Local Oscillator Distribution Board

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1 ARCHITECTURE

1.1 Specifications

The LO Distribution board has to perform the following operation :
Receive 1 sine wave signal of 0 dBm at 6.25 MHz and output 8 sine wave signals of 0 dBm at 6.25 MHz with a voltage controlled phase shifting from 0° to 180°. Moreover the output amplitude signals have to be stable even if the input amplitude varies. Then the LO board should have a phase noise sufficiently low so that it does not bring back any noise at the output of the demodulation board.

1.2 Schematic

1.2.1 principle

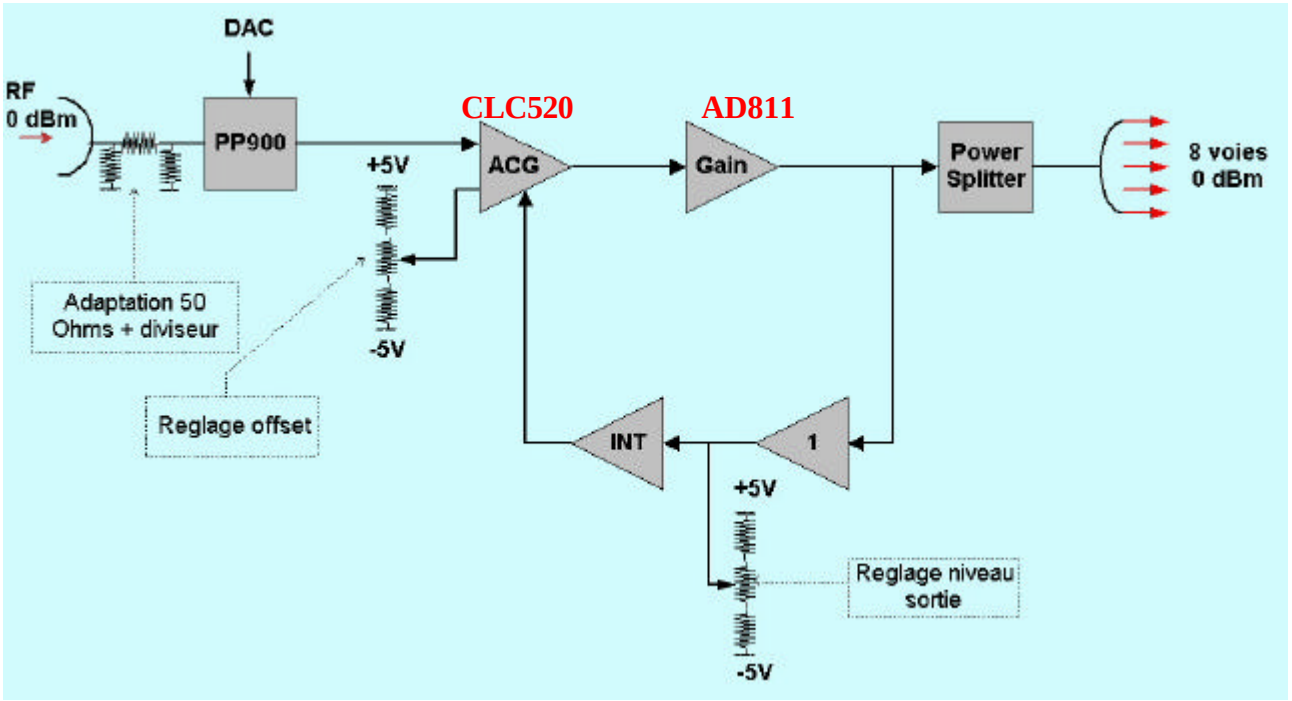


Figure 1 : Electronic principle for the LO board

This system consists of an automatic control of the output signal level using a voltage controlled gain amplifier.
The system gets a 0 dBm signal at 6.27 MHz, and is 50 Ω input adapted with a π resistor bridge. This resistor bridge is used to make a divider in order to attenuate the signal at –11 dBm because of the maximum power input of the PP900 phase shifter (-10 dBm). This phase shifter is controlled by a DAC which is low pass filtered to be less sensitive to high frequency phase noise.
The output signal of the PP900 needs to be raised. To perform this operation a voltage controlled amplifier (CLC520 from National Semiconductor) is used with a feedback integrator.
The principle is:
If the Output Voltage is too low, the slope of the feedback integrator is positive.

If the Output Voltage is too high the slope of the feedback integrator is negative.
In the direct chain an AD811 (Analog Devices) amplifier with a Gain roughly 3V/V is used to relieve the CLC520 by working in its range. The AD811 is a current feedback amplifier, so it has a high slew rate and a large bandwidth frequency.
The CLC520 has an offset adjustment, and the level of the output is controlled by the integrator feedback. In order to have a more stable system(free from power supply disturbances), the voltage reference to regulate the offset and the output level is made by two voltage reference of +/-5V (LM2990 and LM2940).
To distribute 8 outputs a power splitter (PSC-Q8 Mini-circuits) is used, the loss of the split is compensated with the loop feed-forward.

1.2.2 Electronic schematic

See the attached file named Lo_Schem.pdf on the same directory of this note on :
http://wwwlapp.in2p3.fr
Follow this instruction : click on "Groupes de physique" → "Virgo" → "Hardware list" → "Distribution_Lo".

1.3 Phase shifter characteristics : PP900

In order to control the phase shifting by an analogical signal generated by a DAC, we use a specific component that is called PP900. This component is from Synergy Microwave Corporation and is the unique phase shifter that works at 6.25 MHz.

Input Frequency	Input Power Max	Insertion Loss Typ	Phase shift range	Control voltage	Control bandwidth
5.7 – 6.3 MHz	-10 dBm	1.2 dB	0 to 180 degrees	0 to +30 VDC	DC – 50 kHz

Figure 2 shows the phase sensitivity of the PP900 for an input signal of –11 dBm at 6.25 MHz with a Voltage control from 0 to 30 V.
Figure 3 shows a zoom of the phase sensitivity of the PP900 for an input signal of –11 dBm at 6.25 MHz with a Voltage control from 0 to 4 V.

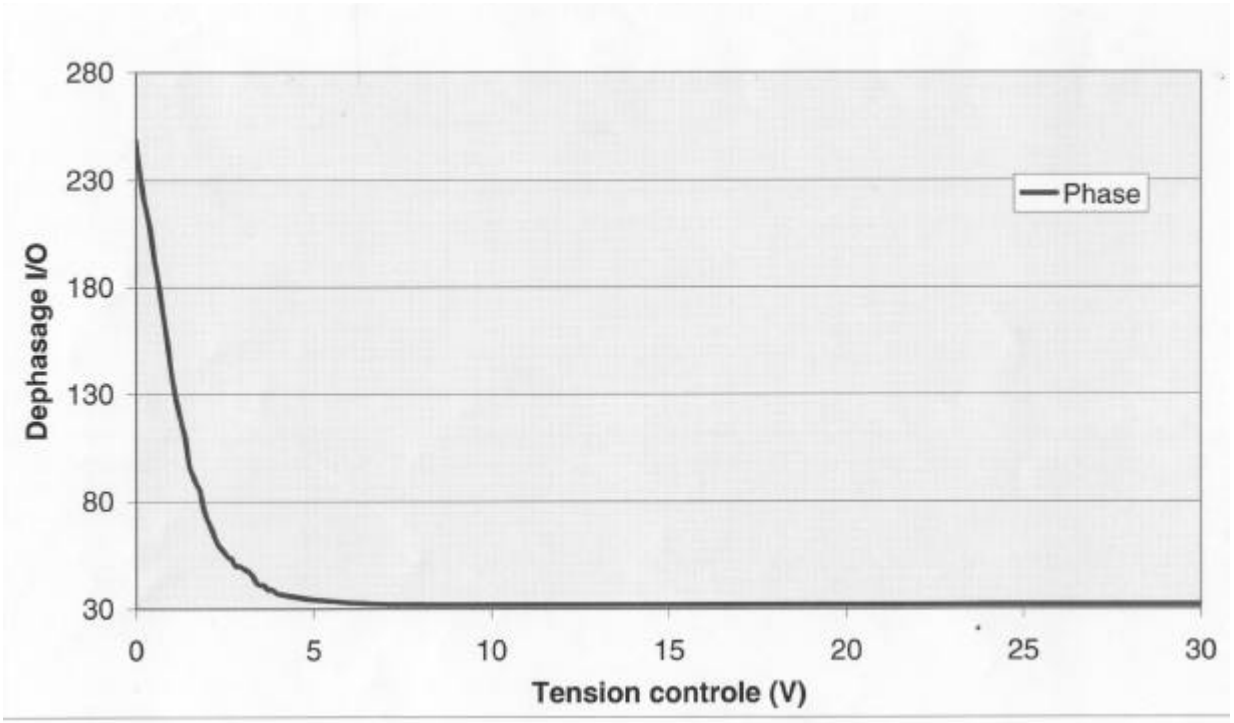


figure 2 : PP900 phase sensitivity versus DAC voltage control

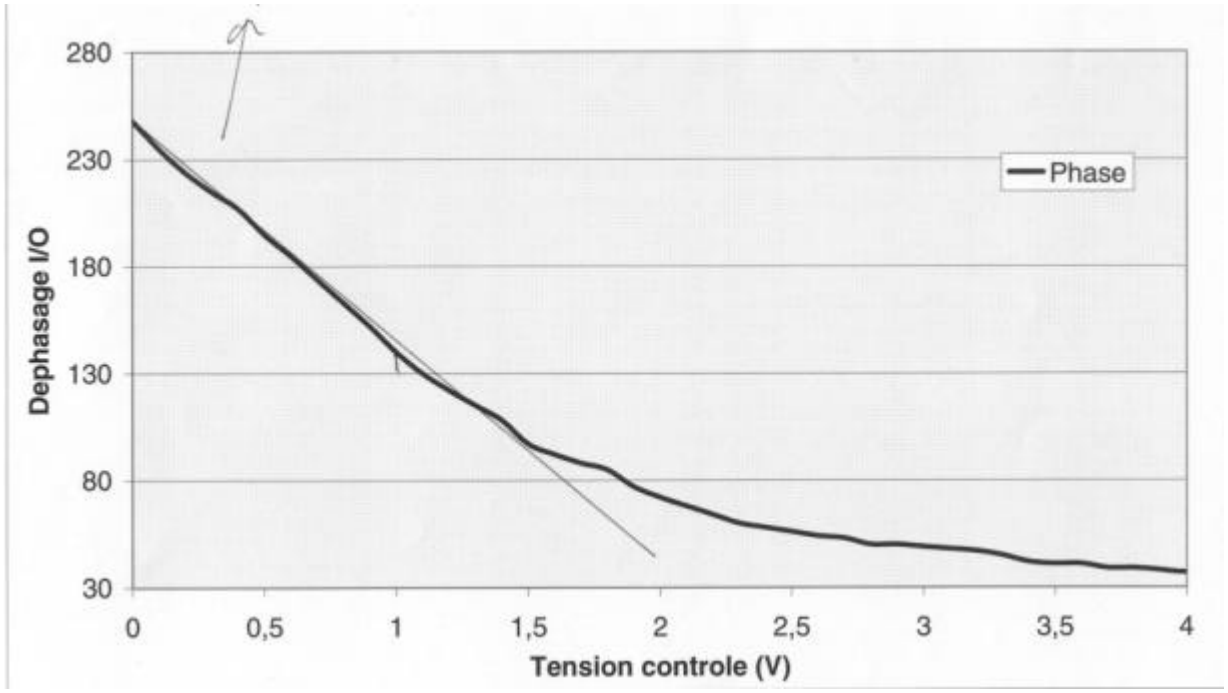


figure 3 : PP900 phase sensitivity versus DAC voltage control

As man can see, the phase sensitivity increases when the voltage control approaches the zero area. The LO board includes a divider bridge by 2 which divides the DAC voltage in order to have a better accuracy and so that the 180° fits with the 10 VDC of the DAC.

2 TESTS

2.1 Measurements characteristics of the LO board

The characteristics of the LO board is given by the following measurements :
The phase range is the phase shifting characteristic with a DAC voltage range (180° range specification).
The harmonic represents the linearity of the system.
The noise is the lonely board amplitude noise.
The amplitude variation is the amplitude jitter on 1 hour.

- Phase range (from 0 to 6V DAC) : from -63° to –270°.
- Harmonic @12.5 MHz : -34 dBm.
- Noise : 1.95 µV/√Hz
- The maximum Amplitude jitter observed on 1 hour (Min, Max) : Δ = 0.05 dBm = 3.6 mV.
- No amplitude shifting.

2.2 Amplitude variation

2.2.1 Equipment used for test

- RF spectrum analyser HP4395A or equivalent
- 1 synthesised function generator Stanford Research Systems DS345 or equivalent
- 1 digital oscilloscope with 1 probe or DC voltmeter with 0.1 mV resolution

Note : All outputs must be terminated with a 50 Ω load.

2.2.2 Procedure

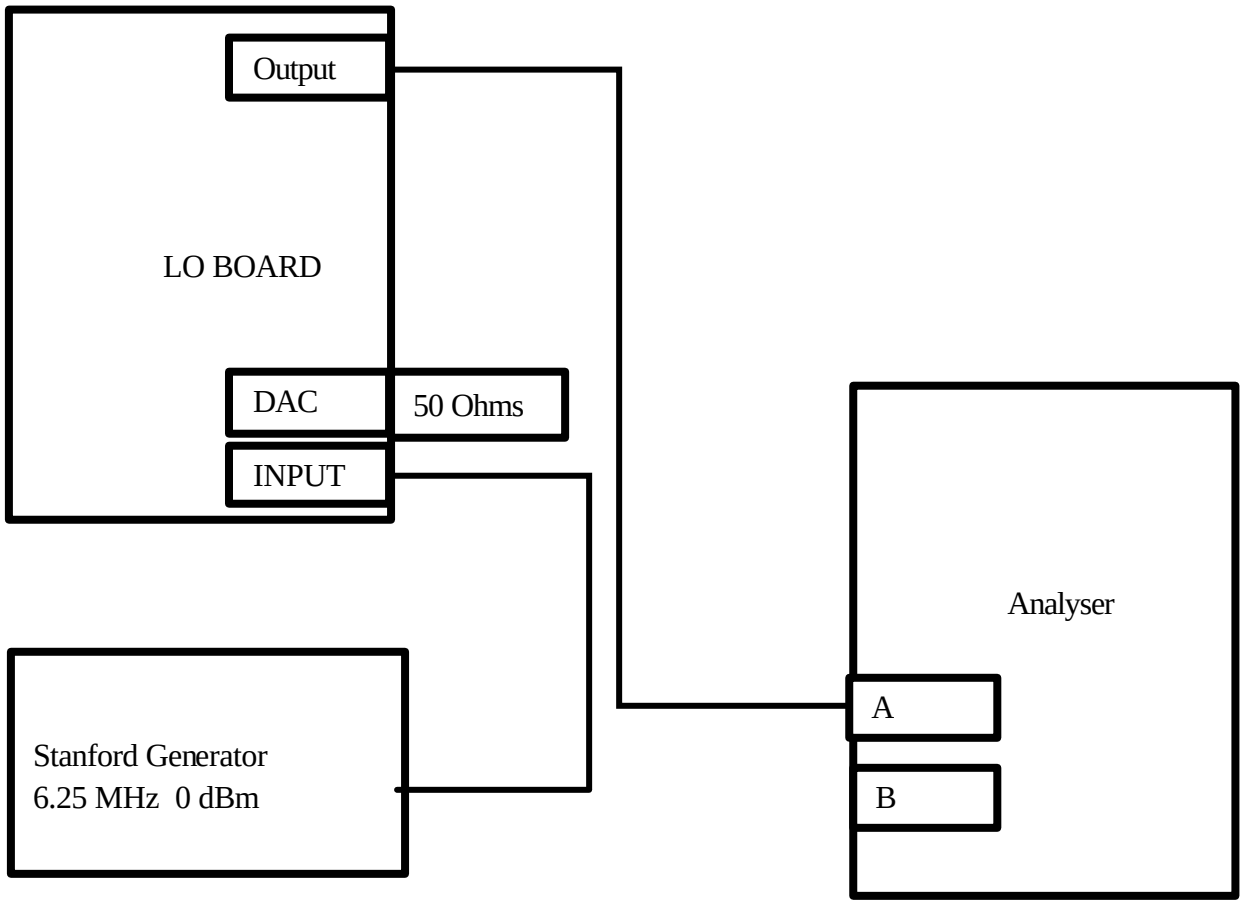


figure 4 : Assembly for the level variation measurement

This operation is performed twice on the two channels of the spectrum analyser, then use the data hold menu to take the minimum value on the first channel and the maximum value on the second channel. To be more accurate you have to realise this operation on several minutes and to protect the LO board is protected against environmental conditions by placing the board into a rack.

Results : the maximum Amplitude jitter observed on 1 hour is $\Delta = 0.05$ dBm = 3.6 mV.

2.3 Phase noise

The phase noise of the LO board represents the phase jitter that introduce the LO board onto the demodulation board output. This phase noise decreases the signal to noise ratio that we have fixed for the demodulation board. So the LO board should have a phase noise sufficiently low that it does not bring back any noise at the output of the demodulation board.

2.3.1 Measurement with demodulation board

2.3.1.1 Equipment used for test

- RF spectrum analyser HP35665A or equivalent
- 1 synthesised function generator Stanford Research Systems DS345 or equivalent

- 1 digital oscilloscope or DC voltmeter with 0.1 mV resolution

Note : All LO board outputs must be terminated with a 50 Ω load.

2.3.1.2 Principle

The RF input of the demodulation board is connected to the sine wave generator at a pulsation of 6.25 MHz and the LO input at the same generator through the LO board (see figure 5 below).

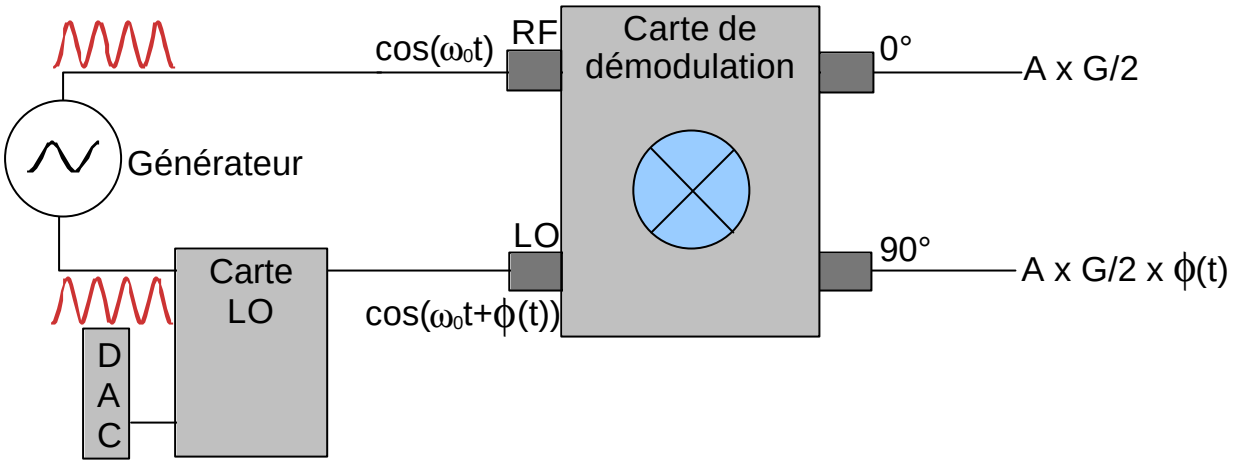


Figure 5 : Layout for LO board phase noise measurement

ω_0 is the pulsation (6.25 MHz).
$\phi(t)$ is the phase variations of the LO board (radians).
A multiplier factor (Input signal amplitude).
G demodulation board gain.

On the phase output (0° channel) the signal can be written:

$A.G.\cos(\omega_0 t) \times \cos(\omega_0 t+\phi(t))=(A.G/2)\,[\cos(\phi(t))+ \cos(2\,\omega_0 t+\phi(t))]$

On the quadrature output (90° channel) can be written:

$A.G.\cos(\omega_0 t) \times \sin(\omega_0 t+\phi(t))=(A.G/2)\,[\sin(\phi(t))- \cos(2\,\omega_0 t+\phi(t))]$

In this equations, the $2\omega_0 t+\phi(t)$ element at 12.5 MHz is filtered by the low frequency output amplifier of the demodulation board.
And if we consider that $\phi(t)$ is small and trend to 0, the equation above can be simplified like this :

On the 0° output : $(A.G/2)\cos(\phi(t)) \sim$ **(A.G/2)*1**
On the 90° output : $(A.G/2)\sin(\phi(t)) \sim$ **(A.G/2)*** f **(t)**

Then the Fourier transform of the quadrature gives the phase noise spectrum of the LO board $\Phi(f)=TF[\phi(t)]$.
The specification was that the phase noise $\phi(t)$ is lower than the noise of the demodulation board b(t) i.e. the LO board does not pollute the signal :

$$\frac{A.G}{2}.\phi(t) < b(t)$$

$$\phi(t) < \frac{2.b(t)}{A.G}$$

with $\langle b(t) \rangle \sim 10^{-6} V/\sqrt{Hz}$

To realise this measurements, the following precautions have been taken :

- Check the 90° phase between the phase and the quadrature ways (+/- 0.1°).
- Adjust the delay between the RF and the LO input to maximise the DC output on the 0° output.
- Adjust the attenuation on the RF way to obtain the wanted DC output.
- Adjust more accurately within 0.1 mV the 90° output to approach the 0 V DC.

2.3.1.3 Procedure

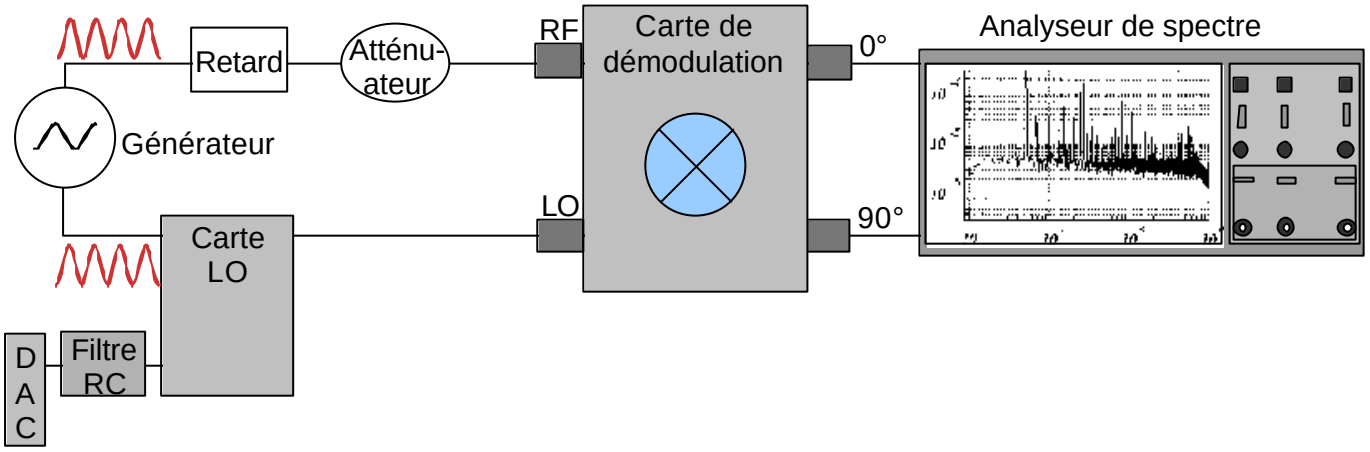


Figure 6 : Assembly for LO board phase noise measurements

This measurement has to be realised with and without the LO board to compare the noise level.

2.3.1.4 Results

The noise has been measured for several DC output values.

With 50 mV DC Output (Small signal)

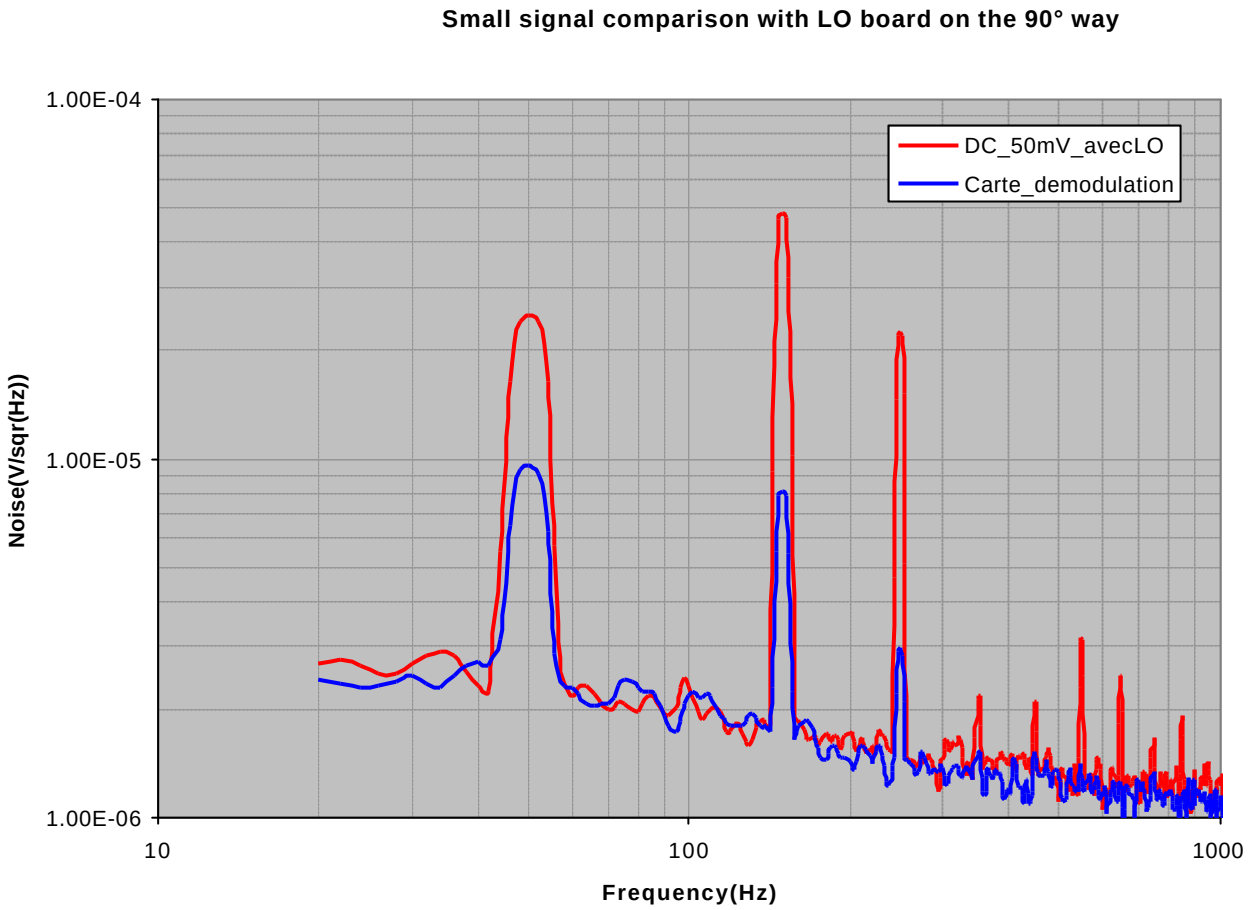


Figure 7 : Phase noise influence on the demodulation board

This gives us :

Demodulation board noise @128 Hz : 1.84 µV/√Hz
90° output 50 mV DC with LO board @128 Hz : 1.71 µV/√Hz

We observed that in the small signal case, we have no difference between the noise of the demodulation board and the noise on the 90° output with a small DC signal. It means that the LO board does not introduce consequent noise in this case.

With 500 mV DC Output

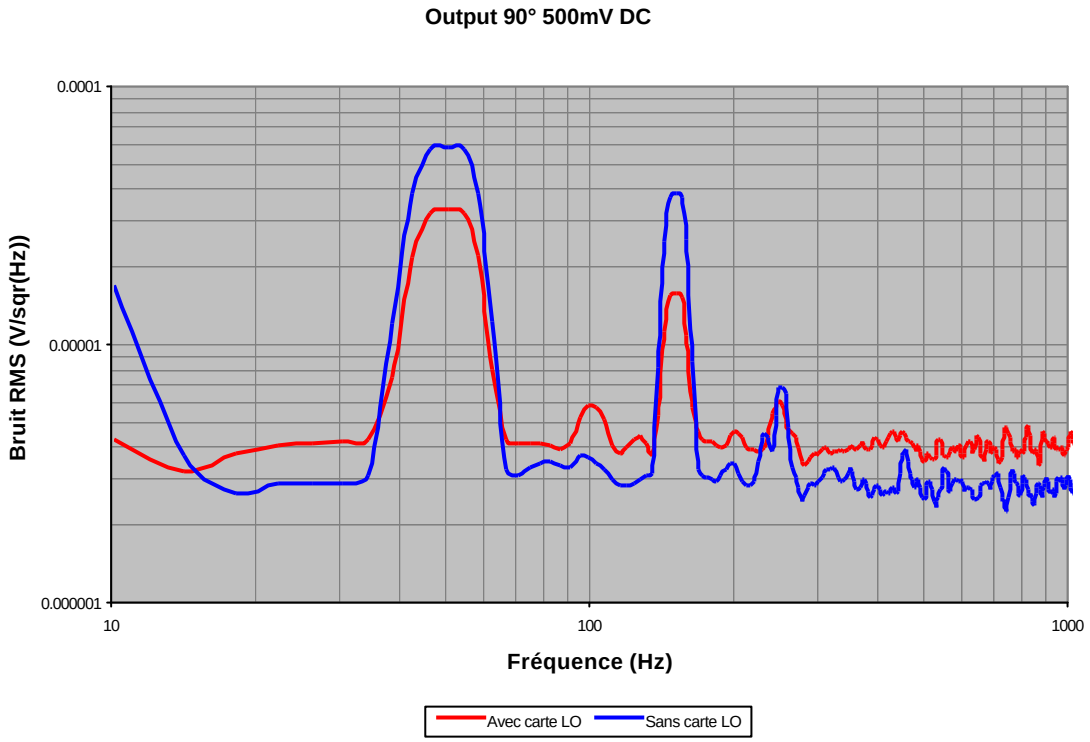


Figure 8 : Phase noise influence on the demodulation board with and without LO board

We observed that the difference between with and without the LO board in this case is significant. Because of the quadratic summations of noise, at 130 Hz, the total noise back is roughly 3 µV/√Hz.

2.3.2 Measurement with a TAK 3H mixer

To understand more precisely the origin of the phase noise, we simplify the signal demodulation by exchanging the demodulation board by the TAK 3H Mixer. This mixer is the one used inside the demodulation board.

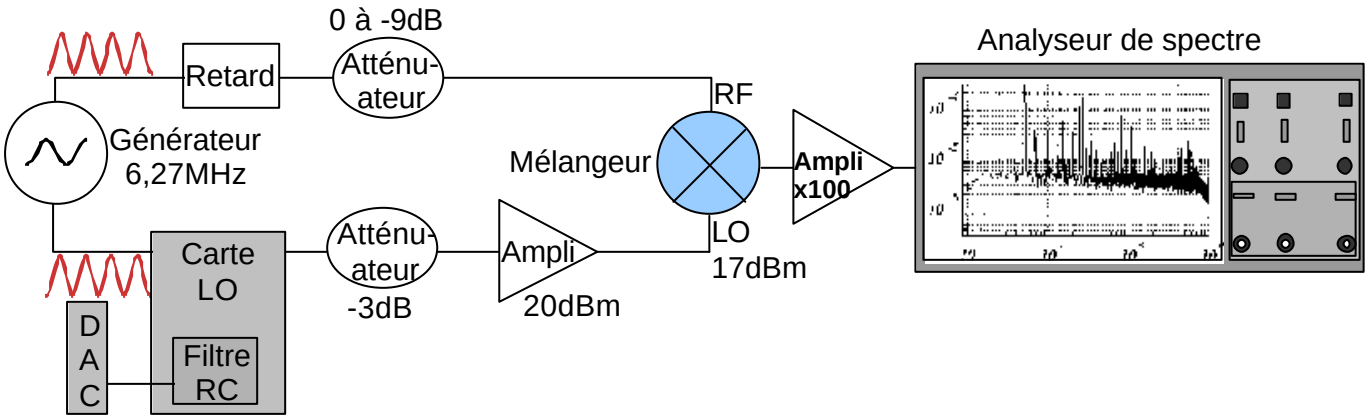


Figure 9 : Assembly for Phase noise measures with a mixer

The procedure used for the test is the same as before. The level of the RF and LO signals are adjusted so that they lie in the mixer working range. The work range of the mixer is to 17 dBm in LO input and a maximum of 14 dBm on the RF input.

On the demodulation board the mixer is followed by an amplifier of gain 12.5, therefore, in order to be in the same conditions as before the output DC signal has to be 12.5 times smaller.

e.g.: 500 mV DC output on the demodulation board represents 500/12.5 = 40 mV DC on the IF output of the mixer.

As before, the RF and the LO inputs on the mixer have to be synchronised to get the maximum DC voltage on the IF output. In order to find the associated 90° output we use the delay line box and shift the phase approximately of 39 ns which correspond to the 90° phase shifting at 6.27 MHz.

Figure 10 shows the measurement for 40 mV DC (equivalent to the 500 mV case with the demodulation board).

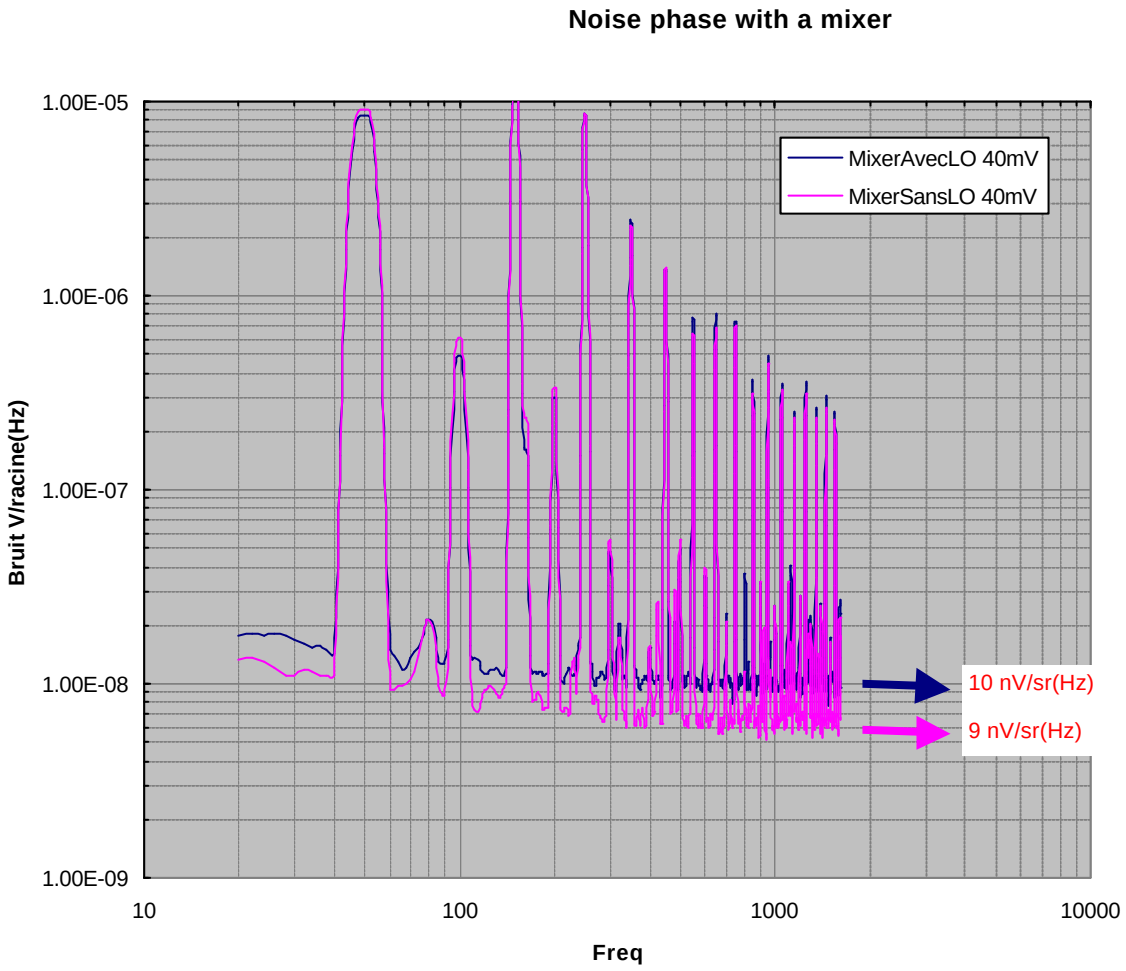


Figure 10 : Phase noise measures with a mixer with and without LO board

Summary table of the average noise with and without the LO board on the 90° output :

Tests conditions	Without LO board at 130Hz	With LO board at 130Hz
Mixer DC Level : 40mV	$9nV/\sqrt{Hz}$ *35*12.5=3.9 $\mu V/\sqrt{Hz}$	$10nV/\sqrt{Hz}$ *35*12.5=4.4 $\mu V/\sqrt{Hz}$.
Demodulation board DC Level : 500mV	3,5 $\mu V/\sqrt{Hz}$	4,5 $\mu V/\sqrt{Hz}$

On the demodulation board, after the output of the mixer, there is a compression filter with a 35 gain at frequencies >12 Hz and amplifier of 12.5 gain.
In consequence, we find a total gain of 35*12.5 after the IF output. The noise measured with the mixer alone is corrected by this factor in order to be compared to the demodulation board case.
For the mixer at 40 mV, we found 10 nV/√Hz, the equivalent for the demodulation board is 35*12.5*10e-9 = 4.37 µV/√Hz. This value is near the precedent test with the demodulation board (4.5 µV/√Hz) with LO board

We find the same result witout LO board :
9 nV/√Hz*35*12.5 = 3.93 µV/√Hz closed to 3.5 µV/√Hz

This shows that the noise is not introduced by the demodulation board and is coming from the Lo board. Further tests will be performed in order to identify which element on the Lo board is responsible for this noise.
Our investigation leads us to suspect the PP900, and show that the LO board inject more noise than has been envisaged.

2.3.3 Noise measurements on the 15 LO boards (see Assembly on figure 6)

We measured the phase noise on 2 DC output level with and without DAC voltage on the phase shifter, the table below summarises the results :

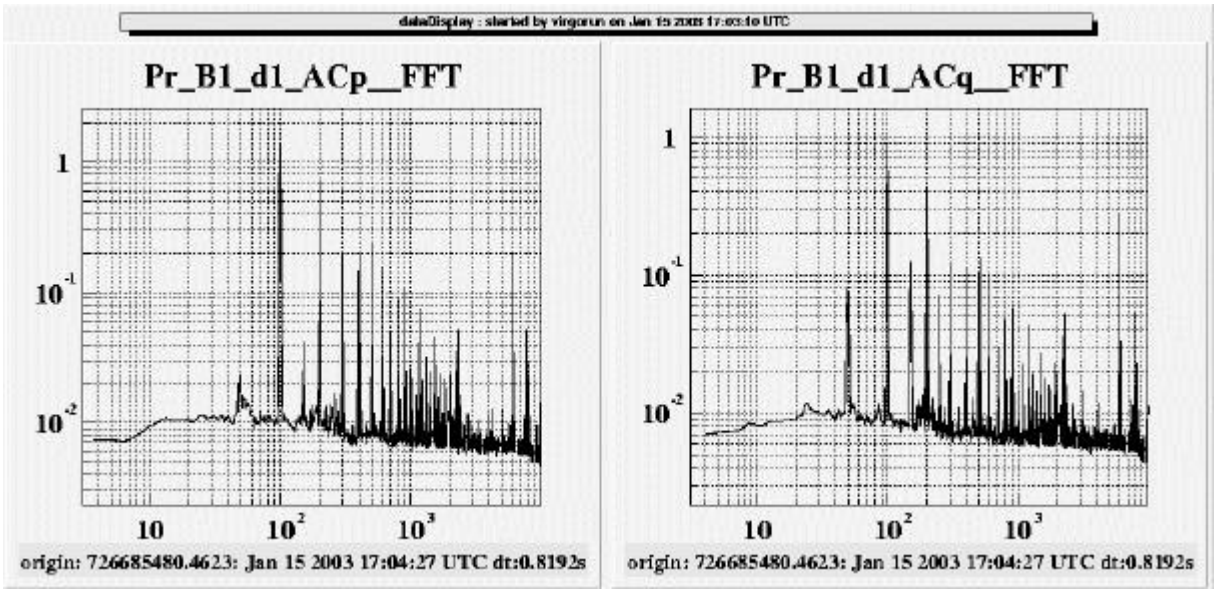
LO Number	DC = 500mV			DC = 5V
	DAC = 0V (µV/√Hz)	**DAC = 2V** (µV/√Hz)	**DAC = 8V** µV/√Hz	**DAC = 0V** (µV/√Hz)
1	4,5	4,35	4,5	80
2	4,7	4,4	4,6	90
3	4,7			87
4	4,7	4,5		88
5	4,5			90
6	Lapp	Lapp	Lapp	Lapp
7	4,7			90
8	4,5			90
9	Lapp	Lapp	Lapp	Lapp
10	4,5			85
11	4,5			
12	4,7			90
13	4,5			95
14	4,6			90
15	4,6			90

Every board have the same behaviour with and without DAC voltage. We notice that more we inject RF signal more the noise growth. The noise reference without the Lo board is 3.5 $\mu V/\sqrt{Hz}$ for a voltage DC of 500 mV.

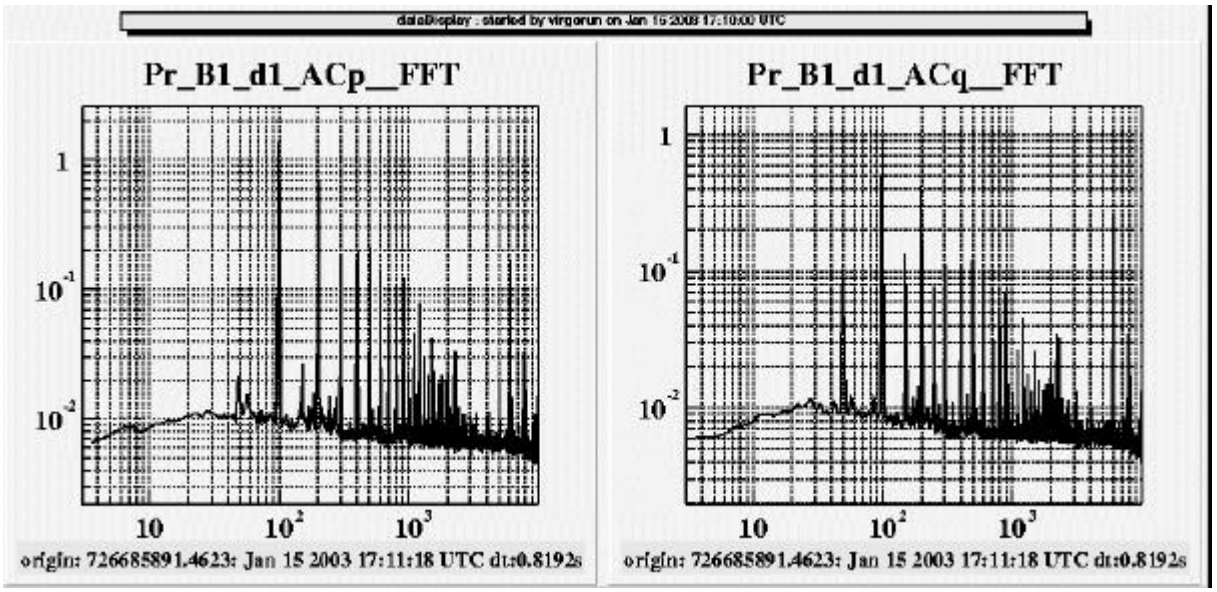
2.3.4 ADC Measurements of noise on the total chain without RF signal, influence of DAC Voltage

Some measurements have been done on site, with the ADC, in order to see the influence of the DAC voltage on the total chain without RF signal.

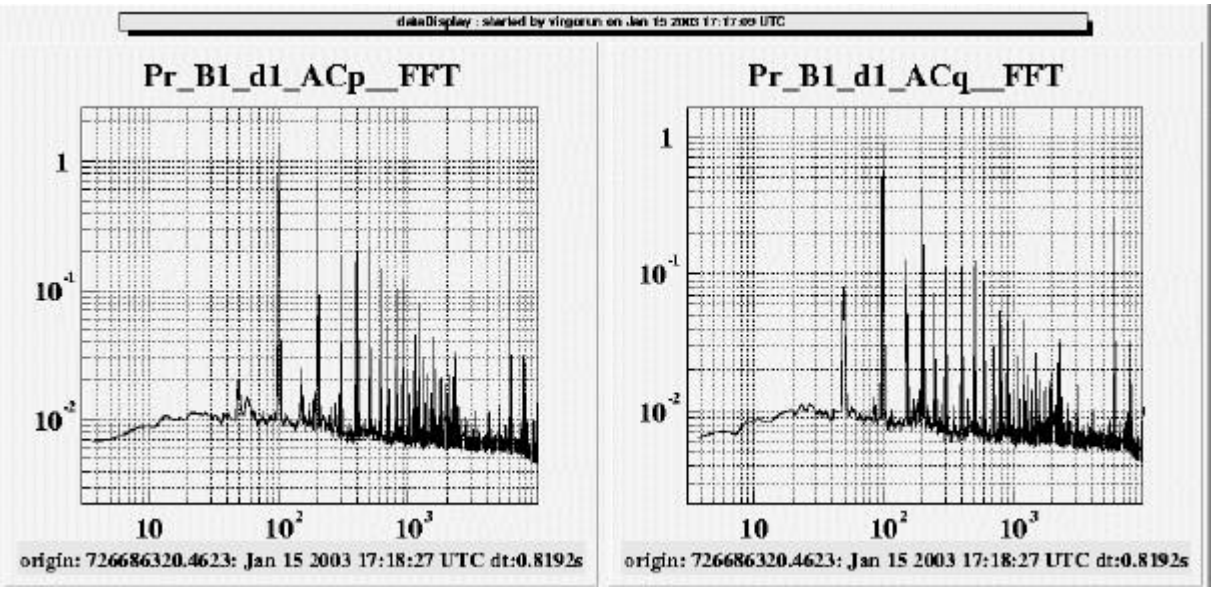
DAC 0V



DAC 2V (roughly 110°)



DAC 8V (180°)



Conclusion :We find the demodulation board noise.

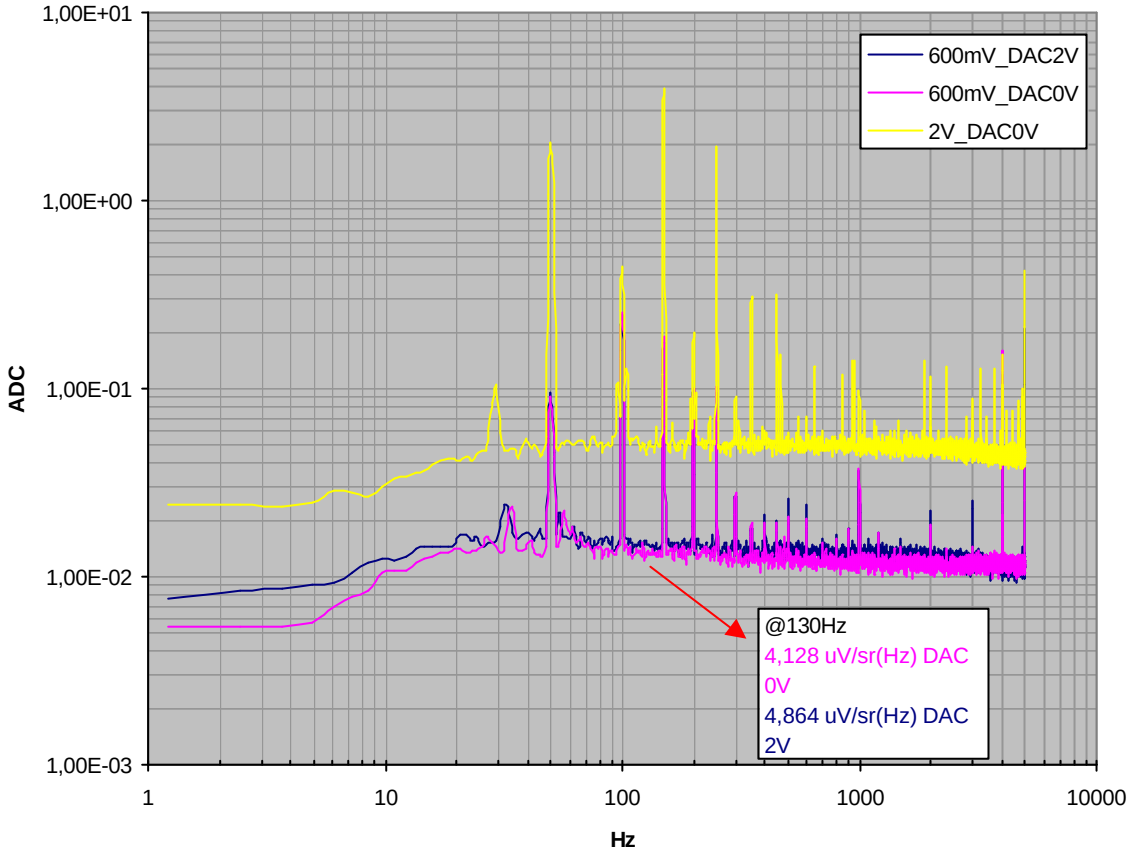
Conclusion :

Without RF signal, the DAC voltage on LO board does not bring any noise on the total chain.

2.3.5 Noise measurements of the total chain on several output DC voltage

This operation is the same as 2.3.1 with the total chain.
One uses LO board for the LO input and for RF input, one optimises phase shifting between the RF and the LO to get the maximum of DC output on the 0° way and the minimum of DC on the 90° way.

RF = -12 dBm → 600 mV DC
RF = 0 dBm → 2V DC



Other measures on board D1-11 :

@130Hz Avec DAC 0V → 4.29 µV/sqr(Hz)
@130Hz Avec DAC 2V → 3.69 µV/sqr(Hz)

2.3.6 Conclusion :

The DAC voltage influences very little the noise of the chain and we check that the noise level increases with the RF amplitude.

2.4 Tests with a low pass filter on the output of the lo board

We measured the level of the different harmonics on the output of the Lo board at –40 dBm. However, we noticed that more the amplitude of the harmonic growth more the phase noise on the output of the demodulation board growth. So we decided to apply a low pass filter with a high slope attenuation.

2.4.1 Filter

To do this test, we used a Tchebychev synthesis for a 6 order passive filter with a cutoff frequency of 7 MHz.

The chosen filter is the following :

It is 50 Ohms adapted on input and output.

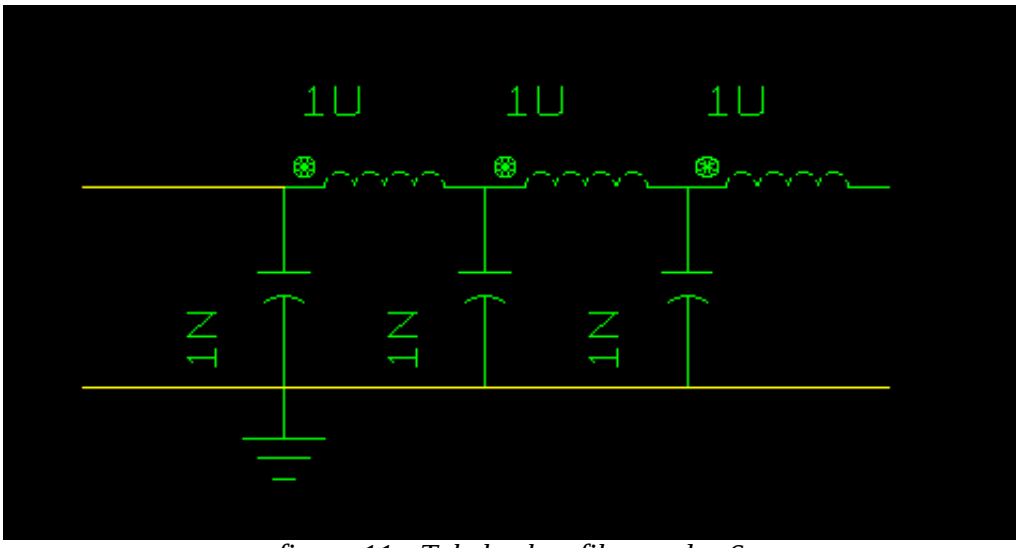
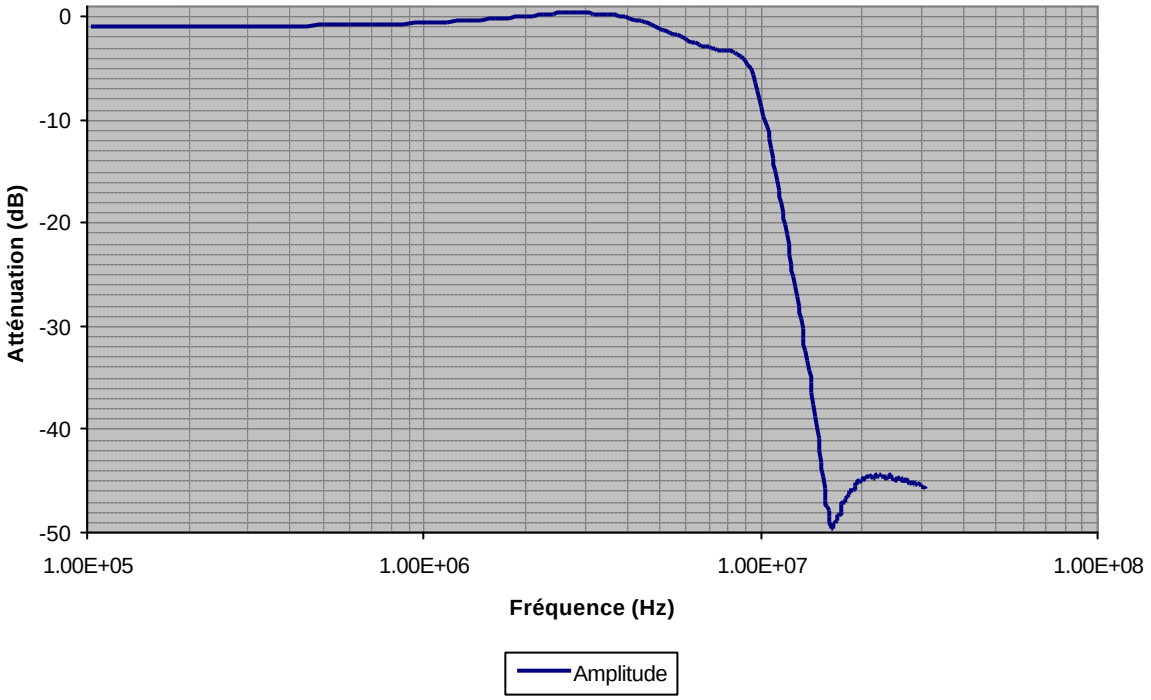


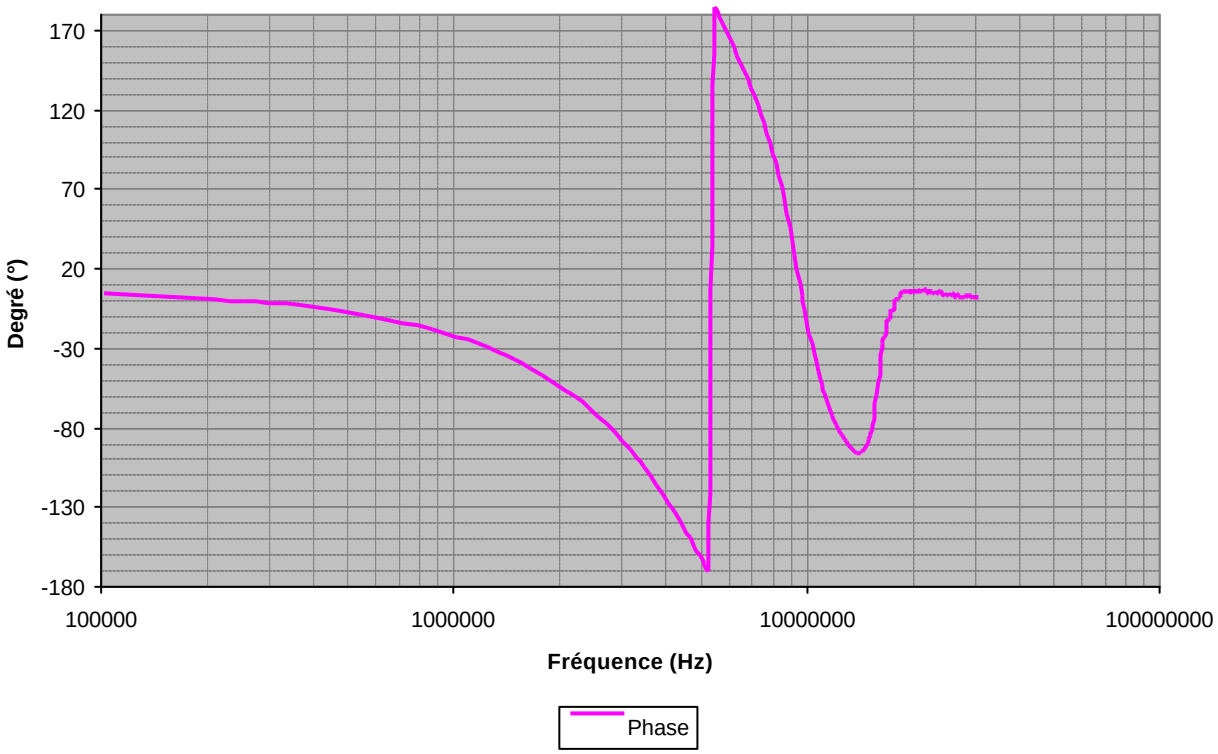
figure 11 : Tchebychev filter order 6

The Bode diagram is the following :

Filtre ordre 6 Fc = 7 MHz Amplitude



Filtre ordre 6 Fc = 7 MHz Phase



We notice that the attenuation at 6.25 MHz is 2 dB and at 12.5 MHz roughly –30 dB. So we found the attenuation of an 6 order. We adapted the AD811 gain in output to release the CLC520 (i.e gain >= 3 V/V)

2.4.2 Results

With this filter, we observed that there isn't any residual 2Ω.
Figure 12 shows the difference with the new filter.

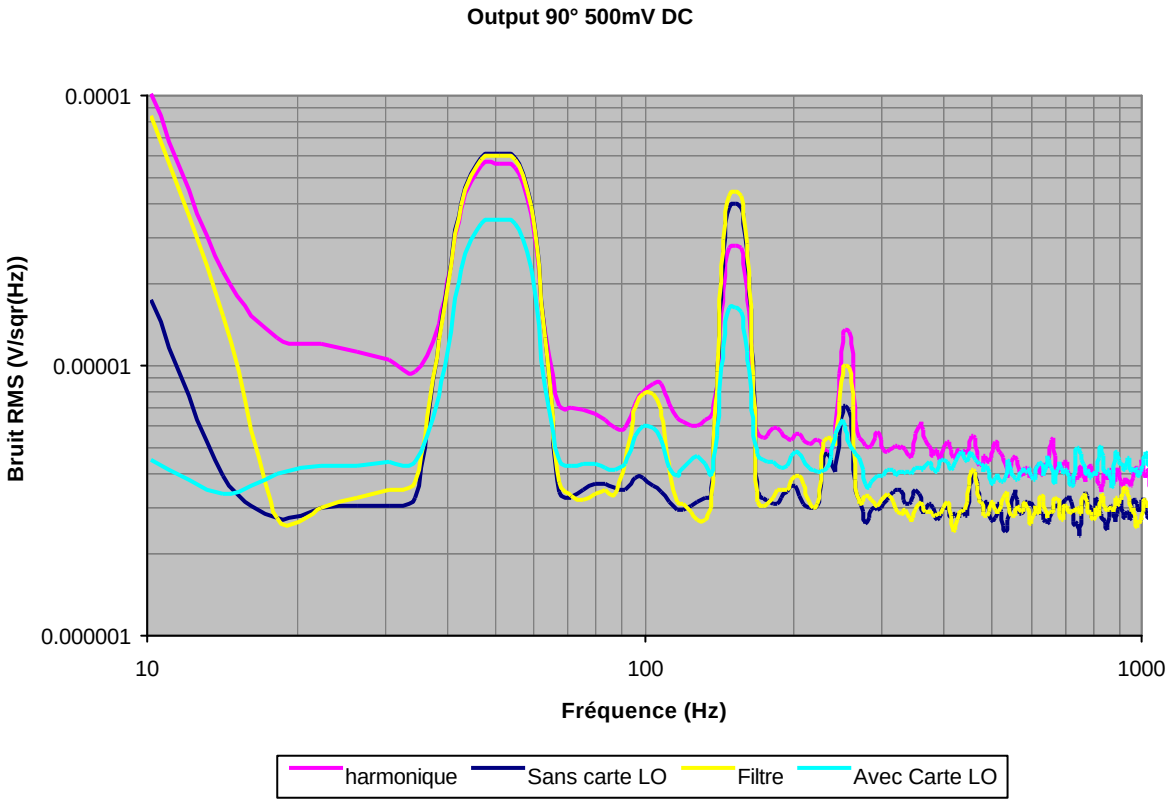


figure 12 : Comparatif des bruits de phase avec le filtre de Tchebychev

The pink curve « harmonique » corresponds to a lo board with just one amplifier (without the CLC520)
The dark blue curve « Sans carte LO » corresponds to our reference i.e. without Lo board.
The light blue curve « Avec Carte LO » corresponds to the precedent measure with the LO board.
The yellow curve corresponds to the lo board with the 6 order Tchebychev filter.

Conclusion : We eliminat the phase noise on the output of the demodulation board. We observed that the responsible of the phase noise is the linearity.

3 ADJUSTMENT PROCEDURE

3.1 Equipment necessary for test

- RF spectrum analyser HP4395A or equivalent
- 1 synthesised function generator Stanford Research Systems DS345 or equivalent
- 1 digital oscilloscope with 1 probe or DC voltmeter with 0.1 mV resolution

3.2 Adjustments

Note : All outputs must be terminated with a 50 Ω load.

3.2.1 DC Offset

- The generator is connected to the « IN LO » input : sine wave, 6,25 MHz, 0 dBm amplitude.
- The probe of the oscilloscope is connected to the «DC offset point » on the CLC520 integrated circuit.

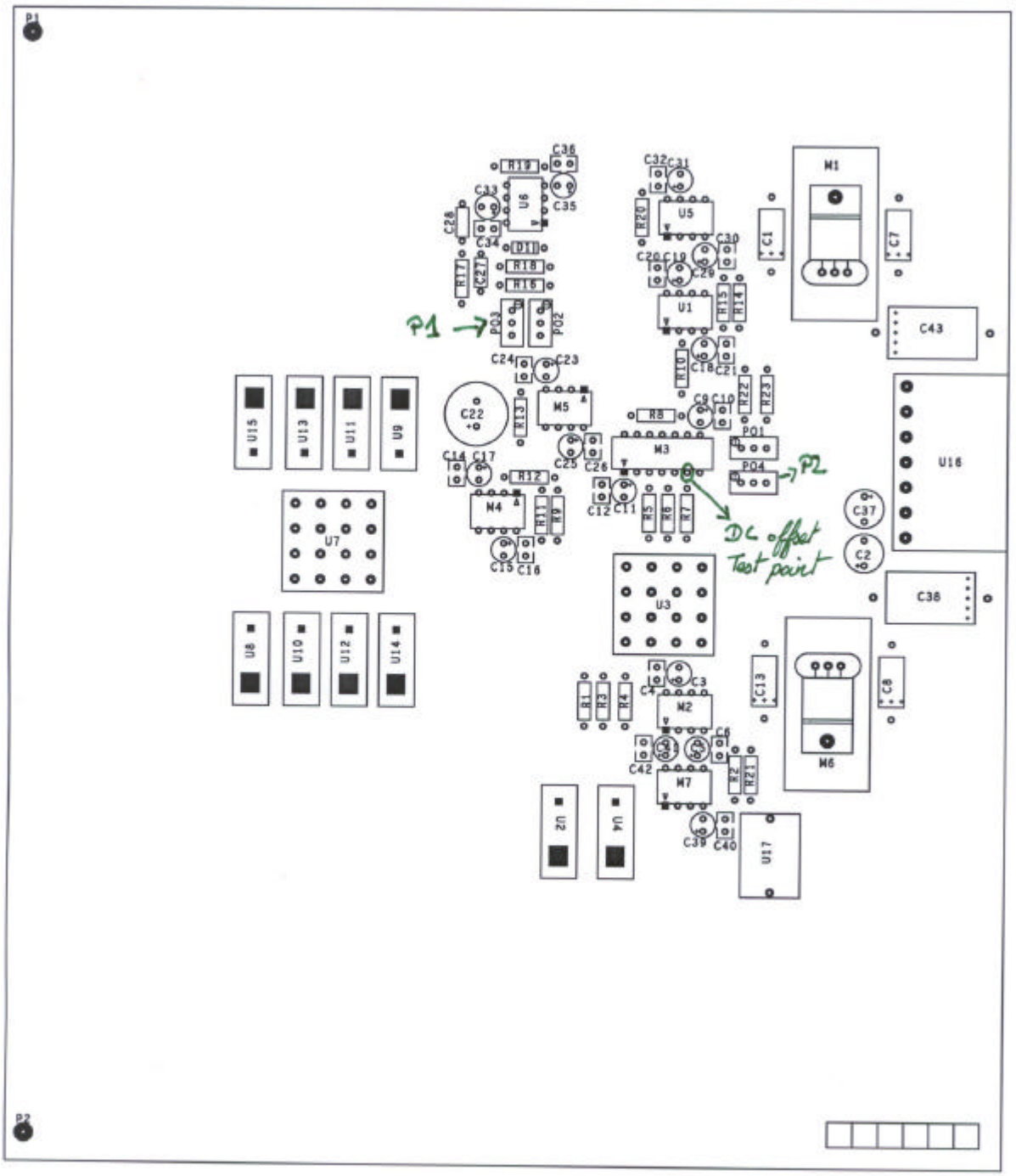
Adjust the potentiometer P2 to cancel the DC offset.

3.2.2 Output level

Connect one output to the spectrum analyser or the oscilloscope (50 Ω).

- Adjust the potentiometer P1 on the board to set the output level at 0 dBm (632 mVpp with the oscilloscope).
- Check the DC offset and re-adjust it if necessary.
- Return to the beginning if necessary.
- To tune your board accurately use the front potentiometer

See the implantation schematic of the board on next page.


P1
P2
P1
P2
DC offset
Test point
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
U11
U12
U13
U14
U15
U16
U17
M1
M2
M3
M4
M5
M6
M7
C43
C38

4 FABRICATION

4.1 Bill of material

package name	device type	component value & tolerance	comp class	refdes	totl
C50X32	CAPA-0.1U,CER50V10% 0.1u		DISCRETE	C4 C6 C10 C12 C14 C16 C20 C21 C24 C26 C30 C32 C34 C36 C40 C42	16
CHA100X50	CPOL-10U,CHA25V 10u		DISCRETE	C8 C13	2
CHA100X50	CPOL-1U,CHA63V 1u		DISCRETE	C1	1
CHA100X50	CPOL-2.2U,CHA63V 2.2u		DISCRETE	C7	1
CHA185X105	CPOL-220U,CHA25V 220u		DISCRETE	C38 C43	2
CHR130	CPOL-470U,CHR25V 470u		DISCRETE	C22	1
CHR50	CPOL-6.8U,CHR25V 6.8u		DISCRETE	C3 C5 C9 C11 C15 C17 C18 C19 C23 C25 C29 C31 C33 C35 C39 C41	16
CHR80	CPOL-100U,CHR25V 100u		DISCRETE	C2 C37	2

CONN7PTS	CONN7PTS	IC	U16	1
DIP14_3	CLC520-A	IC	M3	1
DIP2_3	CAPA-100N,CERDIP 100n	DISCRETE	C27	
			C28	2
DIP8_3	AD811	IC	U1	
			U6	2
DIP8_3	BUF634-BUF634P	IC	U5	1
DIP8_3	LT1028-DIP	IC	M4	1
DIP8_3	OP27-DIP	IC	M2	
			M5	
			M7	3
DO35	1N4148	DISCRETE	D1	1
MY_CAPA	10u non pol	IC	U17	1
PASCON183	PASCON-183	IO	P1	
			P2	2
POT45X95D	POT-2.2K,1/2W20T_D 2.2k	DISCRETE	PO1	
			PO2	
			PO3	
			PO4	4
PP900	PP900	IC	U3	1
PSC8_1	PSC8_1	IC	U7	1
R100	RGEN-100,M500MW1% 100	DISCRETE	R9	1
R100	RGEN-10K,M500MW1% 10k	DISCRETE	R13	
			R16	
			R17	
			R22	
			R23	5
R100	RGEN-10K,M500MW5% 10k	DISCRETE	R2	
			R21	2
R100	RGEN-178,M500MW1% 178	DISCRETE	R6	1
R100	RGEN-1K,M500MW1% 1k	DISCRETE	R8	
			R12	
			R18	3
R100	RGEN-2.74K,M500MW1% 2.74k	DISCRETE	R14	1
R100	RGEN-274,M500MW1% 274	DISCRETE	R15	1
R100	RGEN-5.11K,M500MW1% 5.11k	DISCRETE	R11	1
R100	RGEN-51.1,M500MW1% 51.1	DISCRETE	R5	
			R7	
			R10	
			R20	4

R100	RGEN-750,M500MW1% 750	DISCRETE	R19	1
R100	RGEN-78.7,M500MW1% 78.7	DISCRETE	R3	1
R100	RGEN-90.9,M500MW1% 90.9	DISCRETE	R1 R4	2
TO220H_DISS	LM2990T-5_HD	IC	M6	1
TO220H_DISS	LM2940-5_HD	IC	M1	1
total part count 97				

4.2 Implementation