Added Phase Noise measurement for *EMBRACE* LO distribution system

G. Bianchi [1], S. Mariotti [1], J. Morawietz [2]

[1] *INAF-IRA (I),* [2] *ASTRON (NL)*

1. Introduction

Embrace is a system composed by 150 receivers, each one having an up and down converter. This implies that the system needs two LOs (Local Oscillator). The first operation is an up-conversion that realizes the shifting of the central frequency from 1 GHz to 3 GHz. This operation requires a tuneable LO whose frequency varies from 1450 MHz to 2550 MHz. The second conversion shifts the 100 MHz bandwidth, centered at 3 GHz, to 150 MHz. This operation requires a fixed 2850 MHz LO. Both LOs must drive 150 mixers. The mixers used in the receiver boards are ADE-42MH by MiniCircuit; their LO input power level is 15 dBm. In order to distribute the LO to the receiver boards, a Christmas tree architecture has been planned (figure 1).

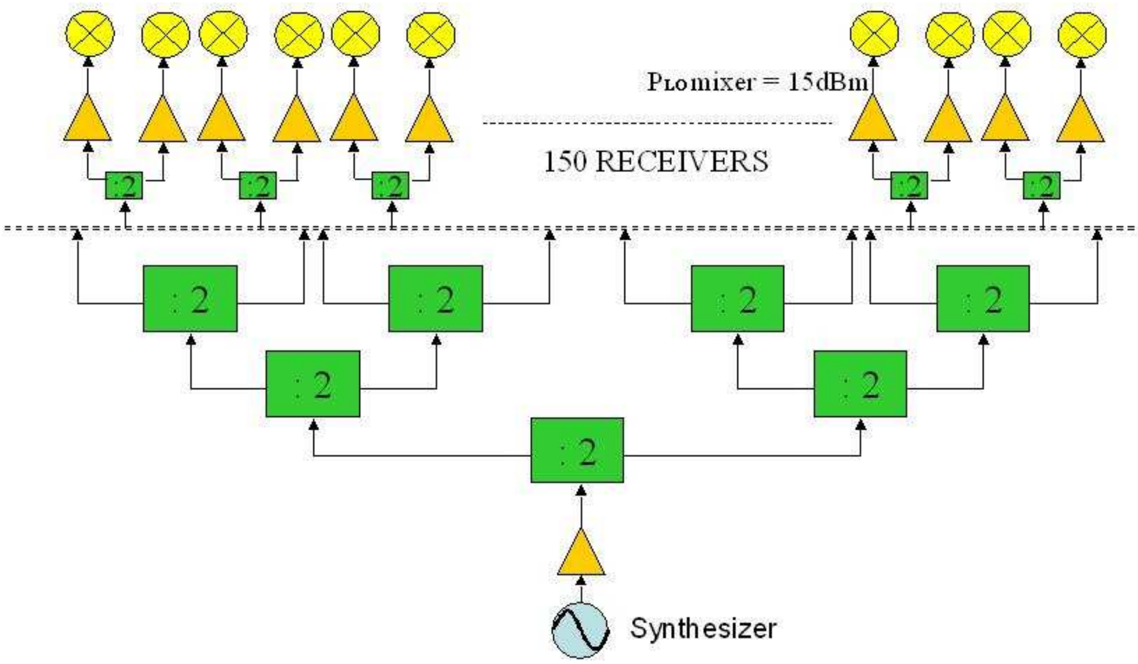

Fig.1. LO distribution system.

The total attenuation of the Christmas tree is about 38 dB (taking into account coaxial cables and connectors contributions). This requires two amplifier stages: one after the synthesizer and the other one before the mixers. It is very important that the amplifiers do not increase the phase noise; it is therefore necessary to measure the effect of the phase noise due to the amplifiers. For this reason, it is important to perform three types of measurements:

1. Additive (residual) phase noise.
2. Absolute (total) phase noise.
3. AM to PM conversion to measure the phase modulation.

The most important one is the Christmas tree additive phase noise, since it allows us to understand the real contribution of the phase noise introduced by the amplifiers and power splitters.

2. Phase noise consideration and theory.

The phase noise measurement it is not easy: it needs extremely precision instruments and care of the test bench. For this reason, we rented an Agilent E5500 Phase Noise Measurement Subsystem for the absolute and residual phase noise measures (figure 2), and we used the HP 8753C network analyzer for the AM to PM conversion measurement.

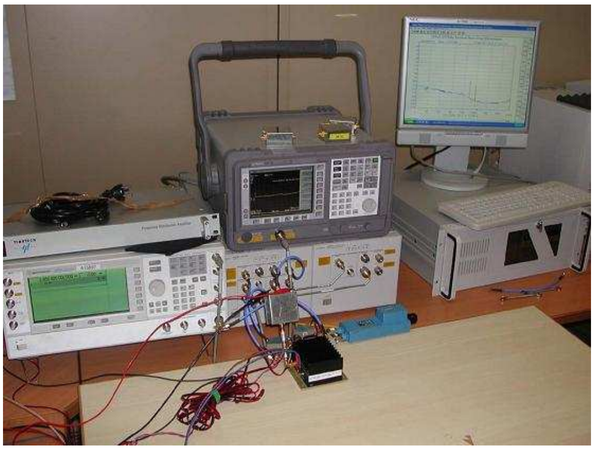

Fig.2. Phase noise test bench.

The block diagram for the additive phase noise measurements is reported in figure 3.

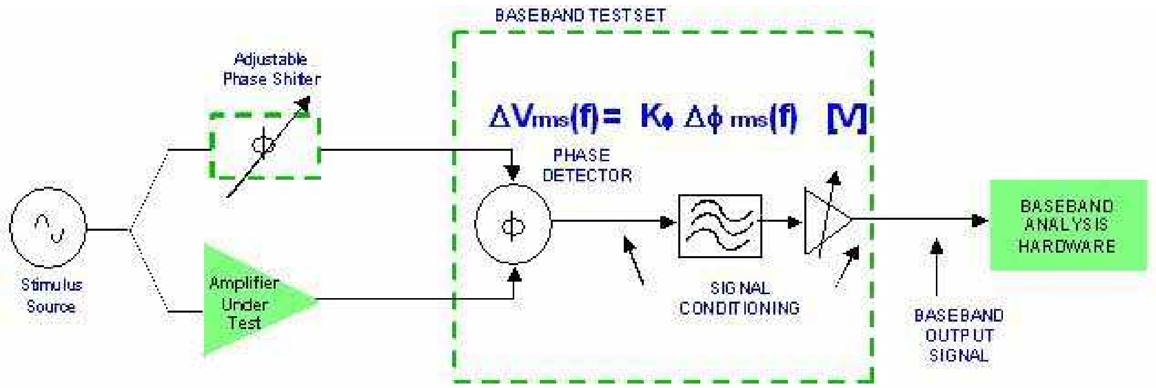

Fig.3. Additive phase noise measurement: block diagram.

Two-port phase noise characterization requires a stimulus source to provide the input signal reference. The goal of the measurement is to have the noise of the source common to both signal paths and arrive correlated at the phase detector. This requires the two signal paths lengths to be as equal as possible. The phase shifter is used to establish quadrature of the two signals at the phase detector. With the noise of the source correlated at the phase detector, the remaining phase noise difference is the noise of the two-port device.
The block diagram for the absolute phase noise measurements is reported in figure 4.

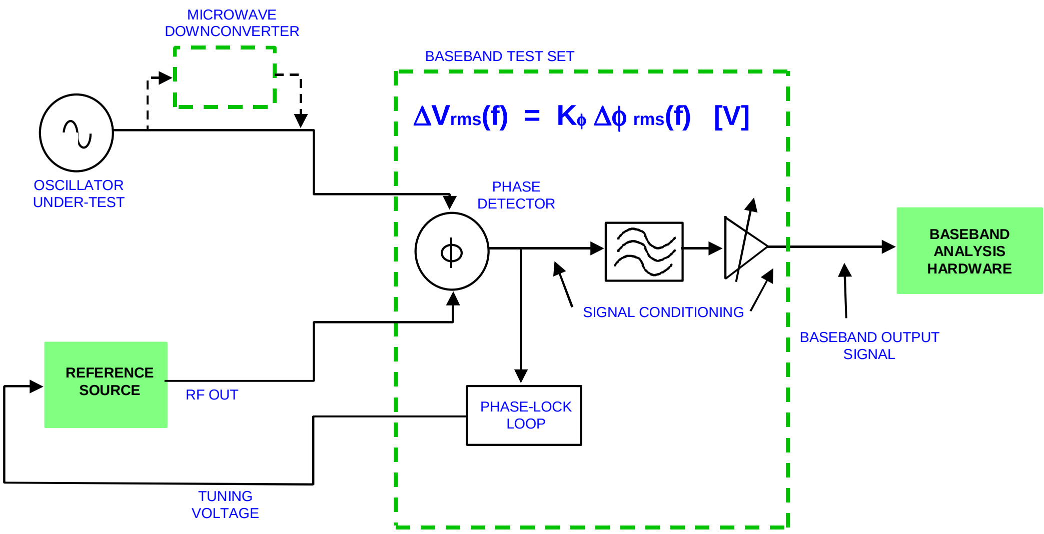

Fig.4. Absolute phase noise measurement: block diagram.

Within this technique, another source is used to provide the reference phase signal for the phase detector. The phase-lock-loop is used to control either of the two sources and establish phase quadrature at the phase detector. The phase noise that is measured at the phase detector is the sum of the mean square phase fluctuations.

3. Phase noise measurements.

<u>ADDITIVE PHASE NOISE</u>

First of all, we measured the instrumental noise, to understand which is the minimum noise value of the system. In figure 5 a graph of the instrumental noise at the maximum input frequency (2850MHz) is reported.

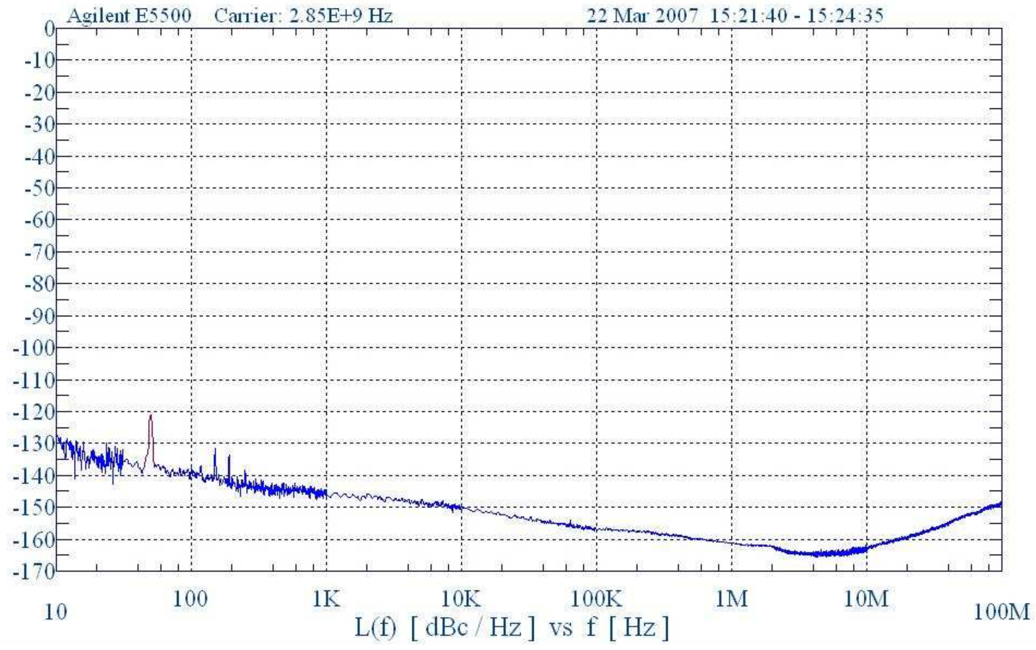

Fig.5. Instrumental noise measure.

Then the additive phase noise of the mixer driver - an HMC480ST89 amplifier from Hittite - was measures at 2850 MHz. The result is reported in the figure 6. The phase noise contribution of the amplifier is very low: in comparison to the instrumental noise, we can observe that the noise increases less than 10 dB for every frequency.

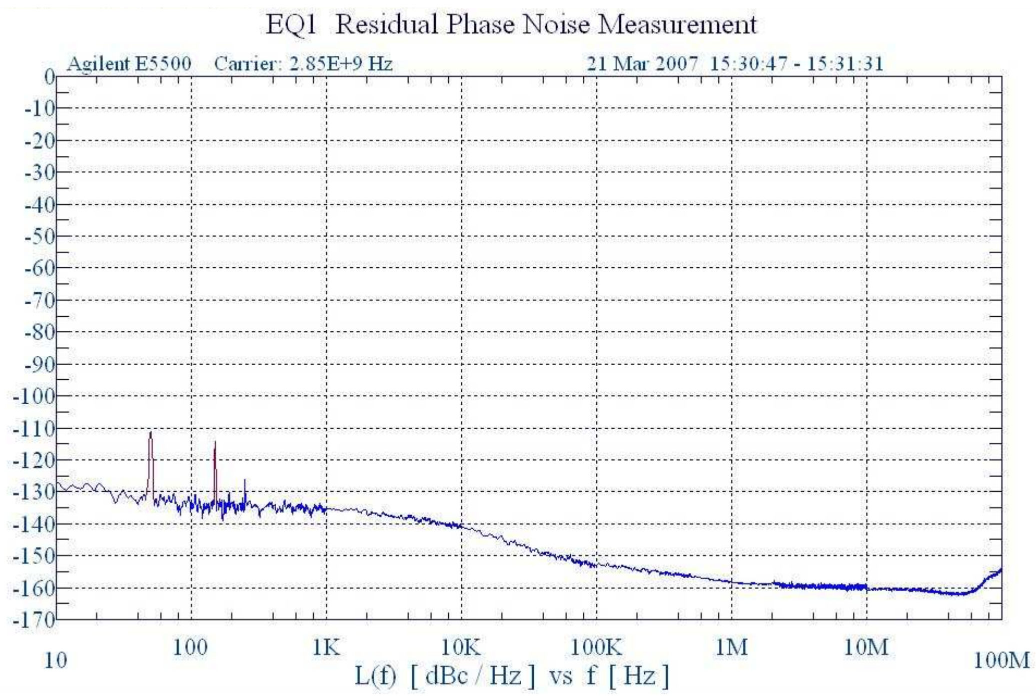

Fig.6. HMC480ST89 additive phase noise.

We also measured the additive phase noise due to the whole Christmas tree (composed by splitters and mixer driver), reported in figure 7.

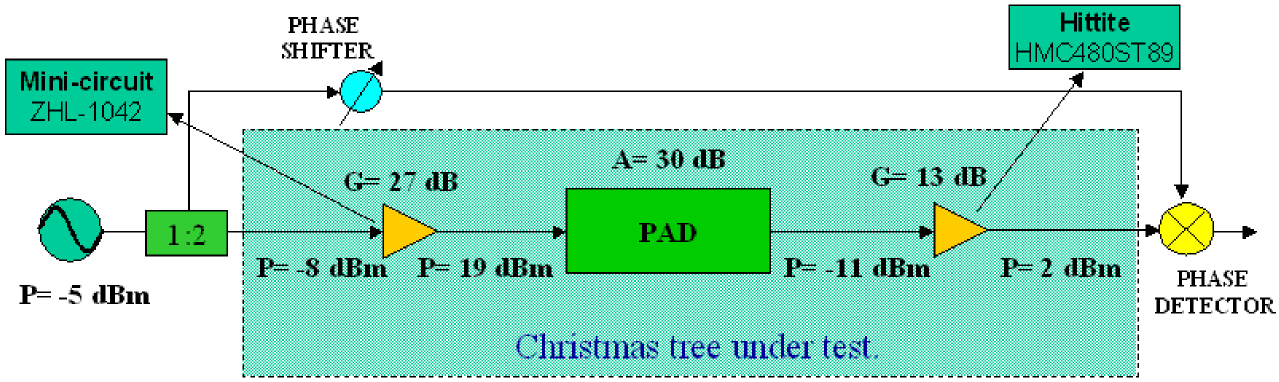

Fig.7. Additive phase noise measurement: whole Christmas tree block diagram.

In order to simulate the effect of the Christmas tree power splitters, 30 dB attenuators were used. The result is reported in the figure 8, where an extremely low integrated phase noise value (less than 0.03 degree) was found.

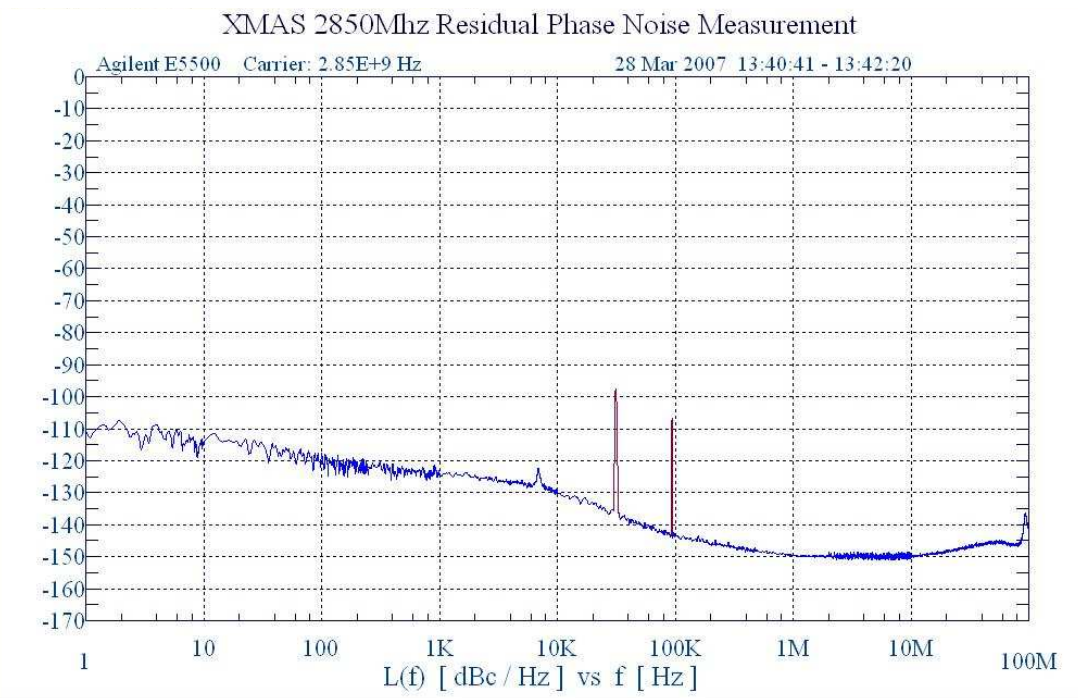

Fig.8. Christmas tree additive phase noise.

The pad was also set along the LO distribution chain at different positions (right next the synthesizer and before the mixer), but no meaningful differences were found in the graph shown in figure 8.

ABSOLUTE PHASE NOISE

In order to understand the phase noise contribution due to the Christmas tree, we have compared two cases as well:

1) Measurement of the synthesizer phase noise.
2) Measurement of the absolute phase noise (synthesizer + Christmas tree).

In the first measure, we found the phase noise shown in figure 9. In this case a Wiltron 68159B synthesizer at 2850 MHz was used.

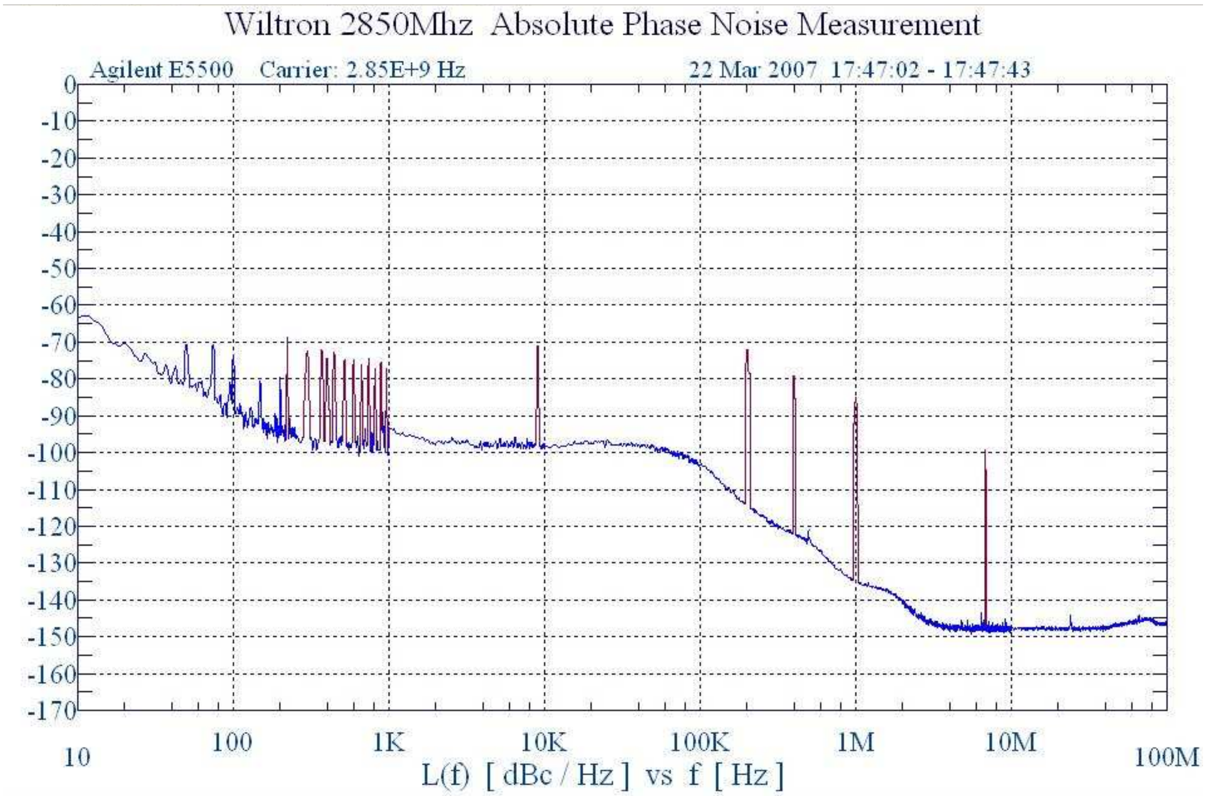

Fig.9. Wiltron 68159B: absolute phase noise.

We then installed the LO distribution chain (synthesizer + Christmas tree, figure 10) and measured its absolute phase noise. As shown in the figure 11, there is an undetectable difference between the two cases. Therefore, the main contribution of the phase noise is due to the synthesizer whereas the contribution due to the Christmas tree is unobservable. In order to minimize the phase noise, a good synthesizer is required!

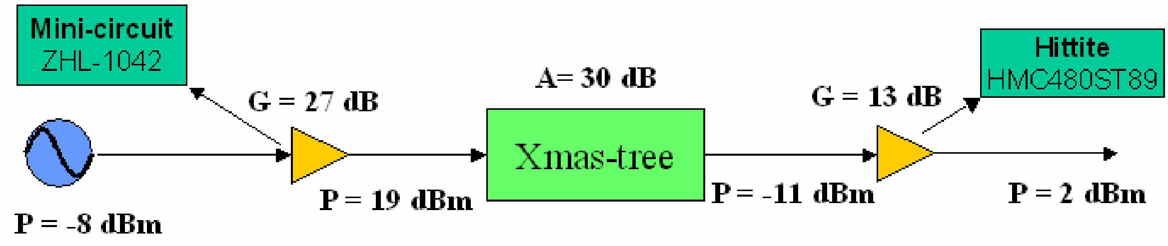

Fig.10. LO distribution chain.

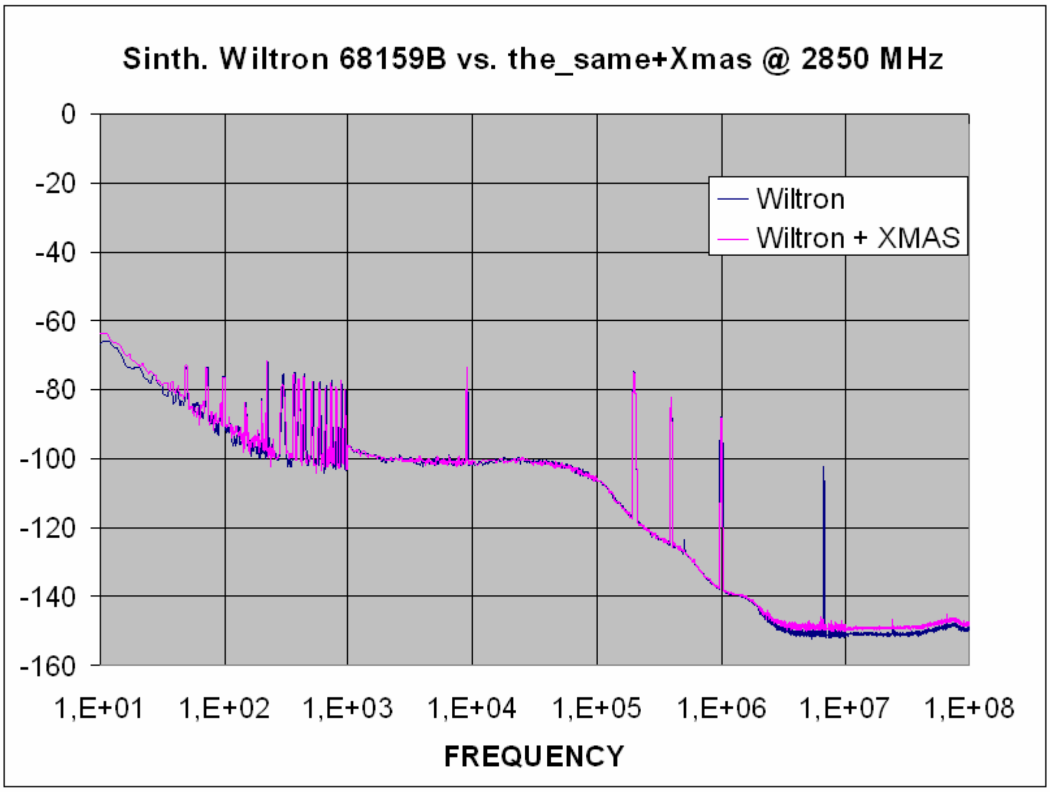

Fig.11. LO distribution chain: absolute phase noise measure.

4. AM to PM conversion

The PM, due to the amplitude variation, was generated in different ways in order to make the measurements. A strong enough amplitude variation has been driven to the PA (Power Amplifier) under test (HMC480ST89) in order to excite the non-linear region.
Due to the available instrumentation, two methods have been performed.

1. The first has been the classical AM to PM conversion measurement using as a stimulus a large sine wave at the operating frequency and observing the phase modulation.
2. The second has been performed by changing the bias conditions and the correlated phase modulation has been observed.

Moreover a third test has been conducted: the variation of the phase due to the temperature variations.

5. AM to PM conversion measure

Test and analysis has been conducted on two set of PA working in L and S band: all PA had similar performances but the last set contained an additional equalizer.
The following two graphics (figure 12 and 13) will show the phase of s21 vs input power for 2 different type of PA.

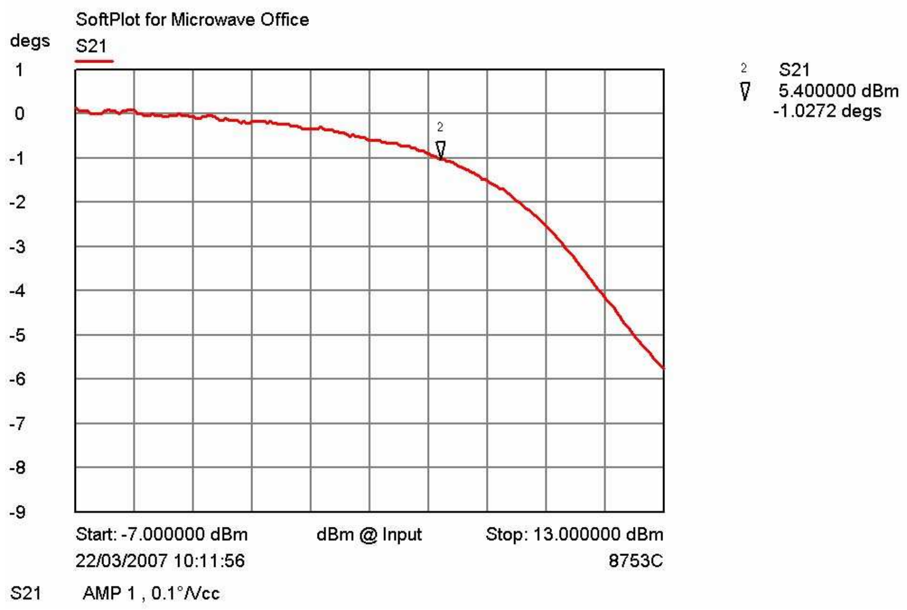

Fig.12. AM to PM conversion of PA “AMP1”

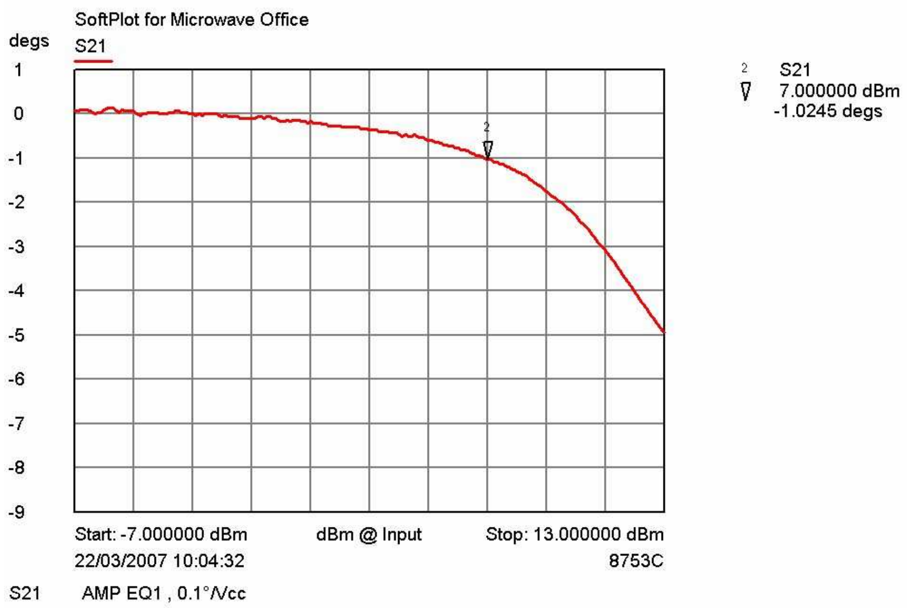

Fig.13. AM to PM conversion of PA “AMPEQ1”

The graphics show a very similar behavior. In order to find an indicative quantity to evaluate the AM to PM conversion , the **Δϕ/ΔP** should be calculated into a convenient range of power.
The following graphic (figure 14) show the derivative calculated from phase behavior of the yet cited PA "AMP1".

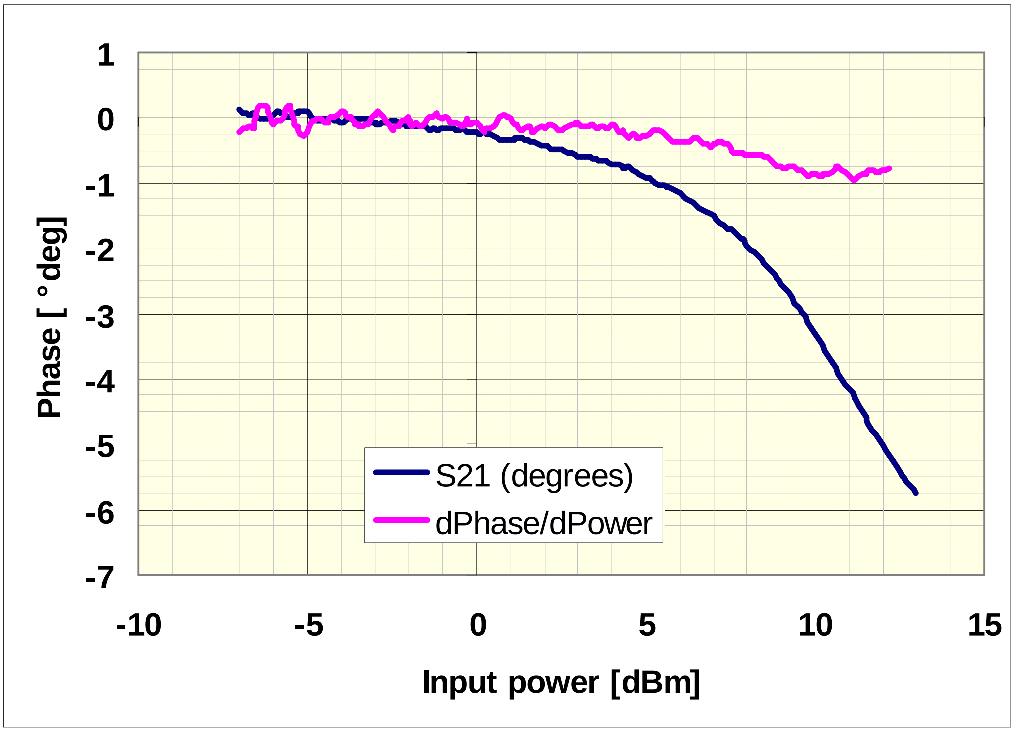

Fig.14. ΔΦ / Δ Power

As may be seen in the picture, the typical value of **ΔΦ / Δ Power = 0.2…0.4 [°/dBm]**.

6. PM due to Bias variations

During the measurement of the PA's, has been found others sources and causes of PM different from AM to PM classical conversion.
More specifically, the supply voltage has been changed around the nominal value and the phase variations has been recorded.

All 4 tested PA showed a phase variation due to bias condition of **0.1…0.2 [°/V].** Since 1mV is an usual residual supply ripple, a phase jitters due to bias supply is near 0.0001 [°].

7. PM due to Temperature effect

Past experience has shown a typical behaviour of Gain vs Temperature of a GaAs Amplifier close to –0.005 [dB/°C] every 10 dB Gain stage.
For a PA driven close to non linear region, this variation will produce a variation of the phase that follows the same law described on paragraph 5.
As an example, into a 10 dB PA providing +15 dBm at the output, a 10°C of temperature variation will increase the gain of 0.05 [dB] and looking at figure 14, the consequently phase variation will be 0.01[°].

8. PM due to adjacent branches variations (simulated)

If one (or more) adjacent LO lines and PA change their own input reflection coefficient due to finite isolation between branches, a phase variation may be observed on the PA under test.
This phenomena may be simulated. The worst case occur for the closest branches (where the isolation is the smaller) and for angles 90° far.

The simulated phase change is:

$$\textbf{Phase Change} = \arctan\left(10^{(RL+ISO)/20}\right)$$

Where:
RL = Return Loss of adjacent RF path
ISO = Isolation of the two RF path.

As example, for two closest path on Christmas tree, 20 dB isolated, feeding two PA with Input Return Loss of 10 dB, if the adjacent branch change its phase or delay, into the observed branch the phase will change of 1.8°. While a completely failure of the same adjacent PA (RL = 0 dB) will produce a phase error of 5.7 [°].

9. Conclusions

The Phase Noise of some Power Amplifiers (to be used in LO branches) has been measured.
The Phase Noise has been measured both in terms of spectral density and integrated over frequency.
The Phase Noise has been measured for different chains including the effect of the strongly attenuating “Christmas tree”.
Also, the correlation of phase changes (jitters) has been observed versus Temperature, Bias Voltage and RF power level (also in non linear region).

The following table summarises the possible causes and the effect observed.

Phase Noise Causes and typical values	
Integral of Spectral Phase Noise Density	**0.03 [°]**
AM to PM (typical value)	**0.3 [°/dB]**
Jitters due to Bias Supply (1 mV]	**0.0001 [°]**
Jitters due to Temperature Variation (10°C)	**0.01 [°]**
Phase Error due to a strong changes into the adjacent RF path	**2 [°]**

For a moderate gain Amplifiers like the models tested and subject of this report, their Added Phase Noise, Jitters and Phase Error (due to both exogenous and endogenous causes) are very small and typically one or more order of magnitude less than other elements of the radio receiver chain.

10.References

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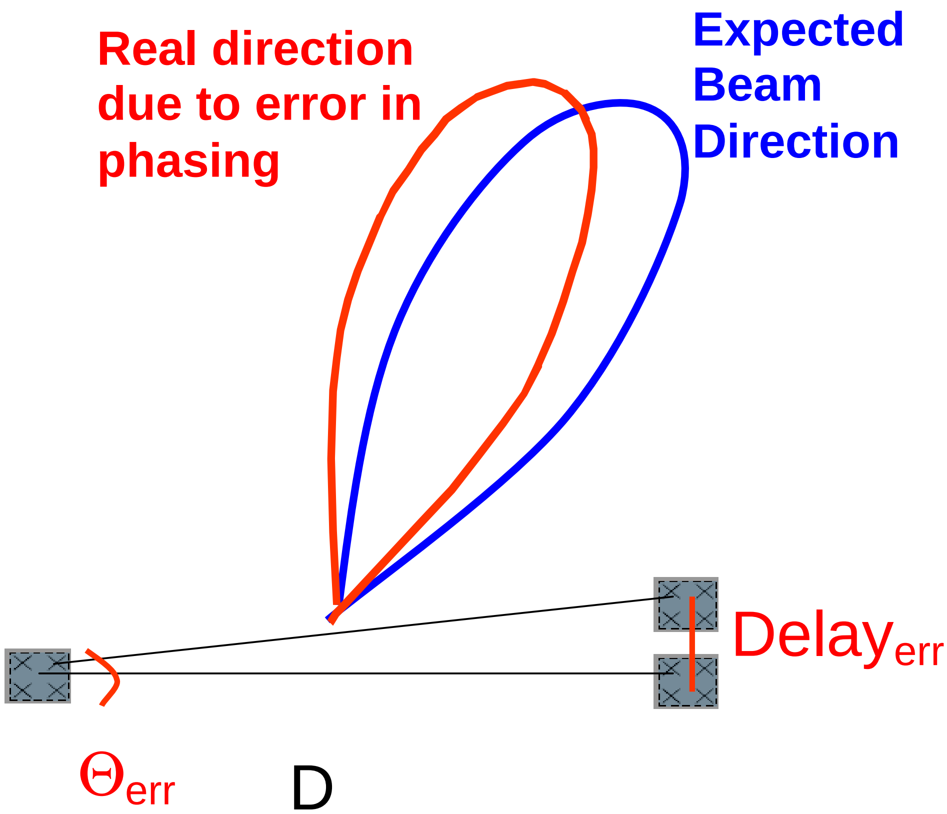
Appendix: Considerations about the permitted phase error

The purpose of this chapter is to give some considerations about how much the phase error and jitters reflects on the confusion level of a telescope.

It's well known, for an interferometer, that the position of the pointing beam depend on the phase relationship of the Local Oscillators. If the Phase difference of two or more local oscillators change, consequently the beam will move on the sky.

Also it's well known that both changing in phase difference and/or delay will produce a movement of the pointing beam.

As we may see in next picture, an error in sky beam direction may be generated by a sort of "rotation" of one end of interferometer around a "shaft" placed to the other end.



Knowing the pointing beam error, by simply trigonometric we may calculate the Delay error:

$$\mathbf{Delay_{err} = D \cdot \tan \Theta_{err}}$$

The Delay error may be really and physically generated by changing the length of one (or more) RF cables, but also a phase changing into one (or more) RF path may generate the same effect. Electrical length and phase are linked by the following relationship:

$$\mathbf{\Phi_{err} = (360 \cdot Delay_{err}) / \lambda}$$

As example, let try to define the maximum acceptable phase jitters starting from considerations related to beam error.

Let the maximum error (jitters) 1/10 of the Beamwidth
Let the Operating Frequency = 1600 [MHz]
Let Interferometer Lenght (D) = 1000 [m].

Solution:

λ	=	3E8 / 1.6E9	=	0.1875 [m]
Beamwidth	=	57 0.1875 / 1000	=	0.0107 [°]
Accepted beam jitters	=	0.0107 / 10	=	0.00107 [°]
$Delay_{err}$	=	1000 tan 0.00107	=	0.0187 [m]
Max jitters	=	360 0.0187 / 0.1875	=	36 [°]