Identifying Parametric Oscillations of Microwave Amplifiers by Subtle Effects in Power Compression Measurements

J.D. Gallego, C. Diez González, I. López, R. Amils, I. Malo

IT-CDT 2019-4

Observatorio de Yebes
Apdo. 148 19080 Guadalajara
SPAIN
Phone: +34 949 29 03 11
Fax: +34 949 29 00 63

Change Record

Revision	Date	Affected Paragraphs(s)	Reason/Initiation/Remarks
A	2019-03-04	All	First Issue

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1. Introduction

The subject of parametric oscillations of radio frequency amplifiers is known since the early days of vacuum tubes. Parametric oscillations are named this way because they are caused by variations of a particular external parameter (bias, frequency, input drive) [1], [2]. While the amplifier may appear perfectly stable under small signal conditions, oscillations can appear as the amplifier is driven harder. These oscillations tend to be very sensitive to input drive level, bias conditions, and operating frequency. Parametric oscillations are caused by non linearity of the active components and the classic characterization of linear amplifier stability (like Rollet K factor) is totally ineffective for predicting them. The problem is very well known in high power amplifiers and it is considered to be relevant for devices working in A or B class near compression or in C-class or superior. However, as it will be shown in this report, the problem may also appear at relatively low power levels.

There are two main types of parametric oscillations:

a) Subharmonic parametric oscillations: assuming a pure CW input signal, the undesired outputs appear at discrete frequencies subarmonically related with the input (f/2, 3f/2…)
b) Spurious parametric oscillations: assuming a pure CW input signal, the undesired outputs appear at frequencies neither harmonically nor subharmonically related with the input frequency. They may show up as well defined independent oscillations, wide or narrow band noise, modulation sidebands or combinations of these. In general, the frequency and bandwidth of the spurious will change with the amplitude of the CW input.

2. QUINSTAR amplifier

The device tested for this report is a Q-Band LNA model QLW-33505520-G0 S/N 1047700007, with WR22 waveguide input and output. This device was procured to substitute a similar device with higher gain which is used in the first stage of the ambient temperature downconverter of the Nanocosmos Gas Cell laboratory receiver. It was found that the device in use was operating close to compression and as a consequence the noise of the system was degraded. The external dimensions of the new and the old QUINSTAR amplifier are identical. Figure 1 shows a picture of this device.

3. Measurement of performance in the linear regime

The performance (S parameters and noise) was measured using a Vector Network Analyzer Keysight PNA-X model N5247A with option 029 (fully-corrected noise figure measurements). Two precision waveguide to coaxial transitions (Q281A and Q281B) were used at the end of the test cables and its effect was carefully de-embedded using the 2-port de-embedding feature of the analyzer. The plots of these measurements are presented in figures 2 and 3. The worst case values in the band are presented in figure 4. Note that the gain ripple is 8.6 dB pp much higher than the initially specified value (3 dB).

Figure 1: Picture QUINSTAR Q-Band LNA model QLW-33505520-G0 S/N 1047700007 tested in this report.

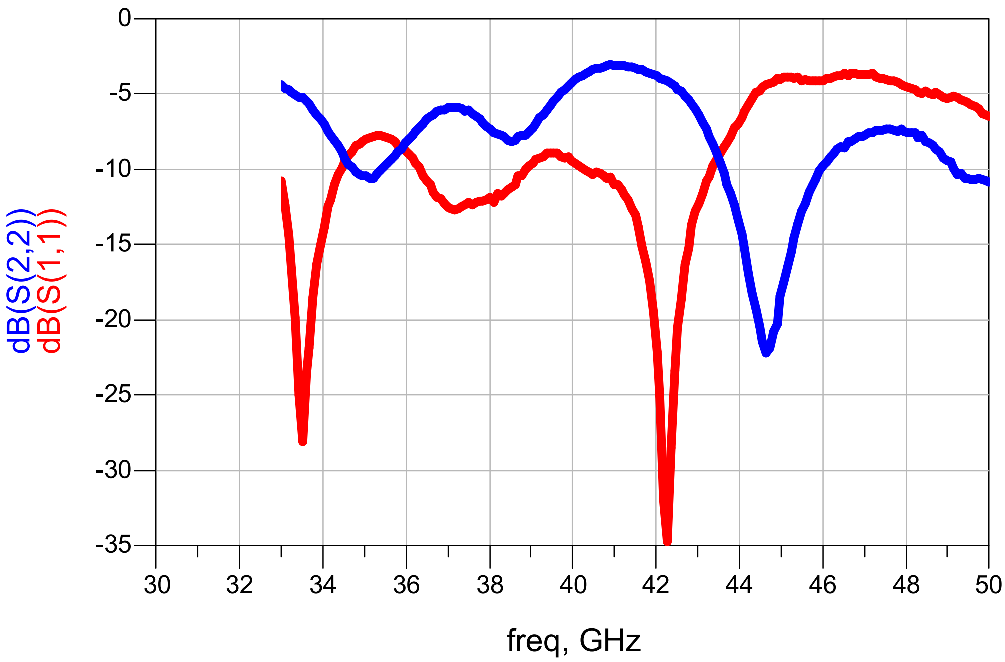


Figure 2: Input and output reflection of QUINSTAR Q-Band LNA model QLW-33505520-G0 S/N 1047700007 measured with Keysight PNA-X N5247A and WG-coax transitions Q281A and Q281B. The effect of the transitions is de-embedded.

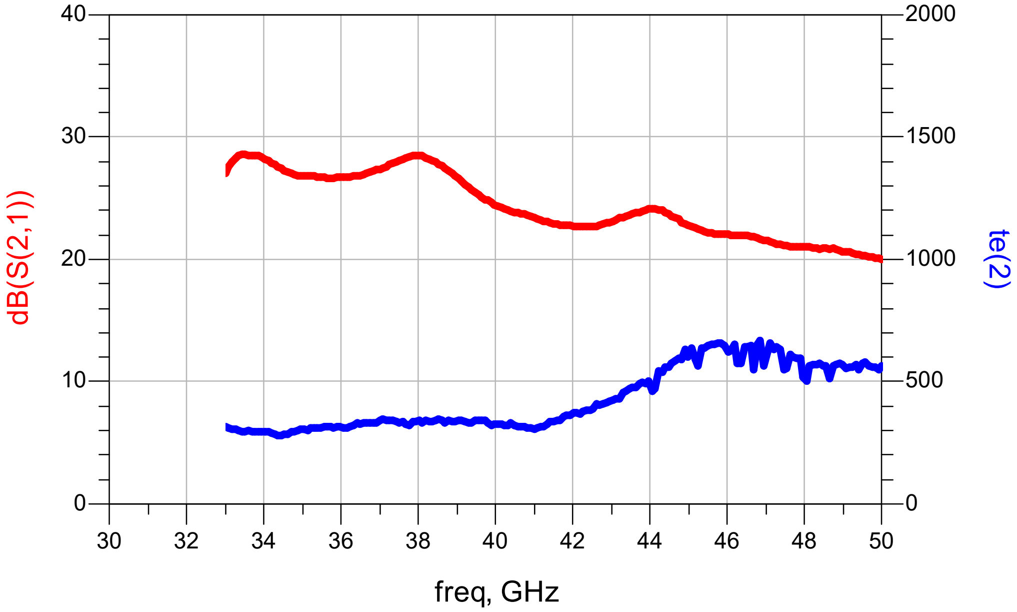


Figure 3: Gain and noise temperature of QUINSTAR Q-Band LNA model QLW-33505520-G0 S/N 1047700007 measured with Keysight PNA-X N5247A and WG-coax transitions Q281A and Q281B. The effect of the transitions is de-embedded.

GAIN (max / min)

m1	m2
freq=33.42GHz	freq=50.00GHz
dB(S(2,1))=28.604	dB(S(2,1))=19.977
Max	Min

NOISE (max /min)

m3	m4
freq=46.85GHz	freq=34.36GHz
te(2)=669.524	te(2)=278.477
Max	Min

REFLECTION (input / output)

m6	m5
freq=46.69GHz	freq=40.91GHz
dB(S(1,1))=-3.595	dB(S(2,2))=-3.052
Max	Max

Figure 4: Worst case values of gain, noise temperature and reflection of QUINSTAR Q-Band LNA model QLW-33505520-G0 S/N 1047700007 in the 33-50 GHz band.

4. Measurement of P1dB compression point

This measurement was performed on the PNA-X with a full two port S parameters and power calibration and de-embedding the effect of the waveguide transitions. The gain was normalized respect to the value at -50 dBm input power and then the power was incremented until a reduction of 1 dB of gain was observed at some frequency in the band. The output power in this condition is the P1dB compression point. The results of this measurement are presented in figure 5. The value obtained for P1dB is -1.79 dBm @ 38.7 GHz, which is lower than the typical value expected from the data sheet (+8 dBm) and also lower than the value measured in the unit presently installed in the receiver (+2.5 dBm).

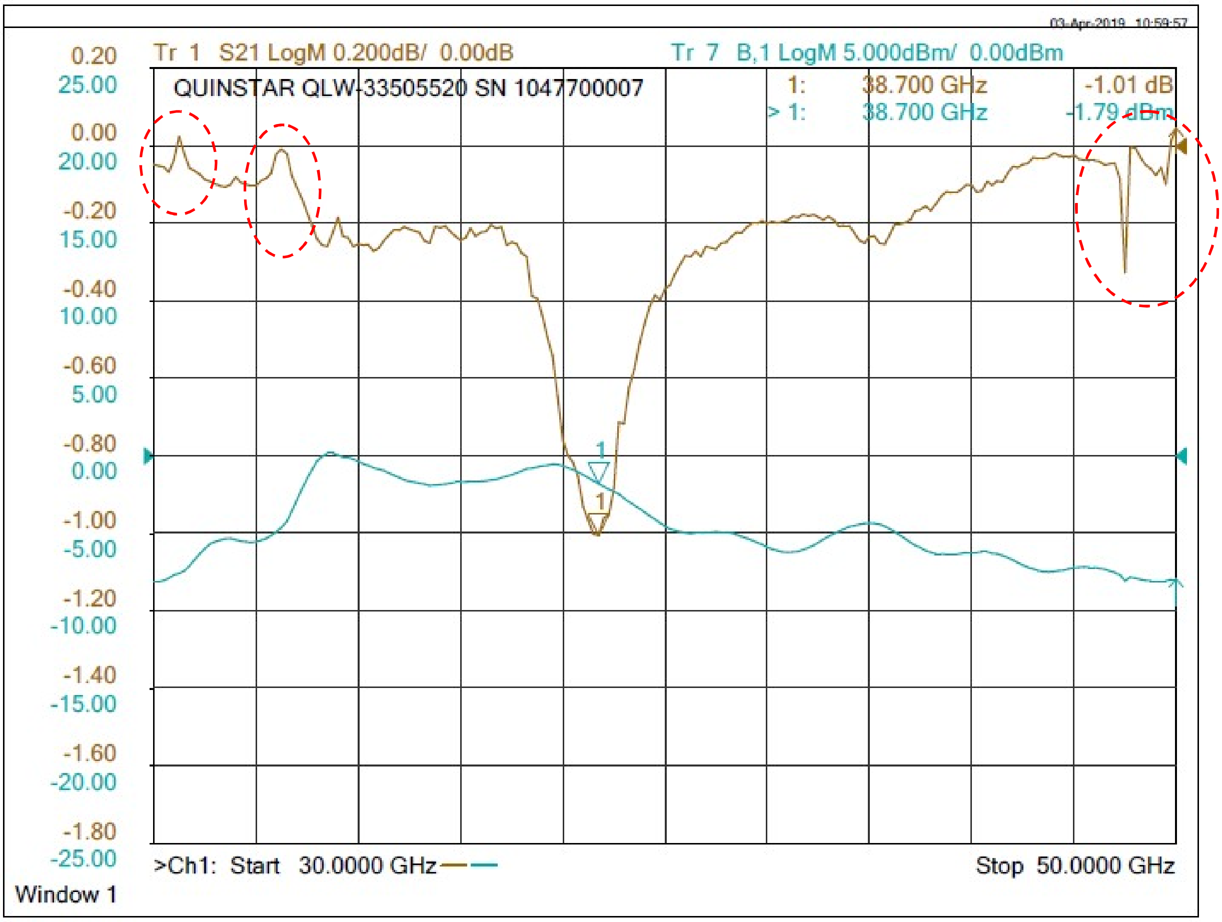


Figure 5: 1 dB gain compression and output power measurement of QUINSTAR Q-Band LNA model QLW-33505520-G0 S/N 1047700007

The plot of the gain as a function of frequency in compression shows some unusual and suspicions features which are outlined with red circles in the figure. These sharp peaks and the fact that at some frequency points there is almost cero compression or even slight negative compression (expansion) indicates that there may be something wrong and further investigation is needed.

5. Measurements of oscillations

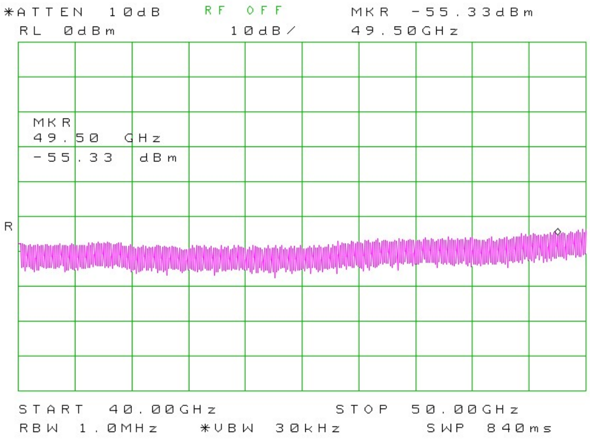
The first thing which was tried was to look for self oscillations of the amplifier. This was done using a spectrum analyzer (Agilent 8564EC) and a non pre-selected external harmonic mixer (Tek WM780A). Past experience shows that this setup allows the detection of oscillations up to at least 150 GHz. Without input signal no oscillation was detected. However, this does not completely exclude the presence of very high frequency oscillations which may be undetectable for the mixer.

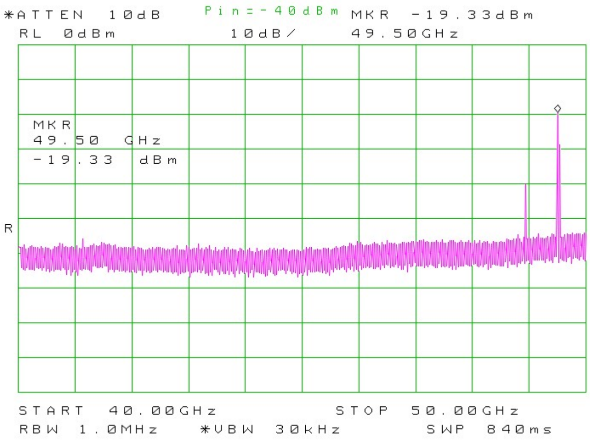
The next step was to analyze the output spectrum with a pure CW signal at the input. In this case the input signal was obtained from the PNA-X in CW mode (with power calibration) and the output was connected to the 8564EC Spectrum Analyzer. A correction (offset) in the reference level was introduced to compensate for loss in the connecting coaxial cable. The results with no input signal and at two different power levels of the CW input are presented in figure 6. The following is observed:

- With no input signal no oscillations are detected.
- With input signal at low level (output -19 dBm) a spurious with no apparent relation with the input frequency appears at -20 dBc.
- With higher input level (output -4 dBm) more spurious appear over the baseline noise. However, the dominant spurious maintains a -20 dBc level.
- The spurious are present even at levels well below the compression point of the amplifier.

A zoom into the different spurious signals of figure 6 is presented in figure 7. The following features are observed:

- The main output is a narrowband and clean signal similar to the one of the synthesizer.
- All the spurious signals are much wider (few MHz), similar to the ones of a free running non-synthesized oscillator.
- The center frequency of the spurious signals varies with the level of the input signal.
- The frequency and relative level of the different spurious signals varies with the frequency of the input signal.





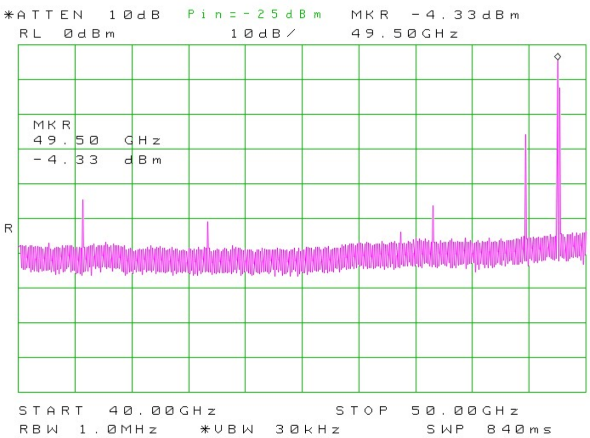


Figure 6: Output spectrum of QUINSTAR Q-Band LNA with a) no input signal, b) input CW at 49.5 GHz, -40 dBm and c) input CW at 49.5 GHz, -25 dBm. The value of the marker indicates the output power at the input frequency.

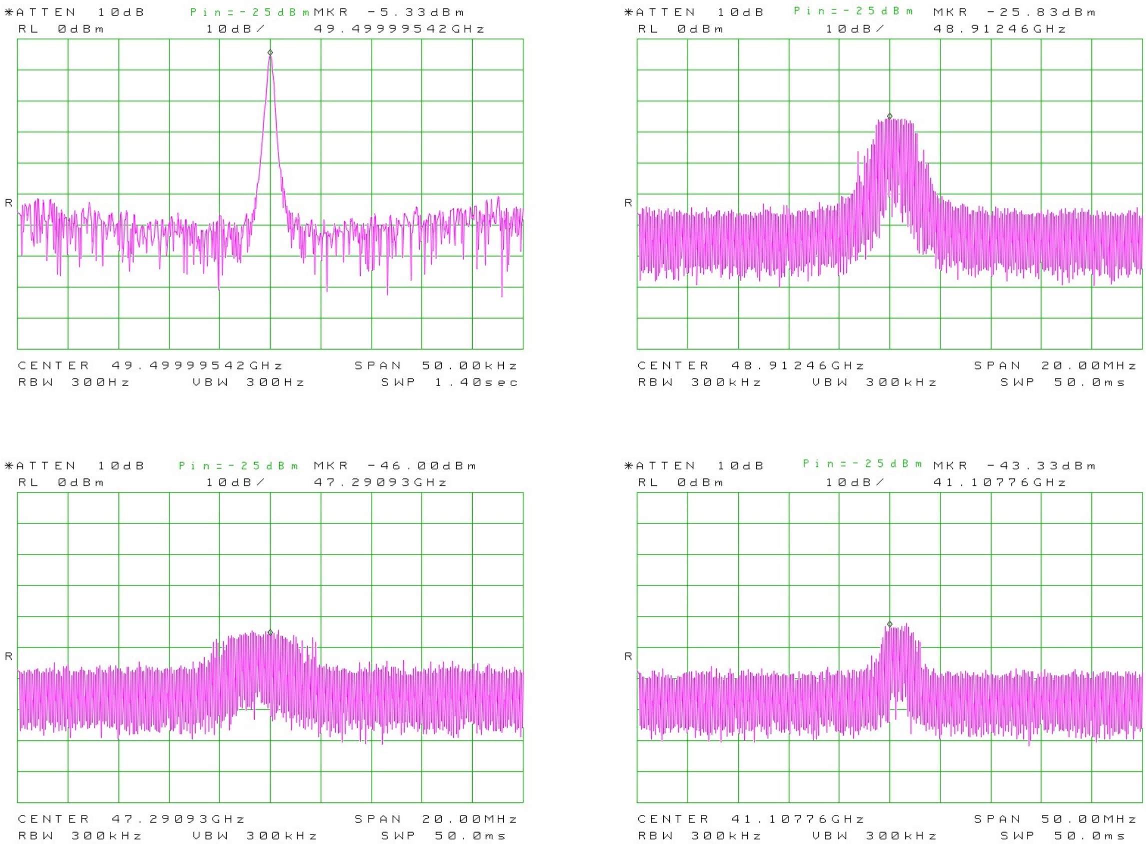


Figure 7: Zoom into several details of the output spectrum of QUINSTAR Q-Band LNA with input CW signal at 49.5 GHz, -25 dBm. Note the different span of the graphs.

6. Conclusions

The measurements of the QUINSTAR Q-Band LNA show an important problem of spurious oscillations which appear when a CW signal is applied to the input. This happens even with very modest output levels. The problem is consistent with the existence of spurious parametric oscillations.

Other possibility which cannot be excluded is the existence of very high frequency (>150 GHz) self oscillations which cannot be detected in out setup. If this is the case, the spurious observed could be originated by some kind of intermodulation distortion between the self sustained oscillations and harmonics of the CW signal applied to the input.

The amplifier should not be used in a radio astronomy receiver. Although the input signal from natural radio sources is random, we could not exclude the presence of parametric oscillations or spectrum contamination with that kind signal.

It is not know if a similar problem could be present in the QUINSTAR amplifiers already installed in the existent Nanocosmos Q-band receivers

7. References

[1] O. Muller and W. G. Figel, "Stability problems in transistor power amplifiers," in *Proceedings of the IEEE*, vol. 55, no. 8, pp. 1458-1466, Aug. 1967.

[2] D. Teeter, A. Platzker and R. Bourque, "A compact network for eliminating parametric oscillations in high power MMIC amplifiers," *1999 IEEE MTT-S International Microwave Symposium Digest (Cat. No.99CH36282)*, Anaheim, CA, USA, 1999, pp. 967-970 vol.3.

8. Appendix I

Data Sheet of QUINSTAR Q-Band amplifier from manufacturer.

QUINSTAR TECHNOLOGY, INC.

SOLID STATE AMPLIFIER DATA SHEET

Model # QLW-33505520-G0 **Job#** 10477 **S/N** 1047700007

Outline G **Input Port** WR-22 **Output Port** WR-22

Customer Specifications			Measured Data			Plot
Frequency (GHz)	33.0 to 50.0		33.0	41.5	50.0	
Small Signal Gain (dB)	20.0		25.6	21.6	20.4	
Gain Flatness (dB)	3.0		3.0dB typ			
Input Return Loss (dB)	5.1		5.1 typ			
Output Return Loss (dB)	7.3		7.3 typ			
P1dB (dBm)	8.0	typ	7.1	6.3	7.2	
Psat (dBm)	N/A		N/A	N/A	N/A	
Noise Figure (dB)	5.5		4.2	3.9	5.2	
DC Current (A) @ + 8 to 12 V	100mA		98	98	98	
DC Current (mA) @ - N/A V	N/A		N/A	N/A	N/A	

Measured in Yebes:

Frequency (GHz)	33 to 50		33	41.5	50	
Gain (dB)			27.05	22.85	19.98	
Gain Flatness (dB pp)	8.6					
Input Ret. Loss (dB)	3.6					
Output Ret. Loss (dB)	3.1					
P1dB (dBm)	-1.8					
Noise Figure (dB)			3.20	3.35	4.68	