Radiometric Stability of RPG Radiometers

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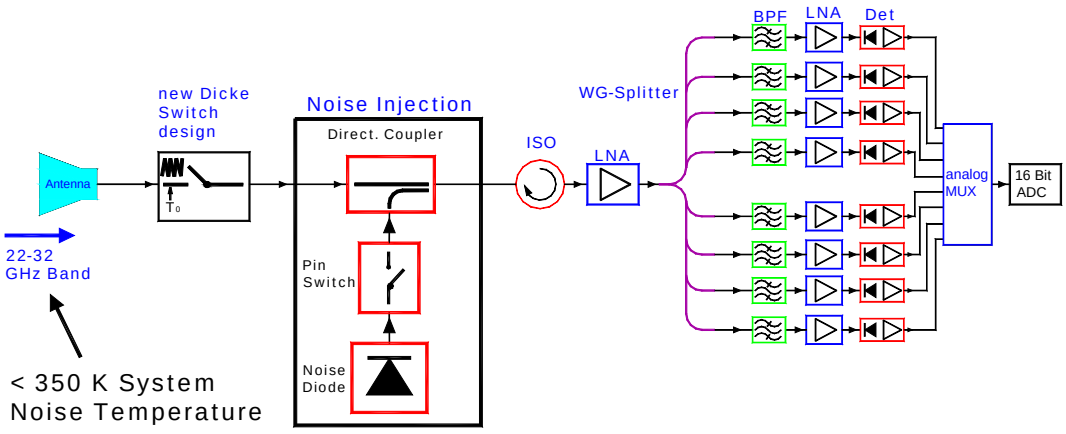
Report

by Th. Rose
Radiometer Physics GmbH,
53340 Meckenheim, Germany

Contents

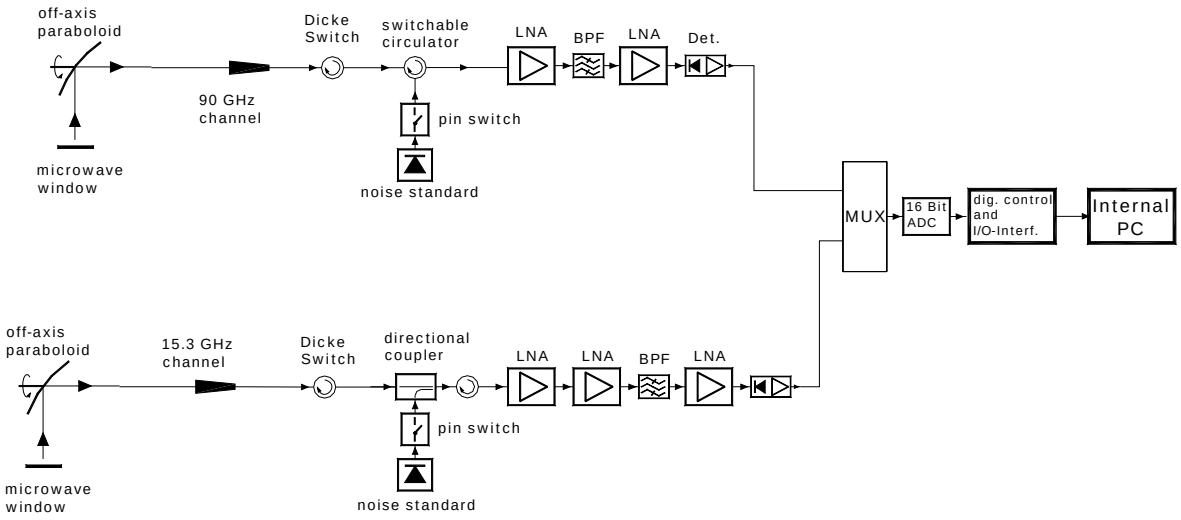
1. Receiver Designs

Direct Detection Filterbank (DDFB) receiver architectures are implemented for RPG radiometers operating at frequency bands < 110 GHz. A direct detection system omits any mixers or local oscillators and performs all reception steps like amplification, filtering and detection at the signal band. This offers a number of advantageous like higher sensitivity, pure passive detection without leakage of LO power and / or RFI with other instruments and the elimination of RFI (Radio Frequency Interference) at IF frequencies where strong external signal sources can be present like radio transmitters, mobile phone transmitters etc. The filterbank design presents a fully parallel channel detection with 100% duty cycle and therefore optimum integration time use.
For calibration purposes these systems are equipped with a full internal auto-calibration input stage comprising a switched noise source for gain stabilisation that is coupled to the active receiver input and a low loss magnetically operated Dicke Switch that serves as a reference target at ambient temperature for the compensation of system noise temperature drifts. Both auto-calibrating standards are continuously operated while the radiometer is measuring on the scene position and does not require to scan external calibration targets.



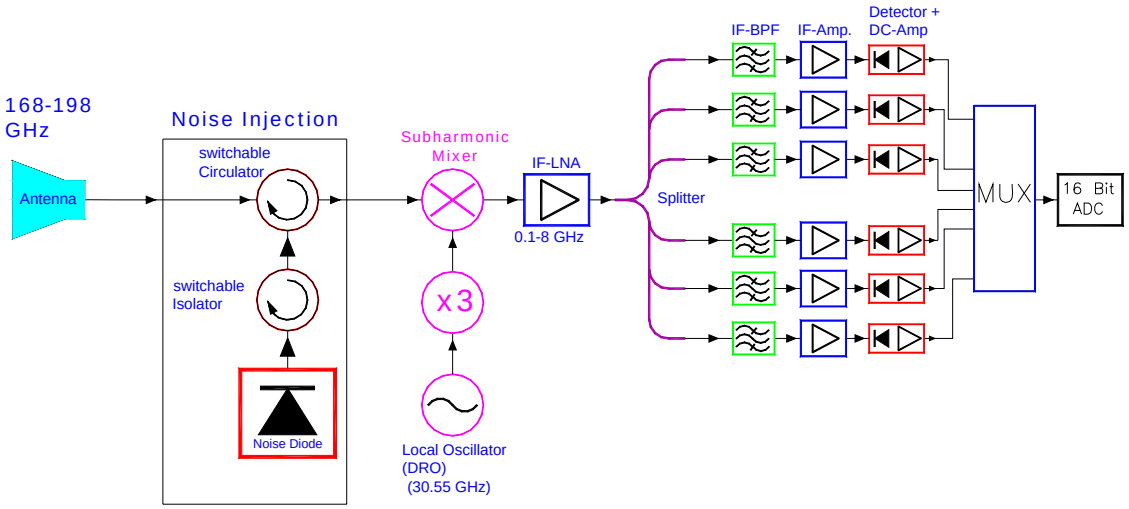
RPG's K- and V-band receiver layout as direct detection filterbanks.

A high thermal receiver stability is achieved by a two stage stabilisation stage that stabilizes the receivers to better than 30 mK over the full operating temperature range. The receiver packages are well thermally insulated to allow for this hogh stability.



Example of a 15/90 GHz direct detection system.

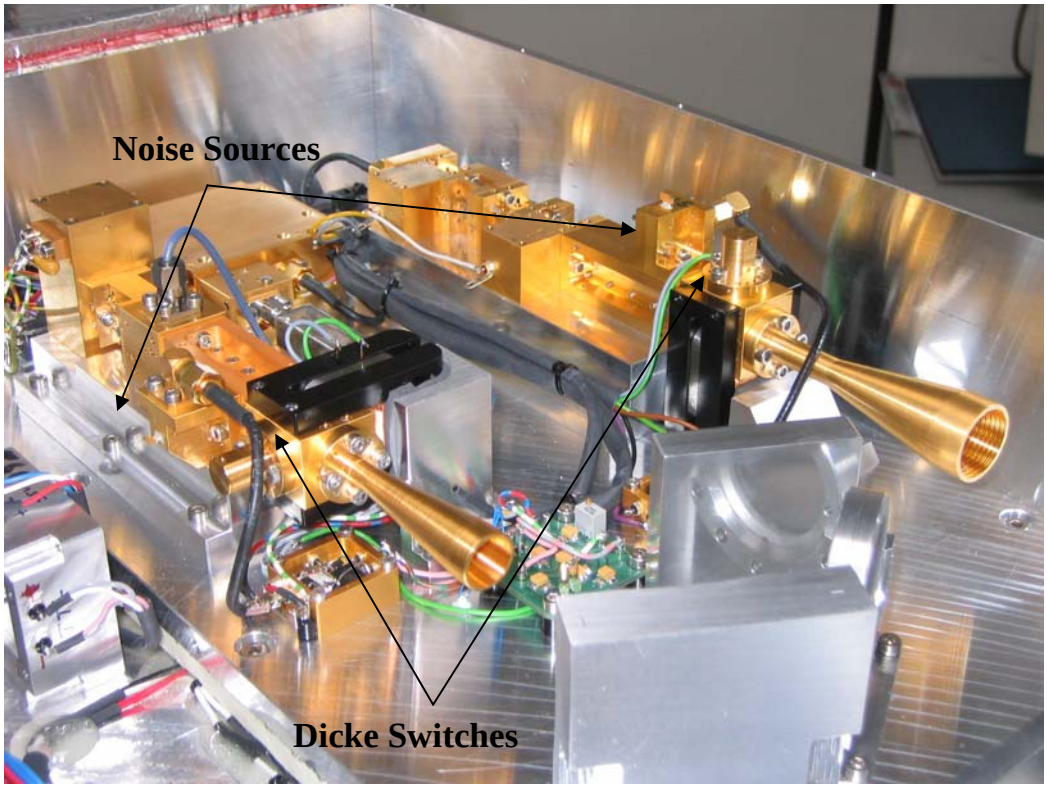
Radiometers at higher frequencies e.g. that are operating on the 183.3 GHz water vapour line are realized in heterodyne technology using subharmonically pumped mixers and DRO (dielectric resonant oscillator) fundamental oscillators multiplied by RPG's W-Band source modules.



Example of a 183 GHz Water Vapour radiometer layout including a switched noise source for auto-calibration.

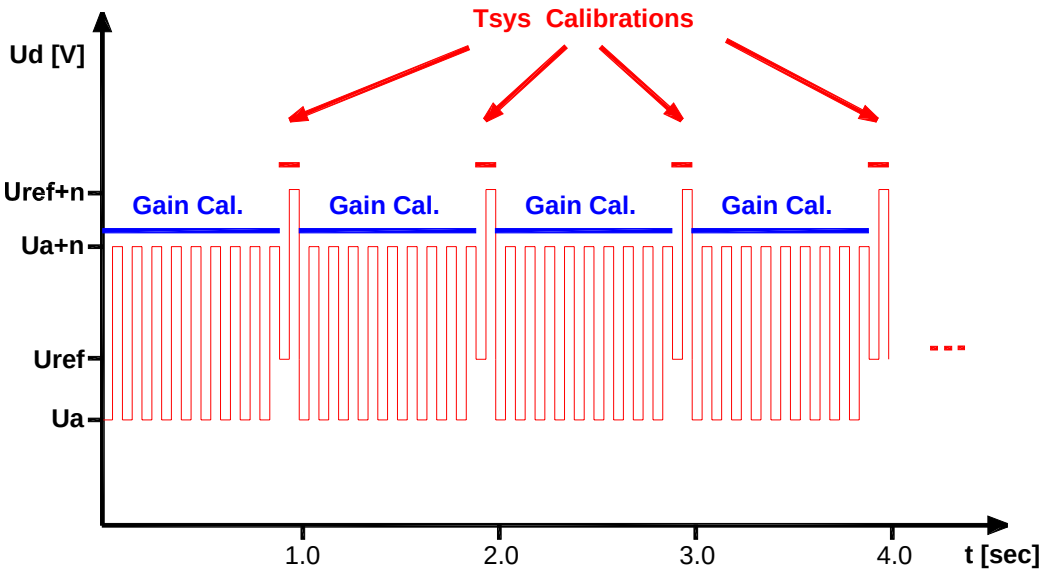
The concept of Dicke switched radiometers has been developped 1946 but its realisation at mm-wave frequencies is quite demanding. RPG has developped noise sources up to 200 GHz with sufficient ouput power (ENR=14 dB) to calibrate a radiometer efficiently. At very high frequencies > 150 GHz a ambient temperature Dicke switch can be replaced by a quasioptic target combined with a switching mirror assuming that the receivers are extremely well thermally stabilized without rapid fluctuations of their system noise temperatures.

Compact V-band DDFB receiver including feedhorn, noise injection, Dicke switch, LNAs, 7-way power splitter, detector section, video amplifiers and 16 bit ADC section. The system is realised all in waveguide technology to avoid SMA connectors that would reduce the system stability.

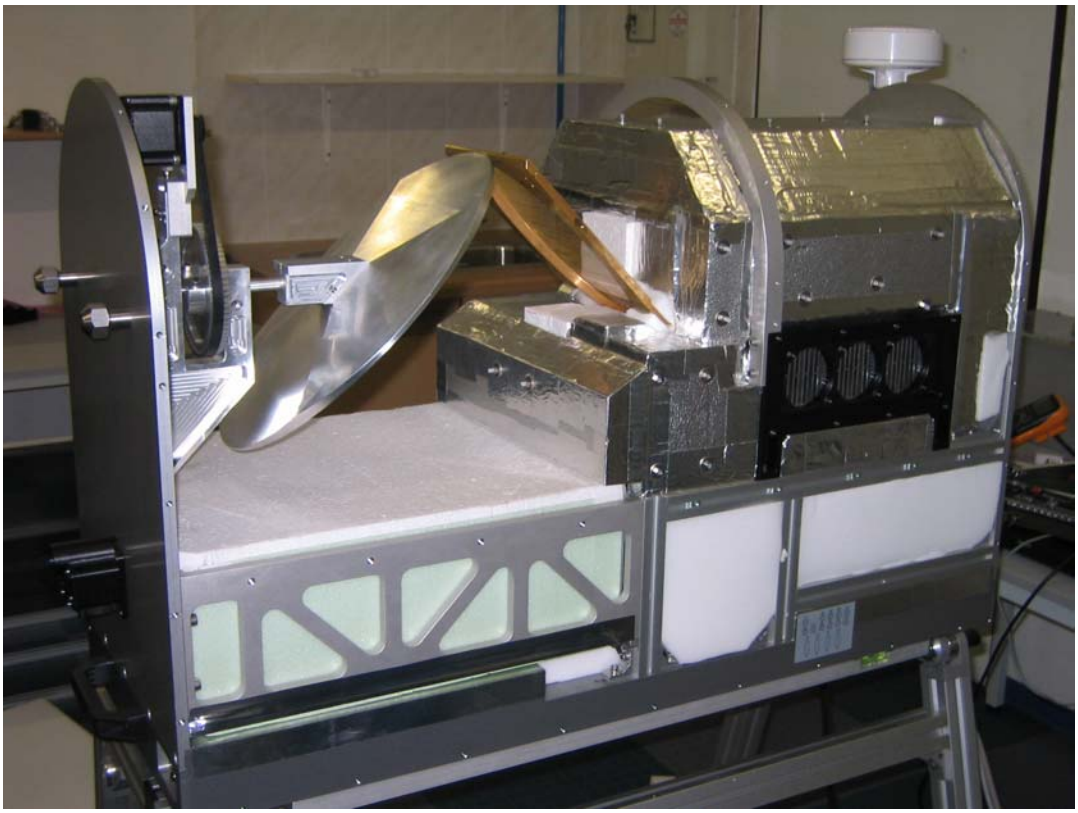


Full auto-calibrating radiometers at 90 GHz and 150 GHz.

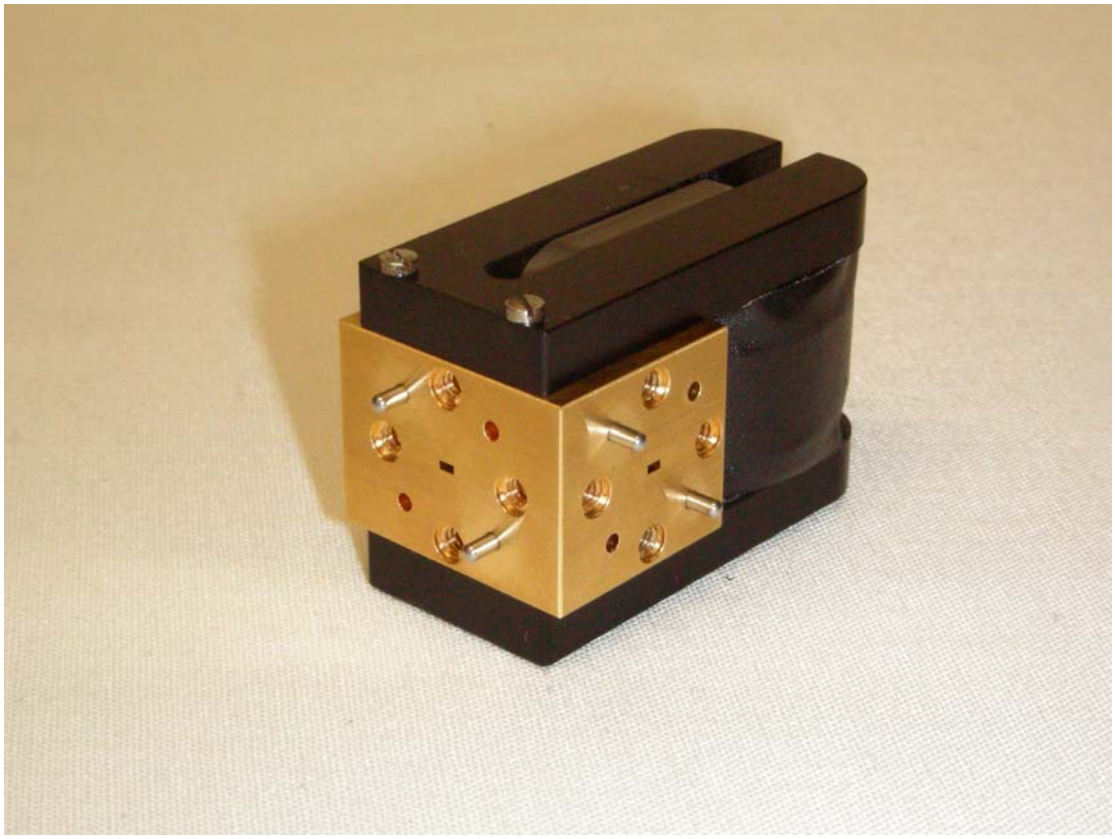
6 channel 183 GHz water vapour radiometer including noise source for auto-calibration.



***Auto-calibration** timing scheme. Noise adding is performed 10 times as often as Dicke switch activation.*



Thermal insulation plus two stage thermal control system stabilizes the receiver temperatures to better than 30 mK.



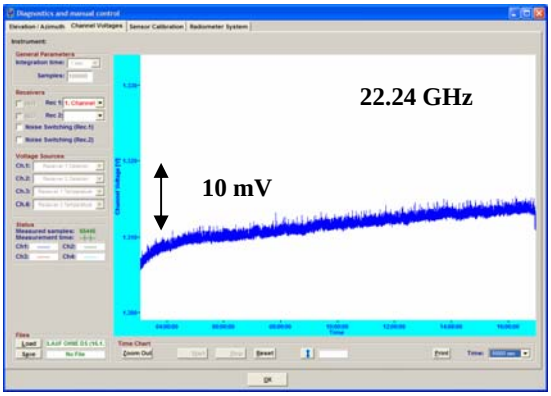
Example of RPG's full W-band (75-110 GHz) Dicke Switch with 0.7 dBtransmission loss.

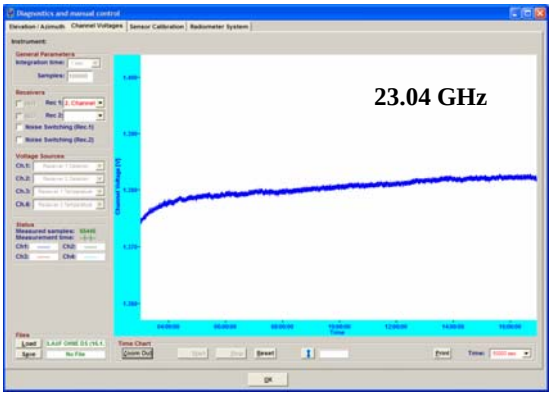
2. Long Term Receiver Stability

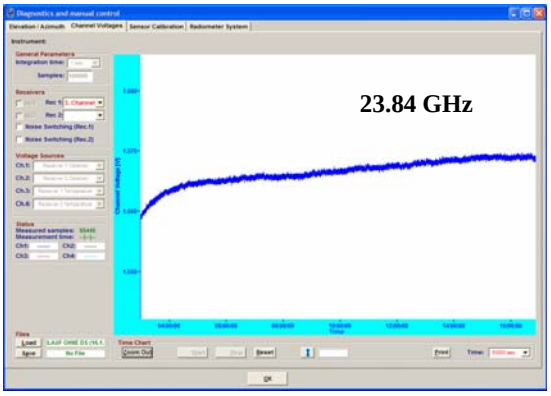
A good indication of the thermal receiver stability is the thermal detector voltage drift as a function of time. The test conditions are:

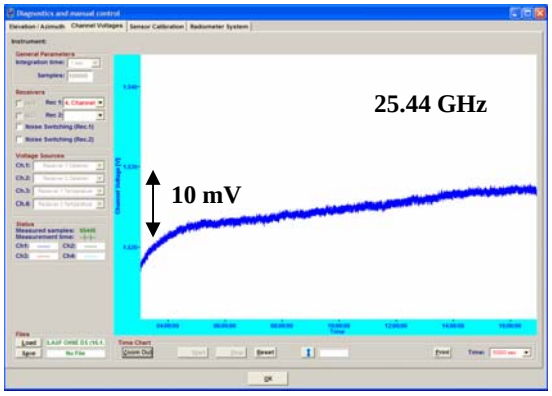
- Receiver input is 'looking' into the ambient temperature target.
- Test duration: 50000 seconds
- No gain calibrations during the test. Free running receivers.

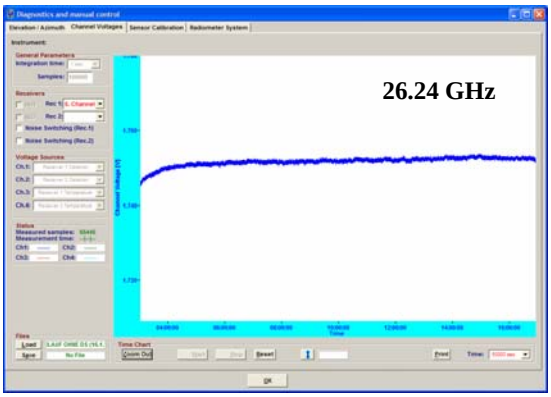
The receivers are running without any calibration for a long time period (50000 seconds) and the detector output voltages should not drift more than 50 mV during this period. A 10 mV detector voltage difference roughly corresponds to a brightness temperature difference of 3 K. During a measurement this receiver drift is compensated by the relative gain calibration.

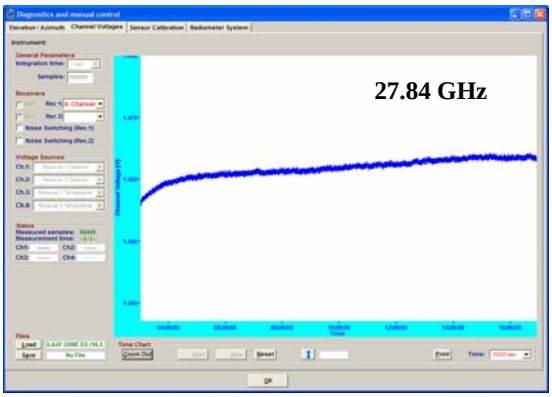

22.24 GHz
10 mV

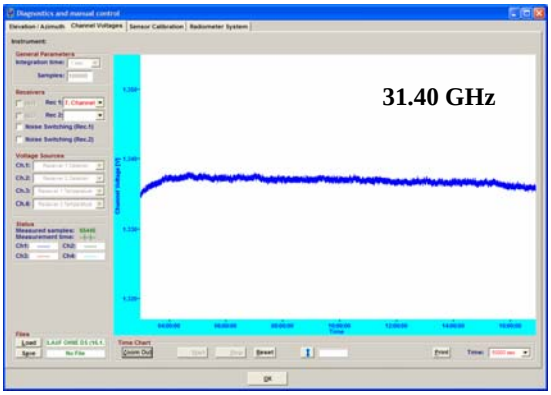

23.04 GHz

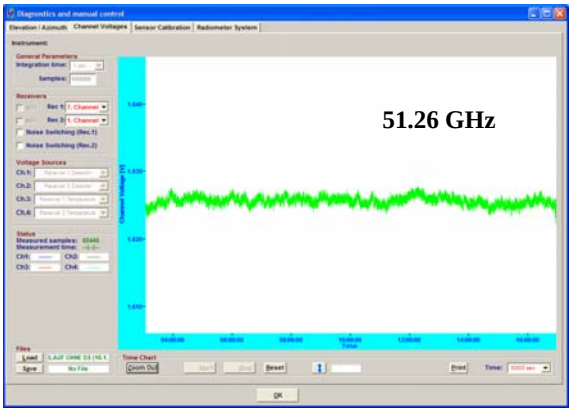

23.84 GHz

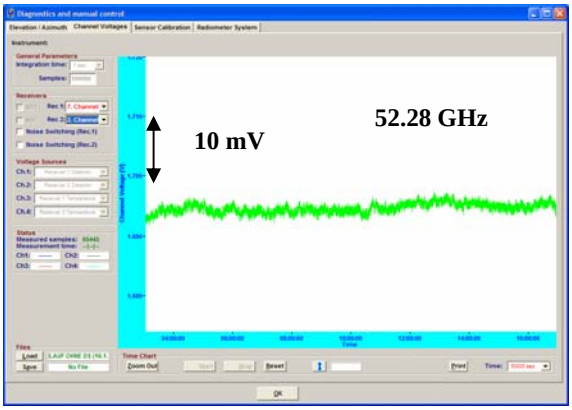

25.44 GHz
10 mV

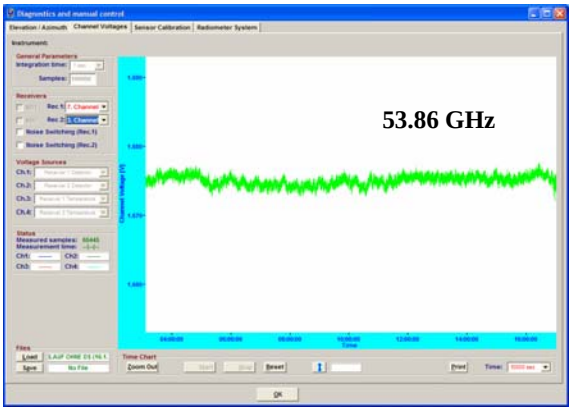

26.24 GHz

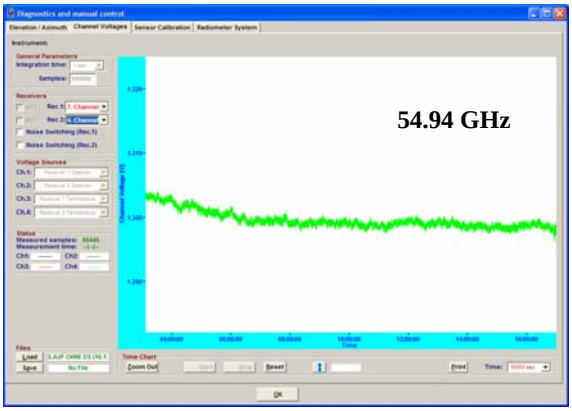

27.84 GHz

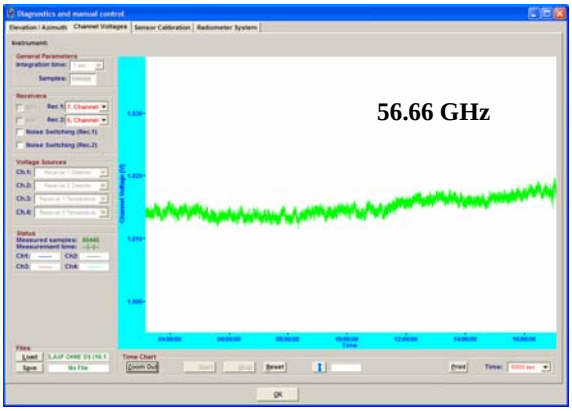

31.40 GHz

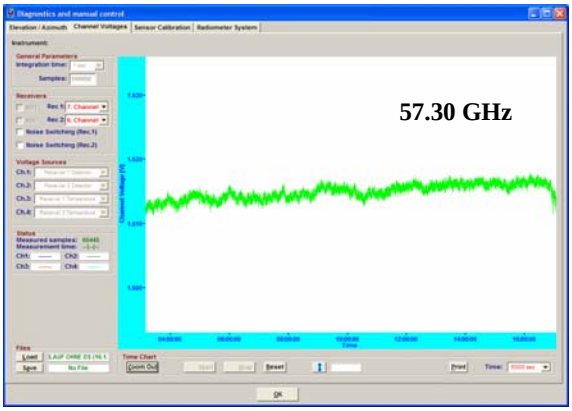

51.26 GHz

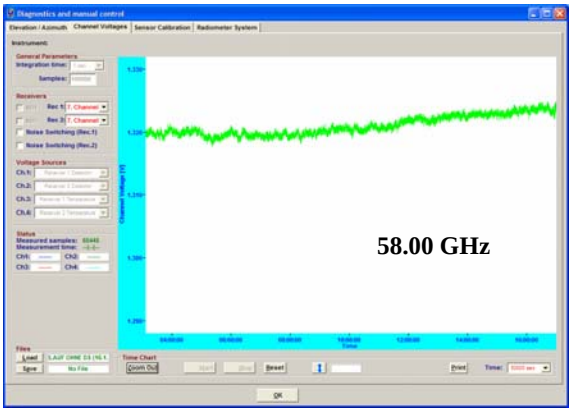

10 mV
52.28 GHz

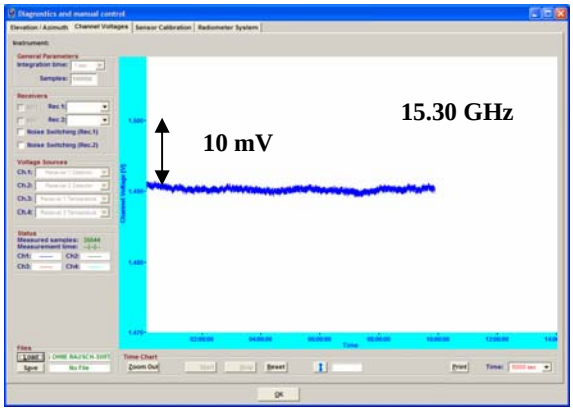

53.86 GHz

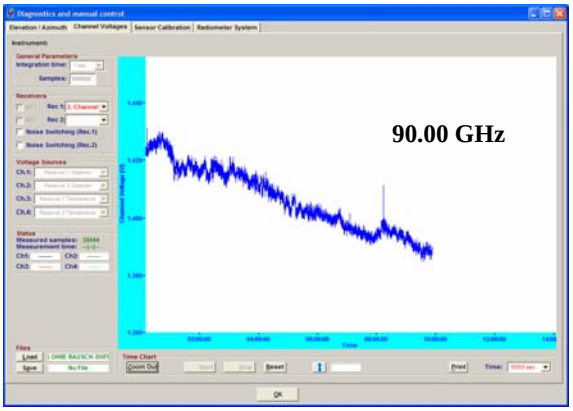

54.94 GHz


56.66 GHz


57.30 GHz

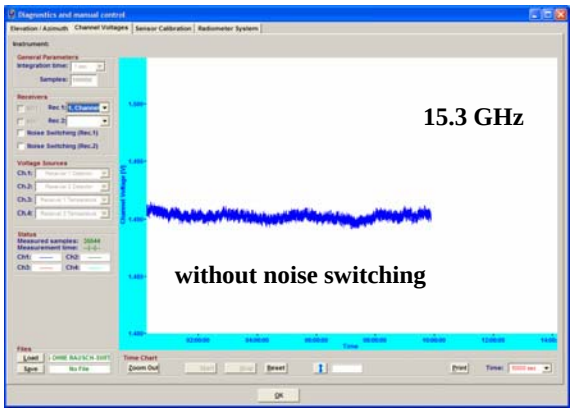

58.00 GHz

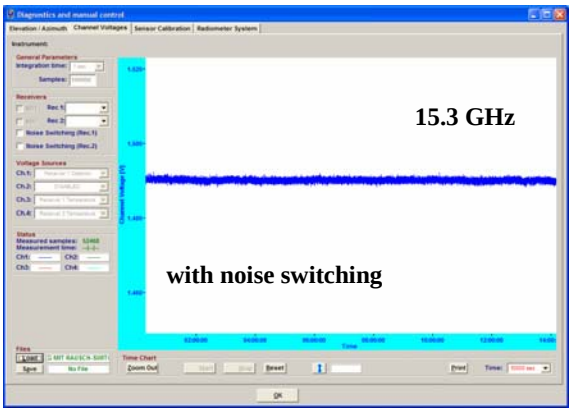


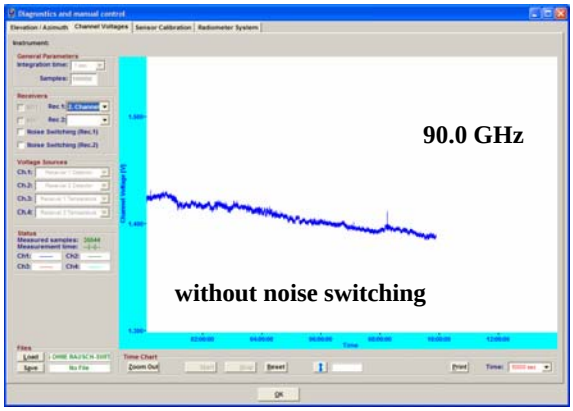


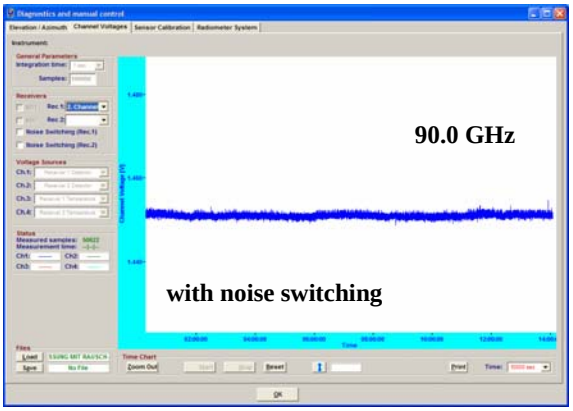
3. Effect of Noise Switching

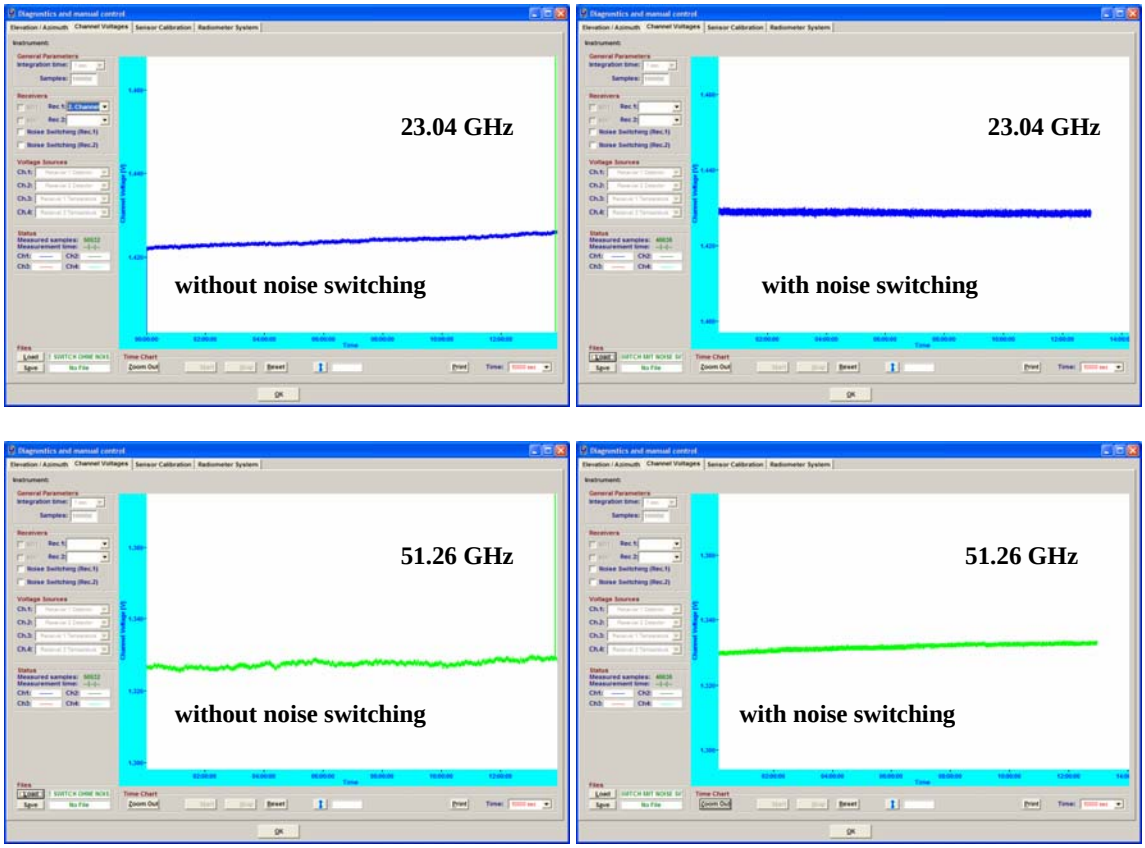
In this test the channel voltages are monitored with the Dicke switches turned ON, so that each receiver is terminated by a constant target temperature. The receivers are operated with only the noise switching (gain calibration) active. Drifts of system noise temperature are not calibrated in this test.







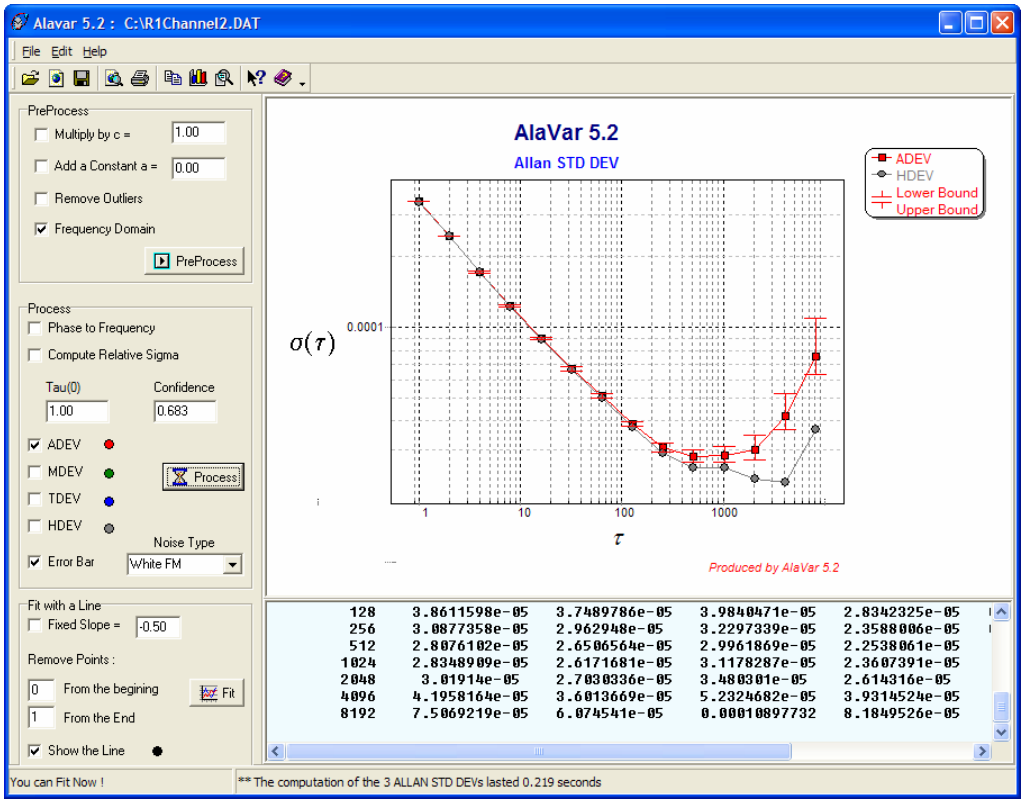




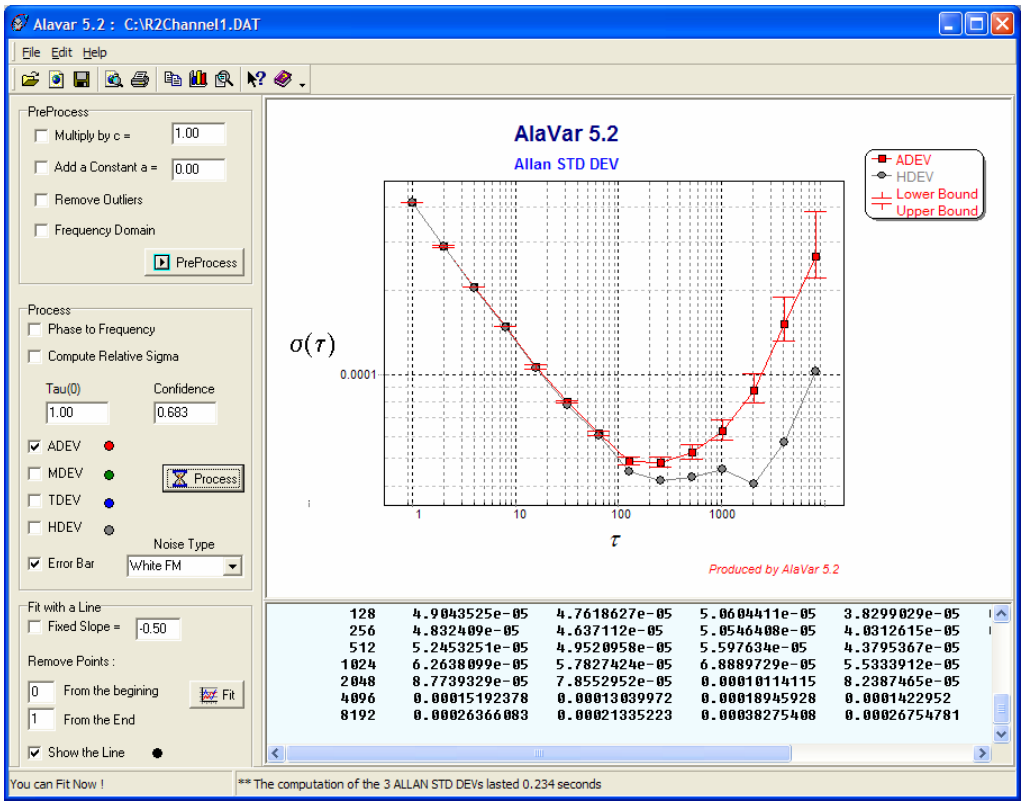
These results show that most of the drifts displayed in section 2 are due to gain drifts that are removed by the noise switching technique. The remaining drifts are caused by slight changes in system noise temperature. At V-band and at 90 GHz the 1/f noise is significantly removed by the noise switching (at K-band). These receivers are both based on InP MMICs which are known to generate higher 1/f noise compared to GaAs based amplifiers.

4. Allan Variance of Channel Voltages

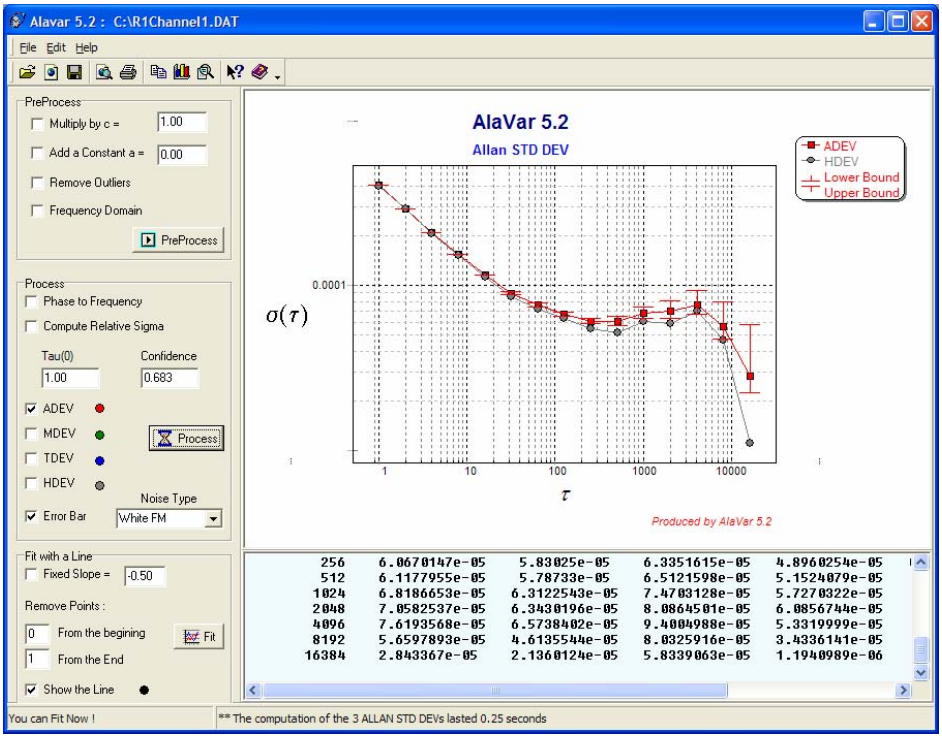
It is interesting to estimate the receiver stability for the noise switching calibration without using the Dicke switch like for the measurements in section 3. In the following some examples of Allan Variance stability is calculated from the data shown in section 3.



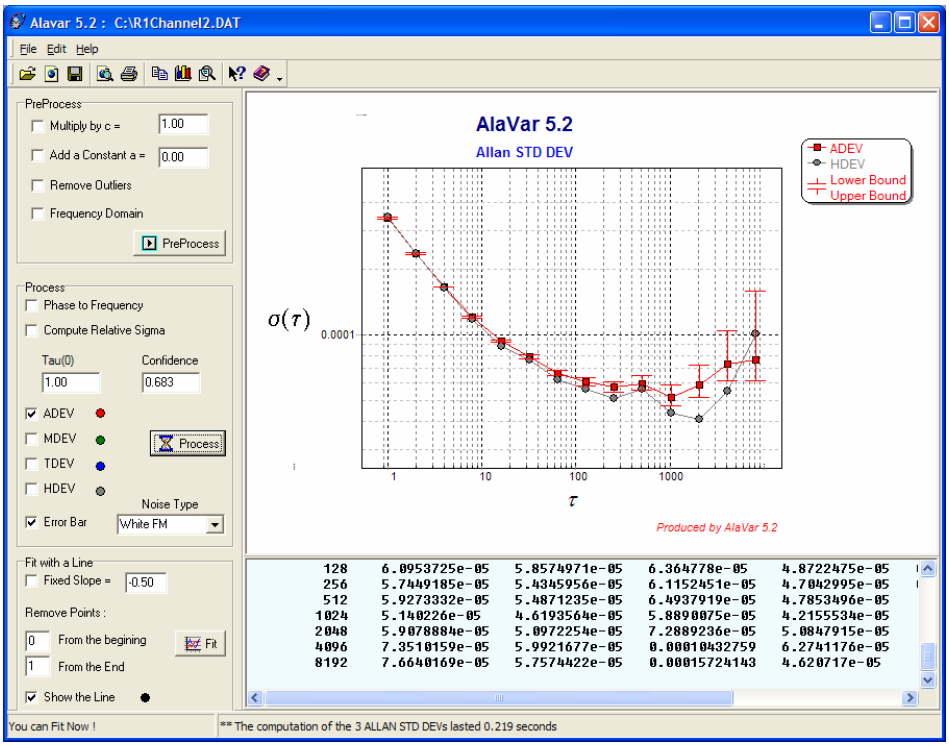
Allan Variance of the 23.04 GHz K-band channel for single noise switching calibration (gain drifts only). The stability is close to 500 seconds.



Allan Variance of the 51.26 GHz V-band channel for single noise switching calibration (gain drifts only). The stability is close to 150 seconds.



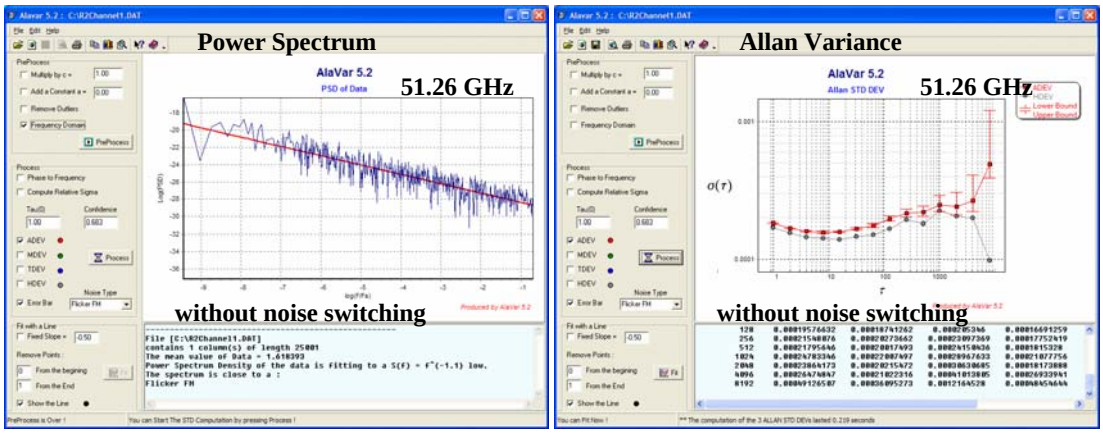
Allan Variance of the 15.3 GHz Ku-band channel for single noise switching calibration (gain drifts only). The stability is close to 250 seconds.



Allan Variance of the 90.0 GHz W-band channel for single noise switching calibration (gain drifts only). The stability is close to 250 seconds.

Channel [GHz]	Stability [s]
22.24	500
23.04	500
23.84	500
25.44	300
26.24	500
27.84	1000
31.40	500
51.26	150
52.28	250
53.86	250
54.94	250
56.66	250
57.30	200
58.00	200
15.30	250
90.00	250

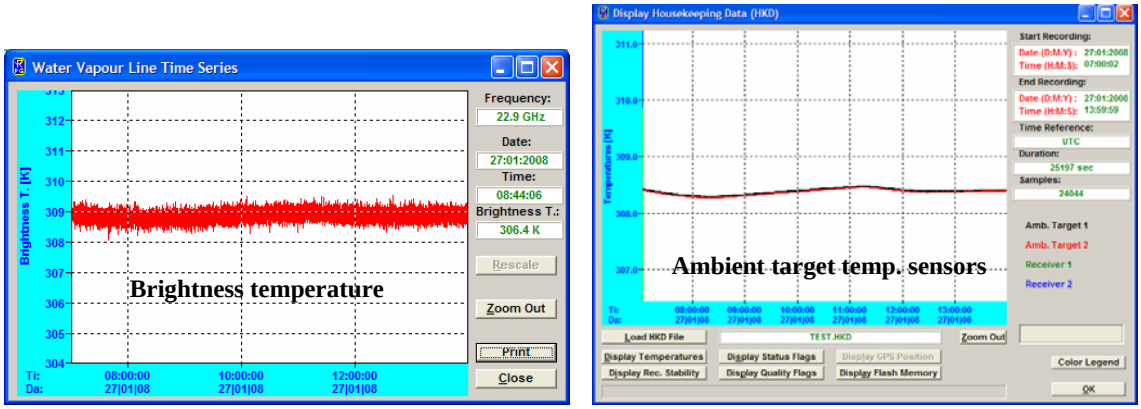
Allan Variance results for single noise switching calibration (gain drifts only).



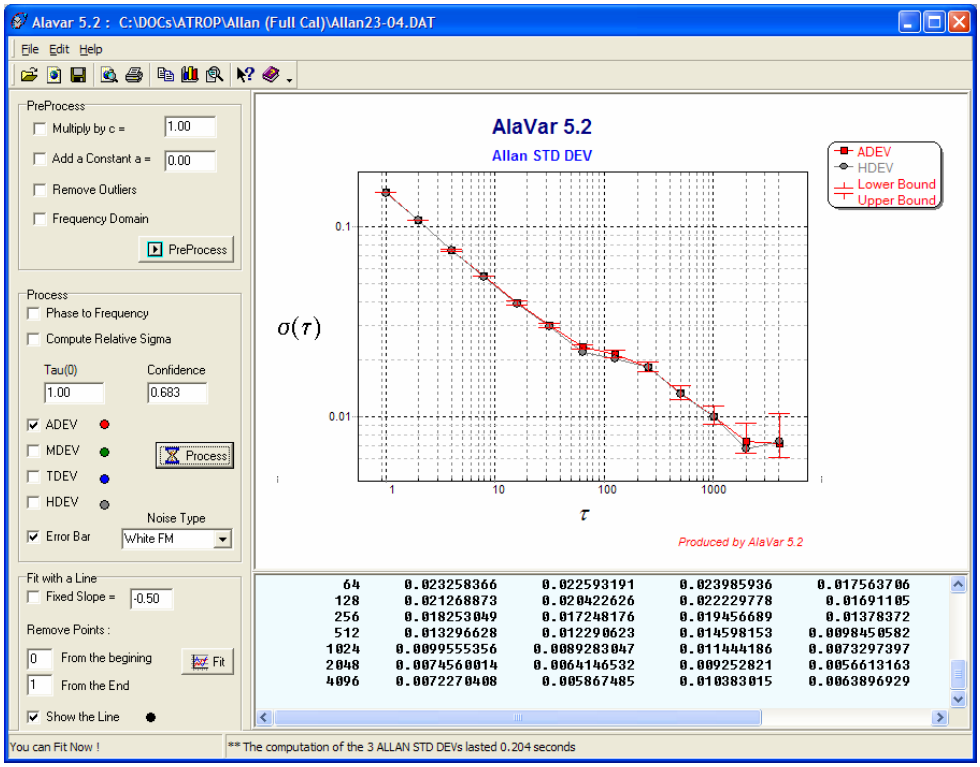
Power spectrum and Allan Variance for the 51.26 GHz channel without and with noise switching. Without noise switching the slope of the power spectrum is much higher compared to the situation with noise switching indicating strong 1/f components.

5. Allan Variance of Calibrated Brightness Temperatures

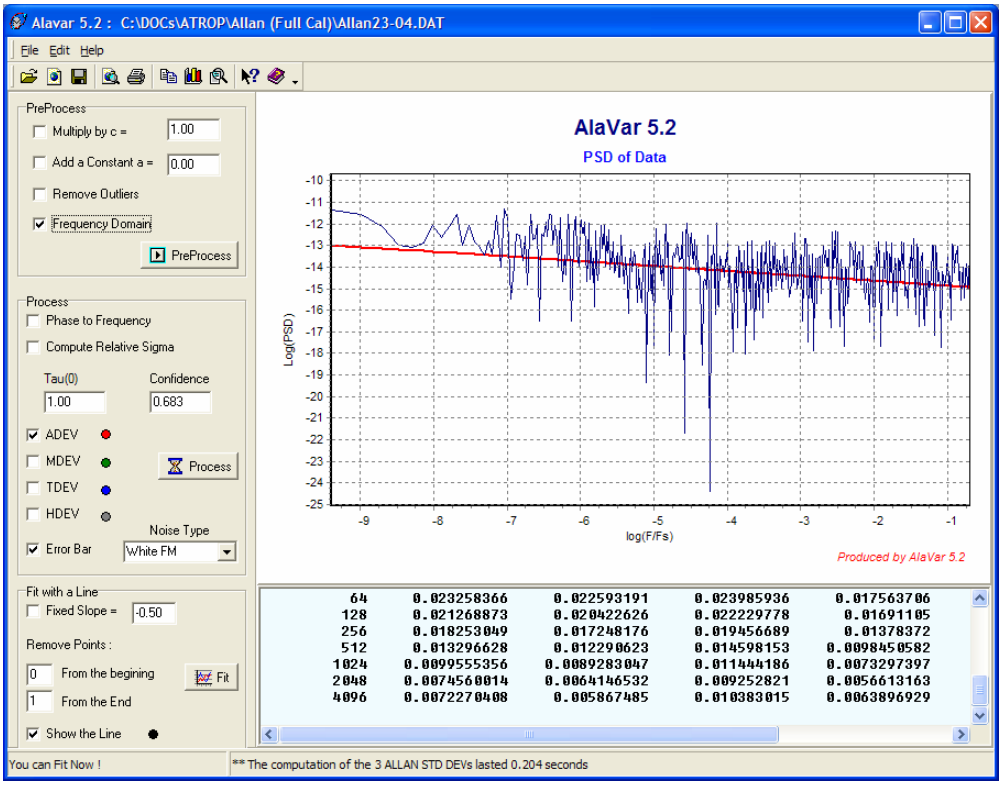
After an absolute calibration (hot / cold) the radiometers are capable of measuring brightness temperatures. It is then possible to perform measurements with the full noise / Dicke switching auto-calibration system. In the following, measurement results are presented with the receivers pointing to an ambient temperature target. The target temperature is accurately monitored and stored in a housekeeping data file to be subtracted from the brightness temperatures for Allan Variance analysis. Both, noise switching and Dicke switching are activated.



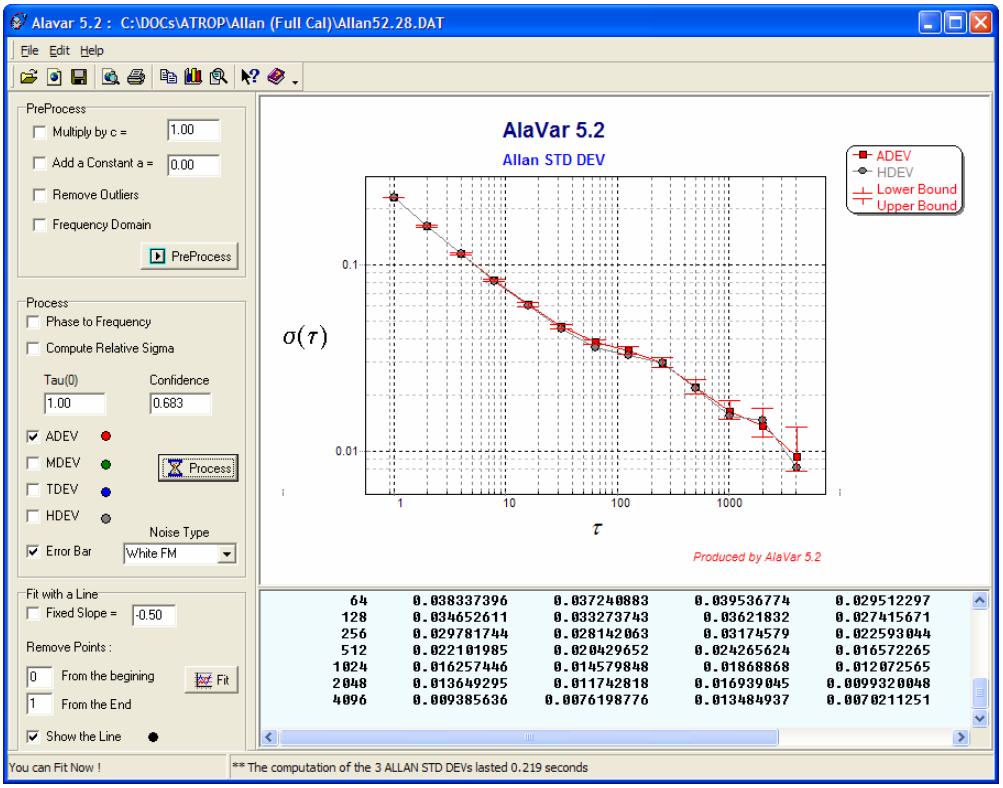
22.24 GHz brightness temperature measurement on ambient target and target temperature, both monitored over a 6 hour period.



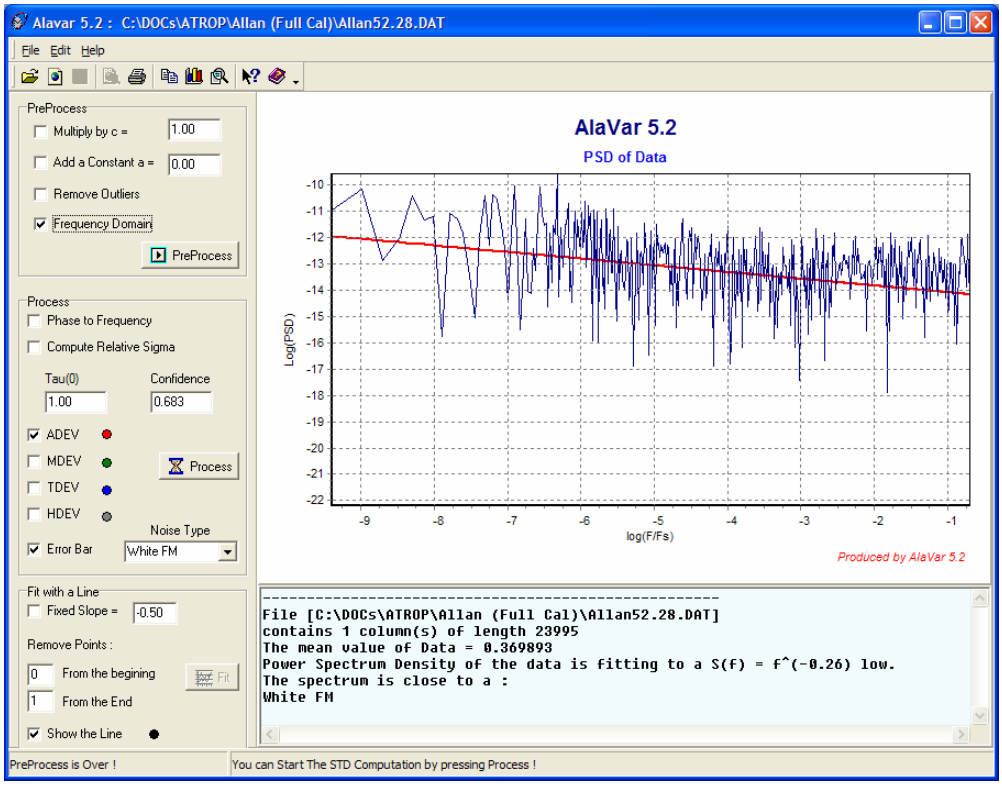
Allan Variance of 23.04 GHz channel with full internal calibration using noise switching and Dicke switching. The stability becomes better than 2000 seconds.



Flat power spectrum of 23.04 GHz channel with full internal calibration using noise switching and Dicke switching.



Allan Variance of 52.28 GHz channel with full internal calibration using noise switching and Dicke switching. The stability becomes better than 4000 seconds.

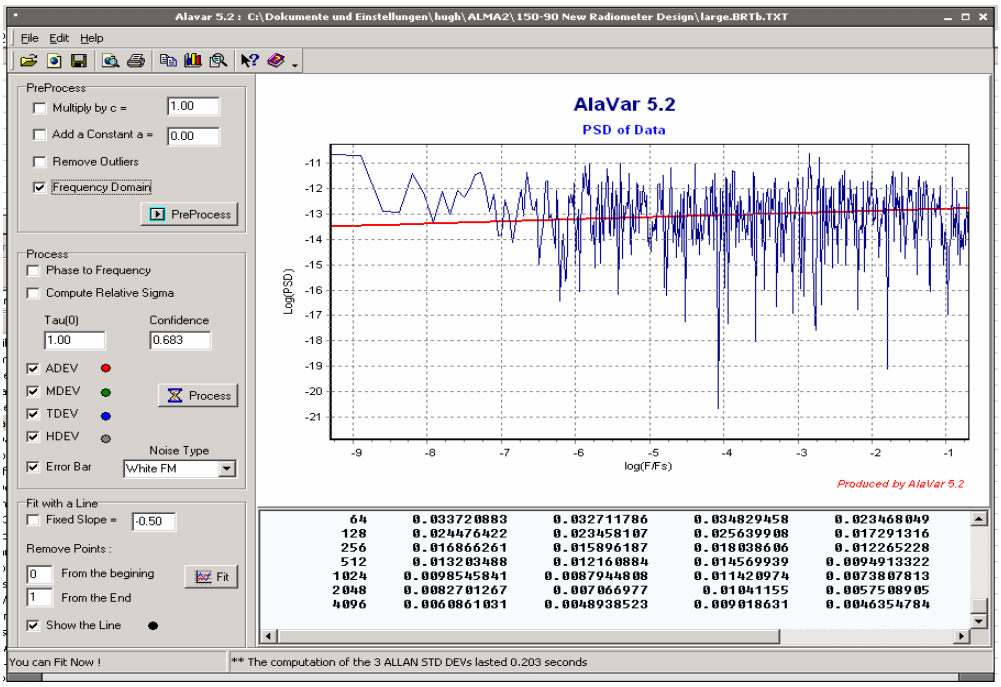


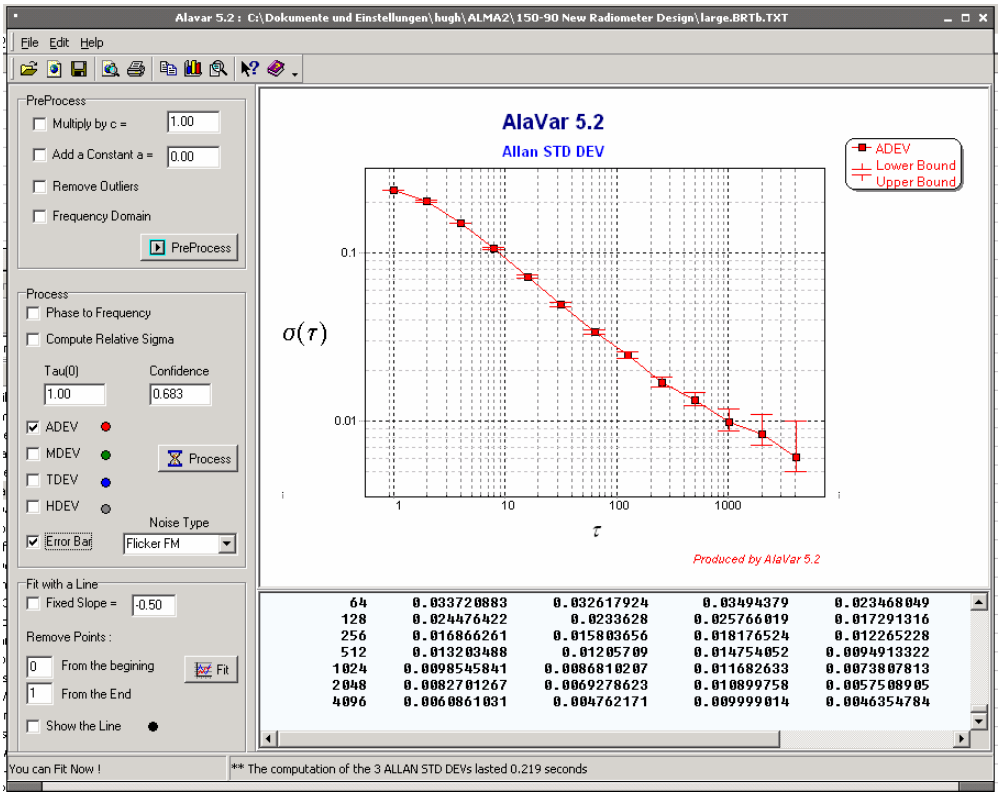
Flat power spectrum of 52.28 GHz channel with full internal calibration using noise switching and Dicke switching.

Channel [GHz]	ADev @ 1 sec	ADev @ 10 sec	ADev @ 100 sec	ADev @ 1000 sec
22.24	0.151	0.053	0.0226	0.0099
23.04	0.150	0.055	0.0230	0.0098
23.84	0.144	0.044	0.0228	0.0100
25.44	0.169	0.052	0.0266	0.0107
26.24	0.180	0.053	0.0272	0.0099
27.84	0.177	0.052	0.0273	0.0111
31.40	0.215	0.070	0.0351	0.0157
51.26	0.222	0.073	0.0372	0.0161
52.28	0.227	0.078	0.0347	0.0163
53.86	0.233	0.078	0.0358	0.0203
54.94	0.259	0.082	0.0393	0.0154
56.66	0.196	0.067	0.0353	0.0155
57.30	0.177	0.060	0.0357	0.0137
58.00	0.178	0.063	0.0437	0.0158
15.30	0.250	0.085	0.0613	0.0273
90.00	0.244	0.083	0.0646	0.0366

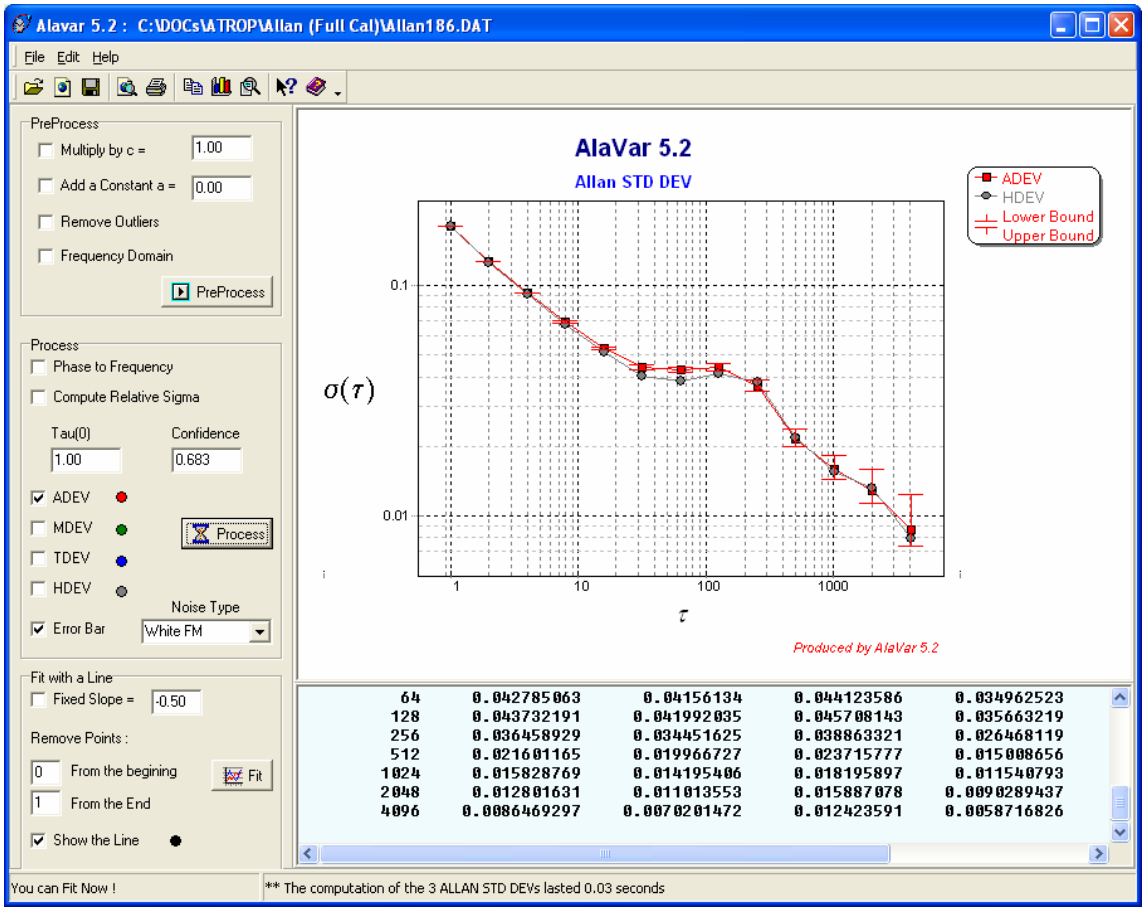
Allan Variance results for full noise switching + Dicke switching calibration.

The concept also works for higher frequency bands like 150 GHz and 183 GHz:





Power spectrum and Allan variance plot for an auto-calibrated 150 GHz radiometer. Stabilities of 4000 seconds can be achieved.



Allan variance plot for an auto-calibrated 183 GHz radiometer.