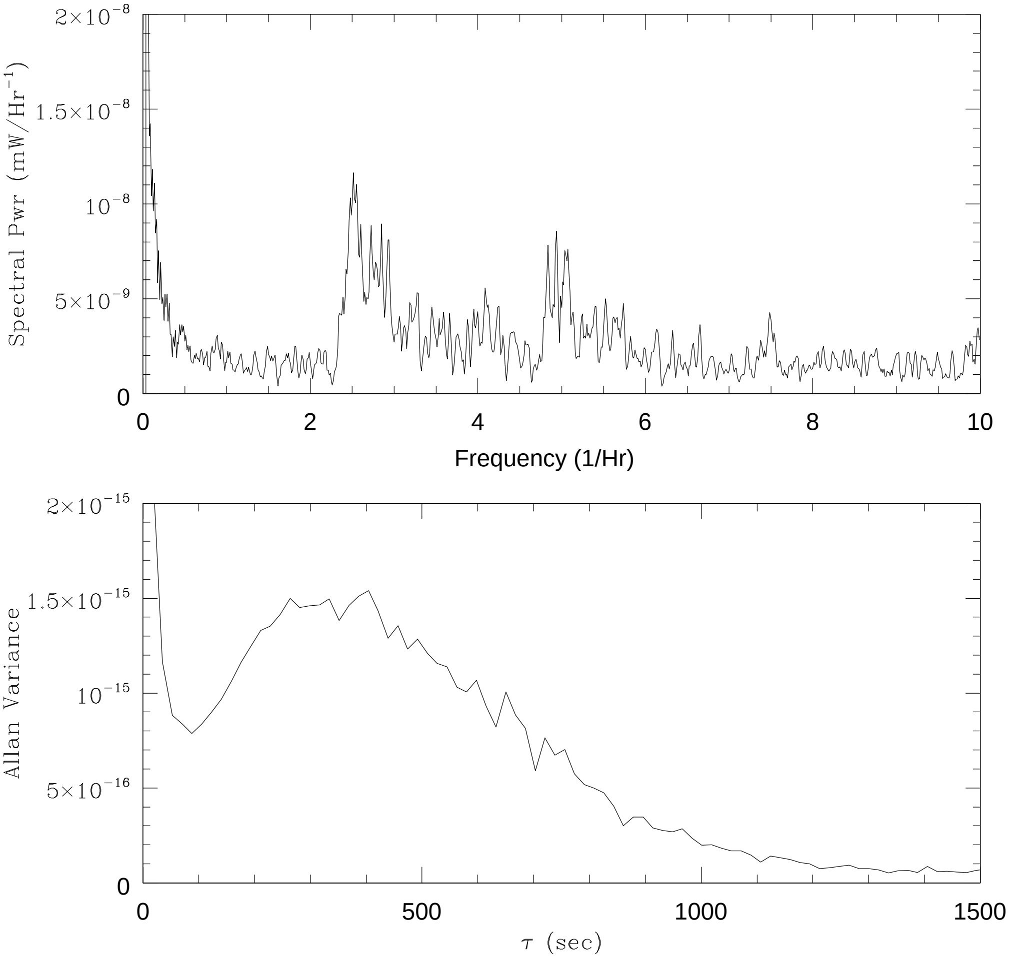

Figure 8: Fourier analysis and Allan Variance on time series of Figure 7 hours 575 to 615.

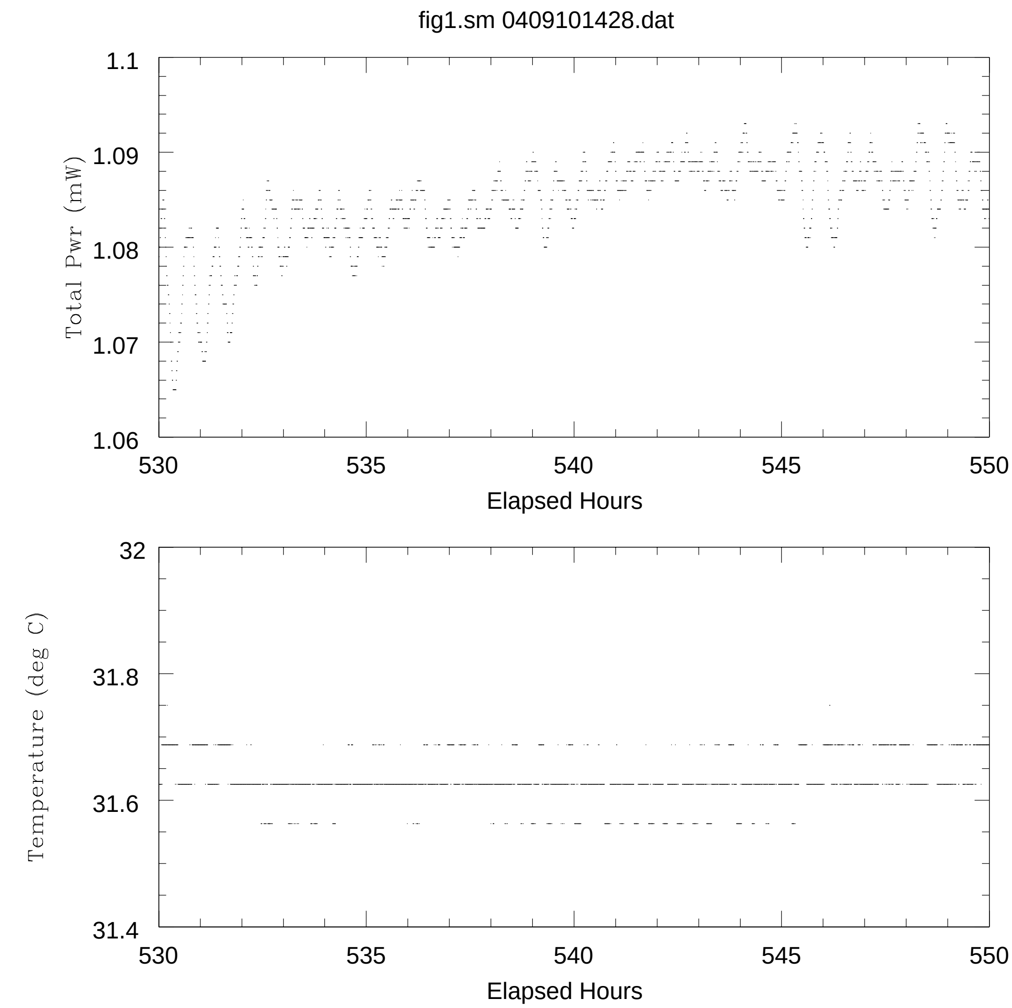

Figure 9: Detail from best 20 hour period when temperature controller was on: hours 530-550.

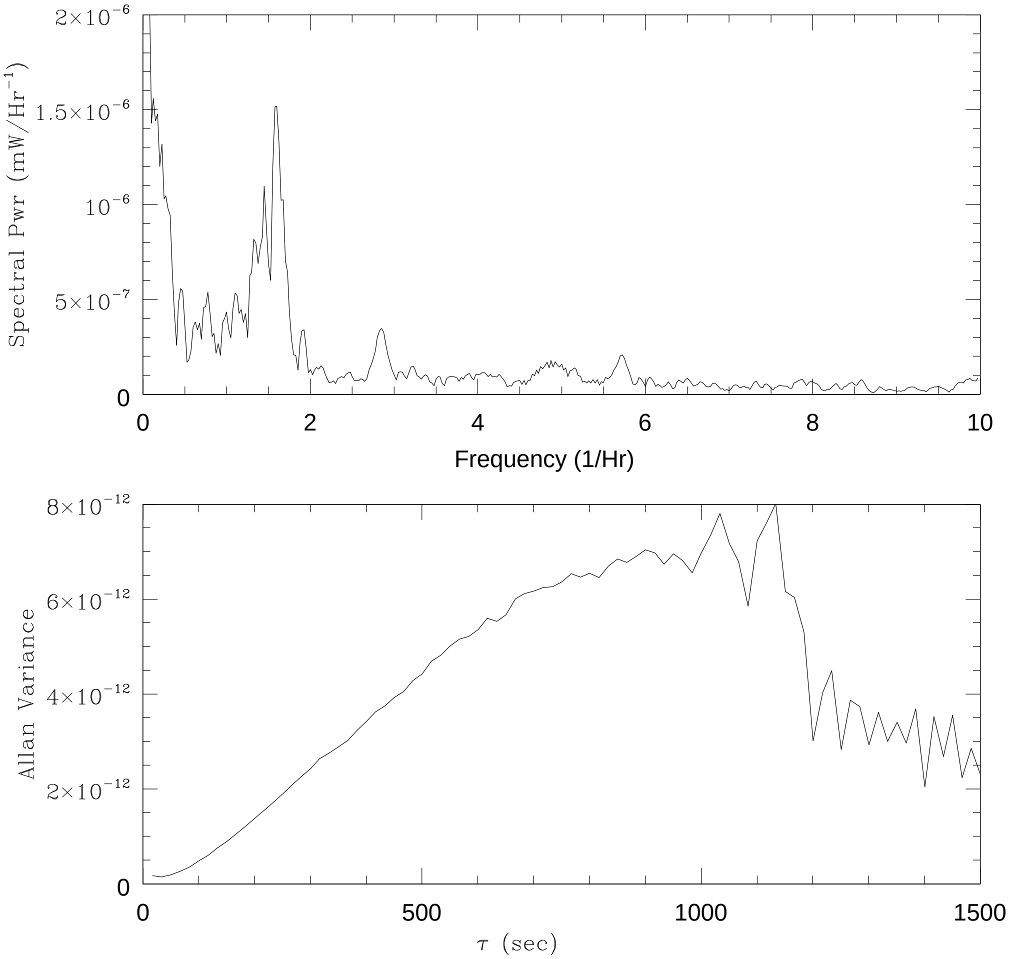

Figure 10: Fourier analysis and Allan Variance of total RF power time series of Figure 9 hours 530 to 550. (Temperature Controller ON.)

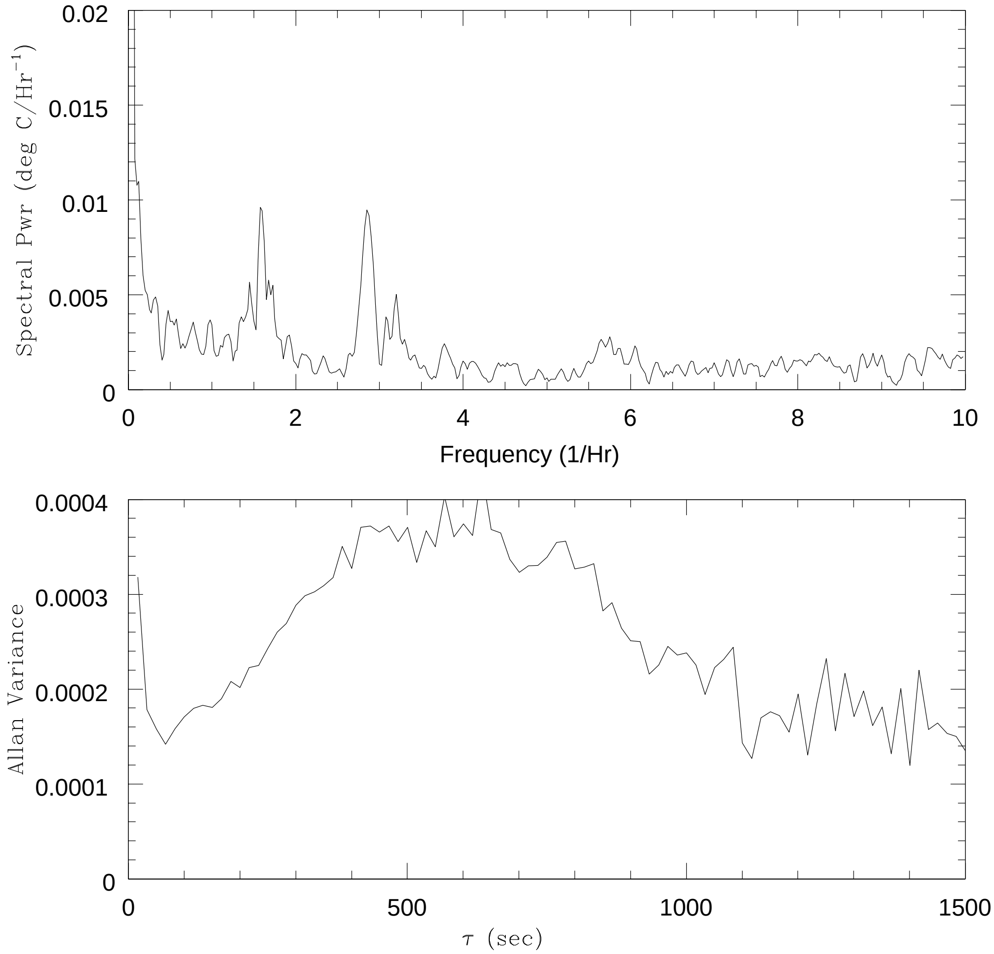

Figure 11: Fourier analysis and Allan Variance of temperature time series of Figure 9 hours 530 to 550. (Temperature Controller ON.)

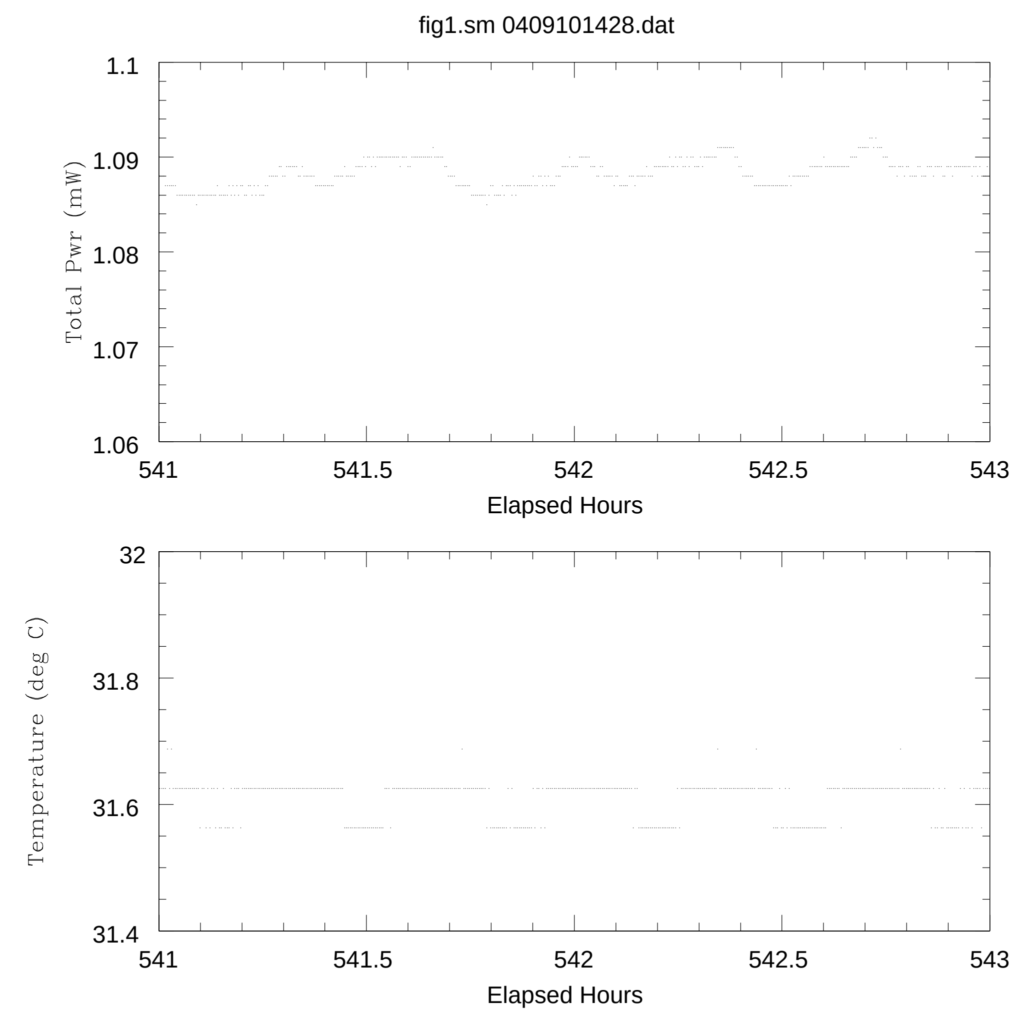

Figure 12: Detail from best 2 hour period when temperature controller was ON: hours 541-543.

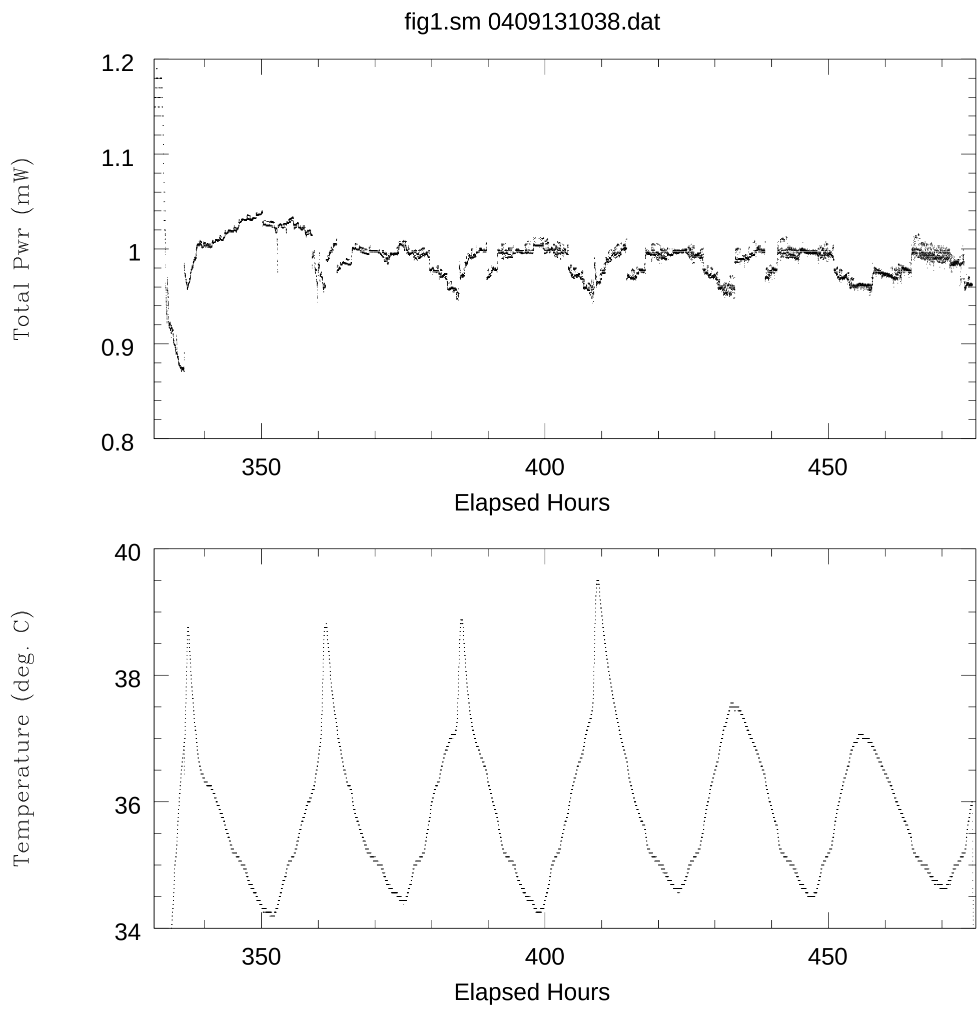

Figure 13: Time series of results with temperature controller OFF. The room air conditioner as also off. Note the large diurnal variation in temperature.

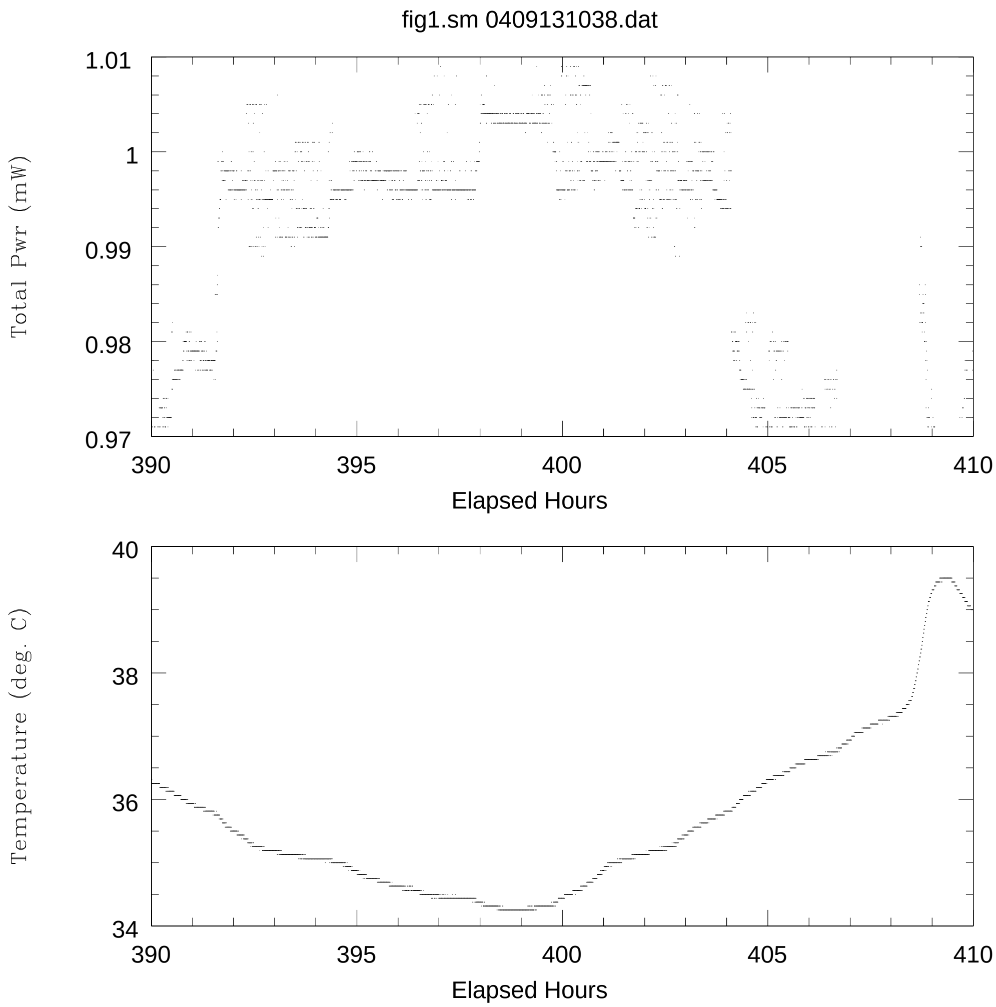

Figure 14: Time series of results with temperature controller OFF. The room air conditioner was also off. RF power scale is made similar to Figure 9 for comparison. In general the RF power varies more but note that there is a one hour period of very high RF stability centered on about Hour 398.8. This time is also at the turning point of the temperature diurnal variation.

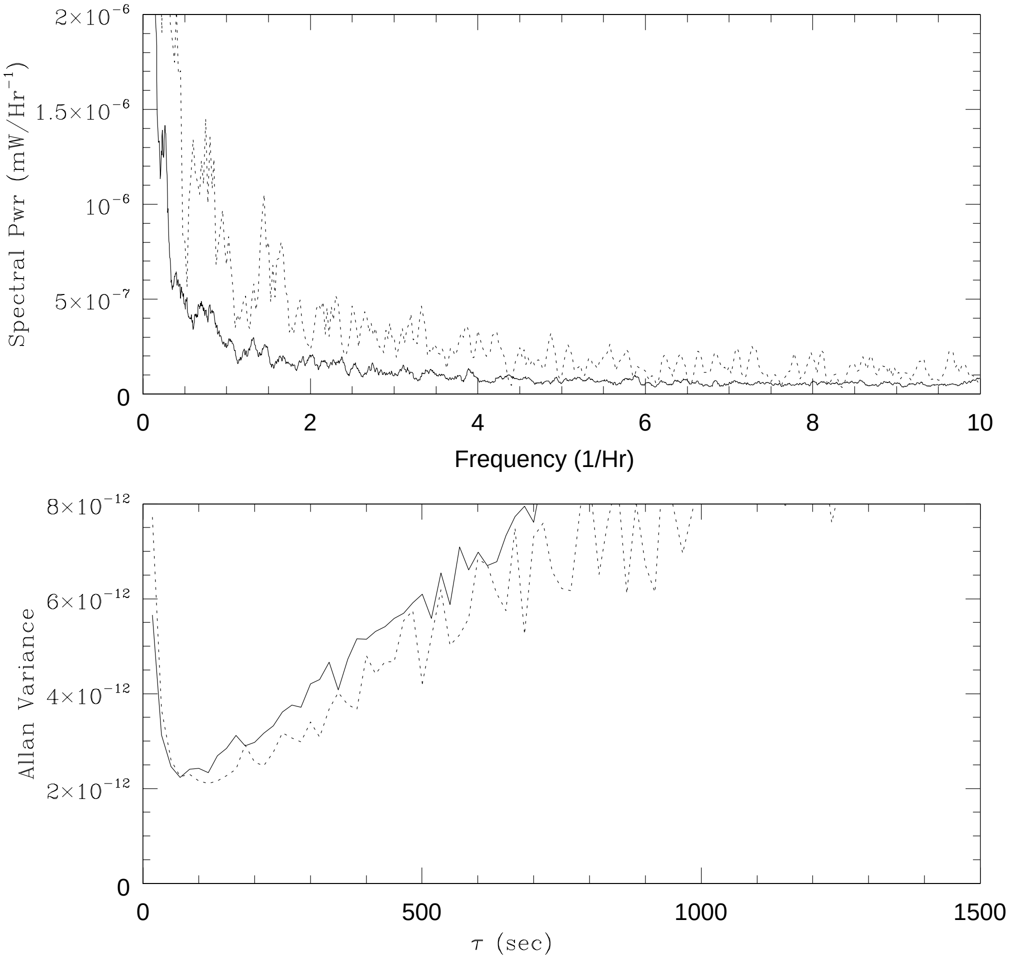

Figure 15: Fourier analysis and Allan Variance derived from the RF Power time series of Figure 13. The solid lines represent analyses derived from a 120 hour interval beginning at hour 340. The dotted lines represent analyses derived from a shorter 20 hour interval beginning at hour 390, see Figure 14. (Temperature Controller is OFF.)

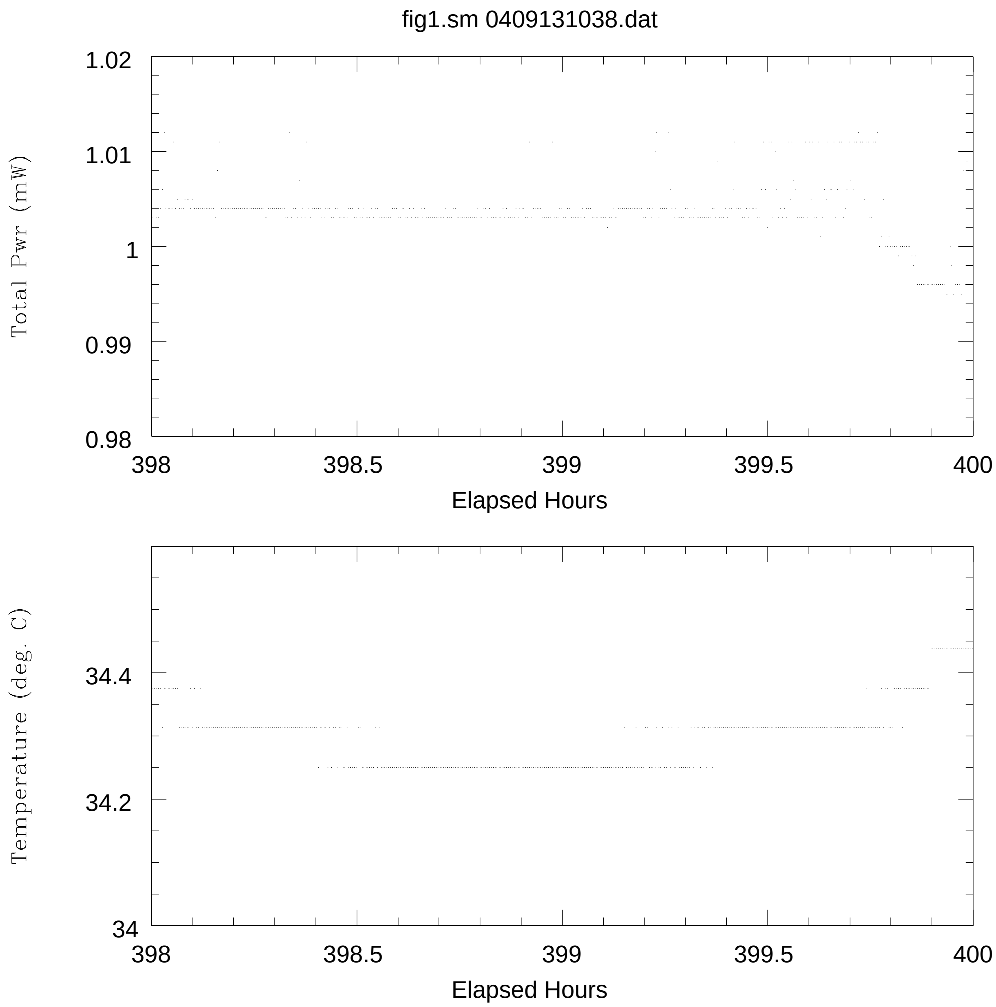

Figure 16: Time series of results with temperature controller OFF. The room air conditioner as also off. This is a good 2 hour period provided for comparison with Figure 12.