# THE LOCK IN MODULATION IN ULTRA LOW FREQUENCY APPLICATION

This work want to show the validity of Lock In modulation in ULF (0.1-30Hz Ultra Low Frequency) reciver application. Transistor, vacuum tubes, resistor and other devices exhibit a low-frequency phenomenon know as flicker noise, often called $\frac{1}{f}$ noise because the mean square density is proportional to $\frac{1}{f^v}$ v≈1. Flicker noise pose serious problems for low-frequency application but Lock In modulation could be the answer.

Theory of Lock In Modulation and Demodulation
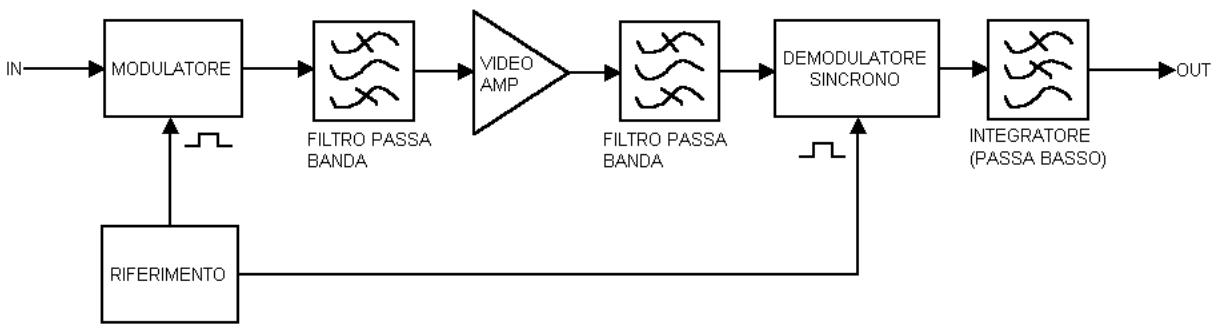
1 General scheme of Lock In ring

The synchronous mod/demod is also called Lock In modulation(Fig.1). It is a modulation on a different frequency from the original signal, to transfer out of $\frac{1}{f}$ noise (fig.2), where is prevailing the instrumental noise or pink noise. This frequency is knowing like f_{chop} and it must be upper knee frequency f_{knee} (Fig. 2), where we have the crossing from $\frac{1}{f}$ noise region to white Gaussian noise region.
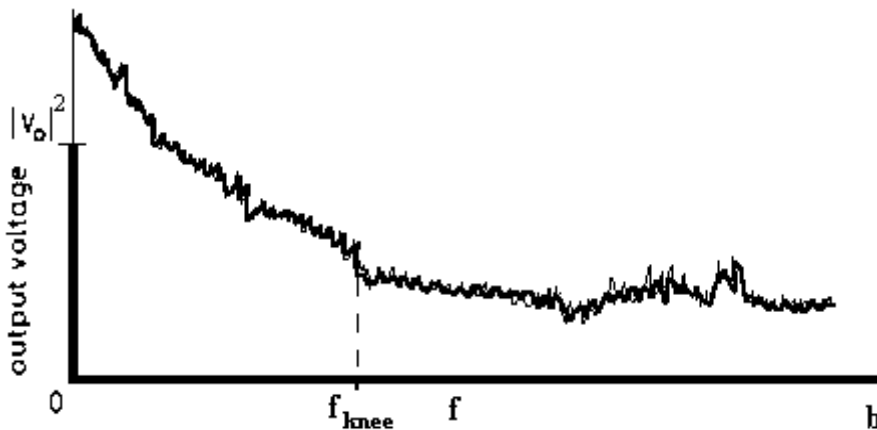
2   Knee frequency.

The Lock In modulation is also calling Chopping modulation, in fact it using Chopper amplifier. We know that traslate a signal in frequency is like to sample it, Lock In modulation is like a sampling at Fc frequency,we have for Nyquist theorem, that Fc must be twice of maximum frequency of the signal.

The action consist to select the interest signal, modulate ,enlarging, filtering with a pass-band filter and demodulated synchronous with the modulator.

The demodulated signal will be enlarging to obtain a signal noise ratio $\dfrac{S}{N} > 1$. We have the advantage that all the offset and the drift produces inside the Lock In are banishing here.

Now we can see the frequency answer of a Lock In system with a time variant signal:

$$\begin{cases} V_0 \cos\omega_1 t \ \ Signal \ \ In \\ A \cos\omega_0 t \ \ Syncronous \ \ Riference \end{cases}$$

Where ω_0 is chopping pulsation and ω_1 is the fondamental pulsation.

The demodulated signal is:

$$V_0 A \cos\omega_0 t \cos\omega_1 t = \frac{V_0 A}{2} \cos(\omega_0 - \omega_1)t + \frac{V_0 A}{2} \cos(\omega_0 + \omega_1)t$$

We have Dsb-Sc (Double Side Band Suppressed Carrier) spectrum, looks like an AM spectrum without the unmodulated carrier impulse, the information is in the double side band (Fig 3).
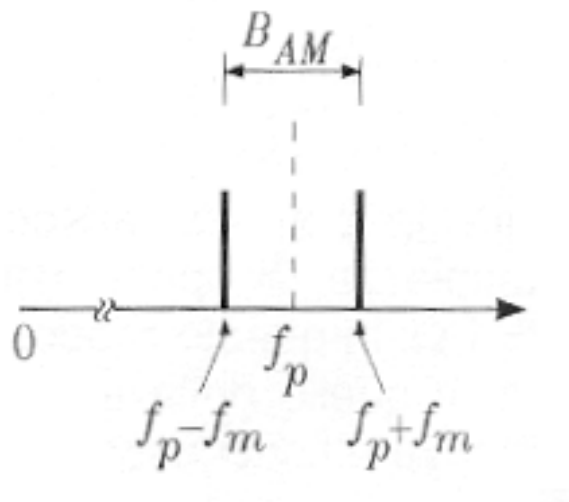

3 DSB-SC Spectrum

2.2   Asyncronism in Lock In Modulation.

The asyncronism in Lock in modulation/demodulation is one of the most recurs tecnical problem. In fact we must to give a very syncronous signal to Modulator and Demodulator. Often the cause of the asyncronism is the different propagation time from the syncronous signal generator and the modulator/demodulator devices .

The importance of a very syncronous reference is given from the fact that a phase difference ϕ from signal to demodulate and the syncronous reference will give an error on the continuos component; this error is extimated to be:

$$V_{out} = V_S \cdot \left[1 - \frac{\Phi}{90} \right] \qquad \text{with: } 0<\Phi<90$$

the wave form are in Fig. 4
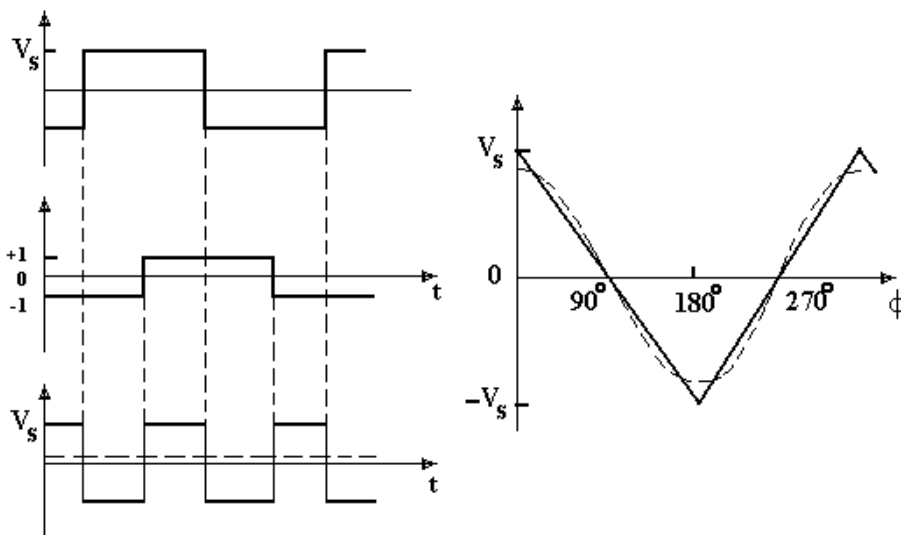
4Amplitude and phase with asyncronism

The demodulated signal, for the phase-displacement have a smaller amplitude. We can see that the amplitude is inversely proportional to the grow of phase differece. In particularly we have the signal annulment at 90° and his multiples, where the demodulated signal is not present. For the odd multiples of 180° we have an invertion of the sign
.

ANALOG DEVICE AD630 Balanced Modulator-Demodulator

We have choose for our examination the Analog Device AD630. It's a hight precision balanced modulator which combines a flexible commutating architeture with the accuracy and temperature stability. Its signal processing application include balanced modulation and demodulation , synchronous detection ,Lock in amplification and square wave multiplication. Its works like a precision Op amp with two indipendent differential input stage and a precision comparator which is used to select the active front end. (Fig 5)
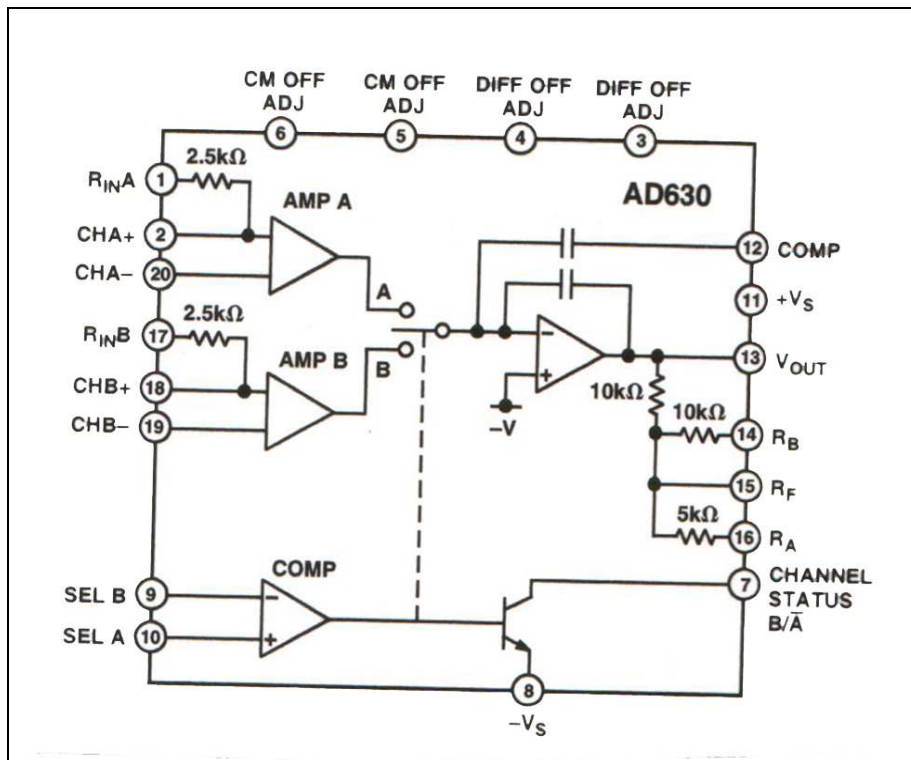

5 Functional block diagram.

Lock In amplification is a technique which is used to separate a small, narrow band signal from interfering noise. Very small signal can be detected in presence of large amounts of uncorrelated noise when the frequency and the phase of the desire signal are known.
Our experiment consist to realize a Lock In ring with two AD630, one like syncronous Modulator and one like syncronous Demodulator
The data sheet says that AD630 could be recover a small signal from 100 dB of interfering noise at 1 Khz, we want to verify if is possible to recover small signal from noise at 100 Hz.

Electric circuit
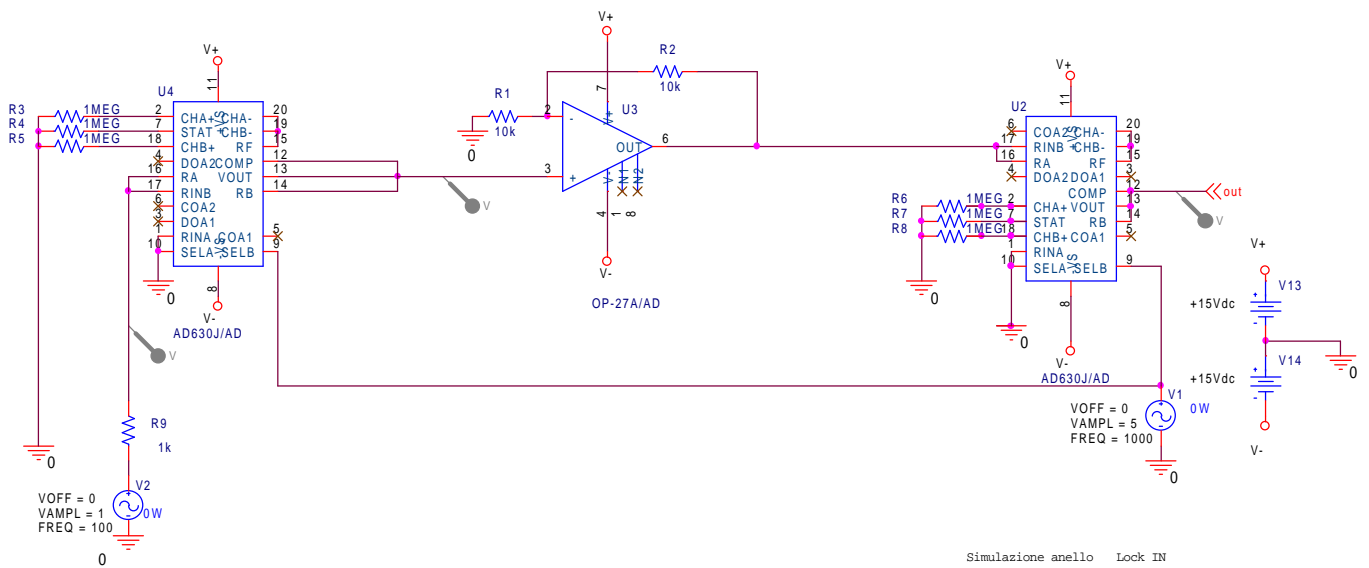
6 Wiring diagram

We have pointing our attention around U.L.F. (0.1÷30Hz) and we have chose a center frequency of 100 Hz for our simulation..

Input signal	Offset	Freq.	V.ampl.
Sin	0V	100 Hz	0.1-5V

Modulated signal	Offset	Freq.	V.ampl.
Sin	0V	1 KHz	5V

Between modulator and demodulator there is an Op amp to enlarge the signal , the Op amp chosen is the Analog Device Op 27 . It must to guarantee a large gainbandwidth represented by:

$$G_{OL} = G \times B = Kost$$

where G is the gain and B the band of aplicated signal. For OP27 the gainbandwidth is about 8 Mhz ; we can have good gain (100,linear) for a signal with 100 Khz band. Last but not least the OP27 have a very good noise figure.

Filtering of output signal

The modulation of a signal by a sinusoidal wave generate some harmonic at nf_s , (for us $f = 1Khz$ frequency, for this reason after demodulation the signal must be filtering with a LPF (low pass filter). The output lowpass filter is a 2nd order Butterworth with Ft=150Hz :
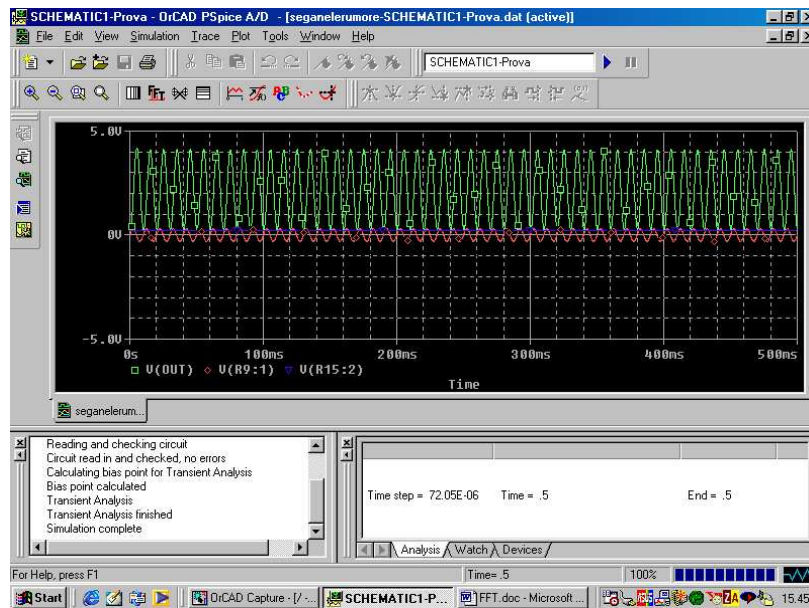
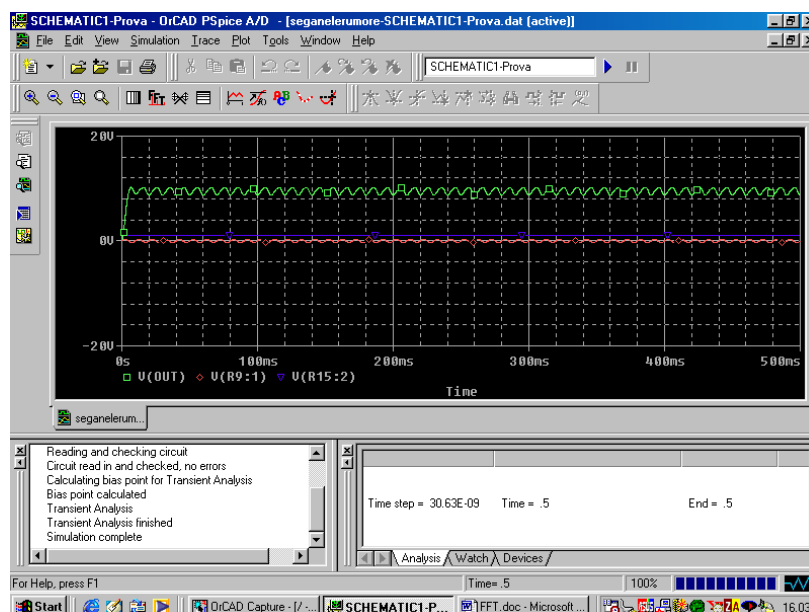| OPAmp.	Approx	Order	Ft	Gain	Config.
OP77	Butterworth	2°	150Hz	1	Invertente

Butterworth Pl 150Hz
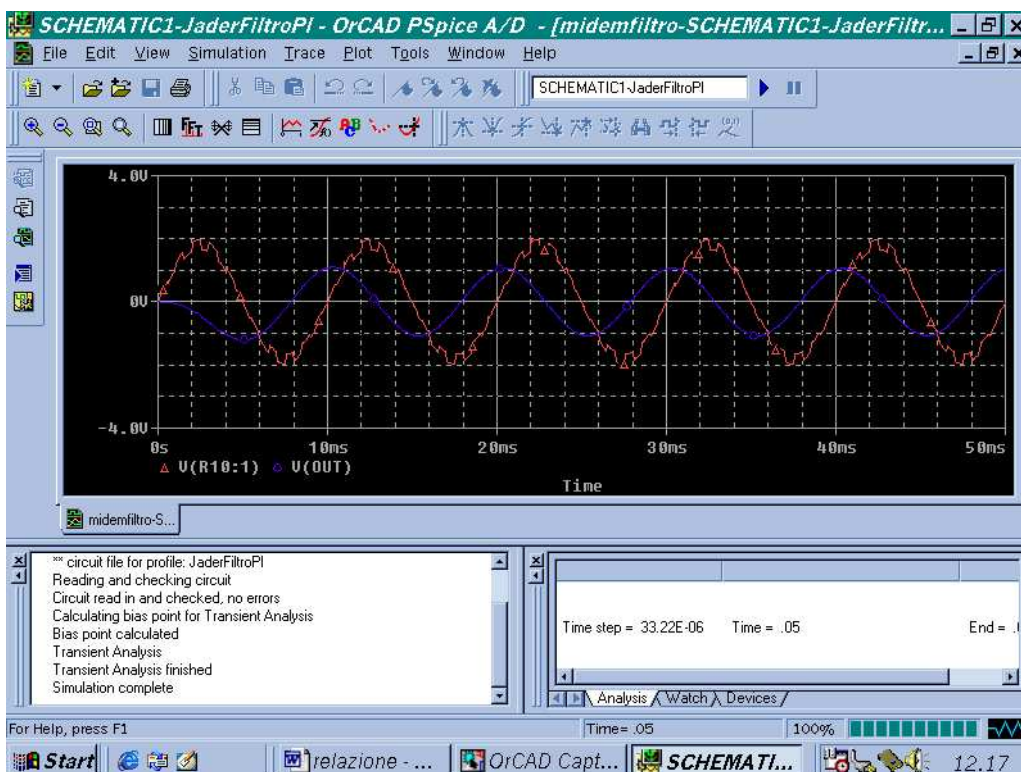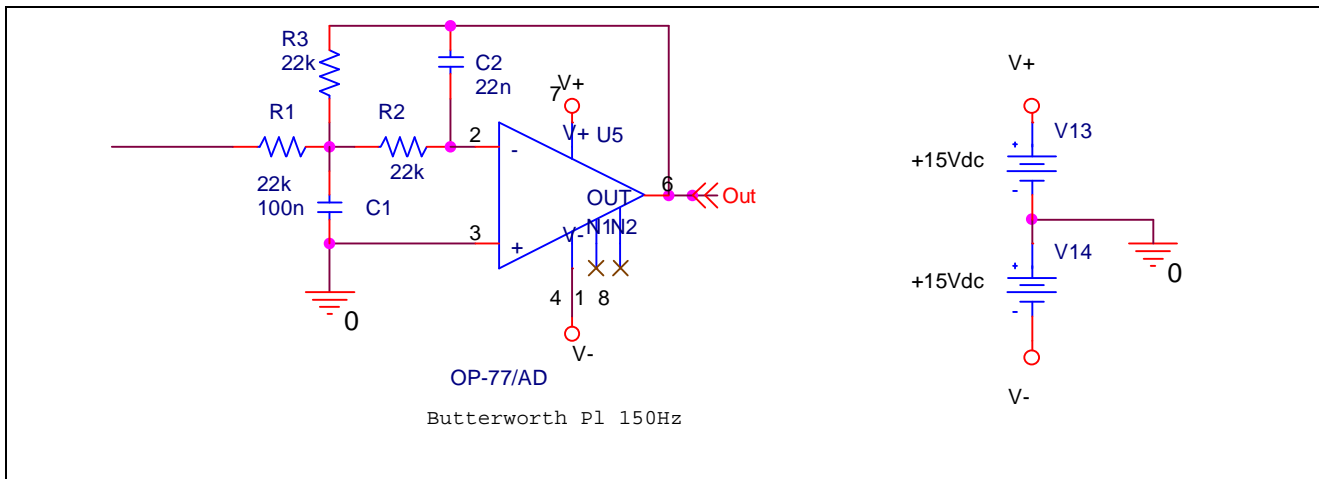
Now we start to simulate by Pspice®, all the Lock In ring. We have to add to input signal (Test signal) a white gaussian variable noise source, than modulated by AD630 enlarging by OP27 and demodulate by AD630. We have to vary the test signal amplitude and to verify the correct recovering of the test signal from varied dB of interfering noise.

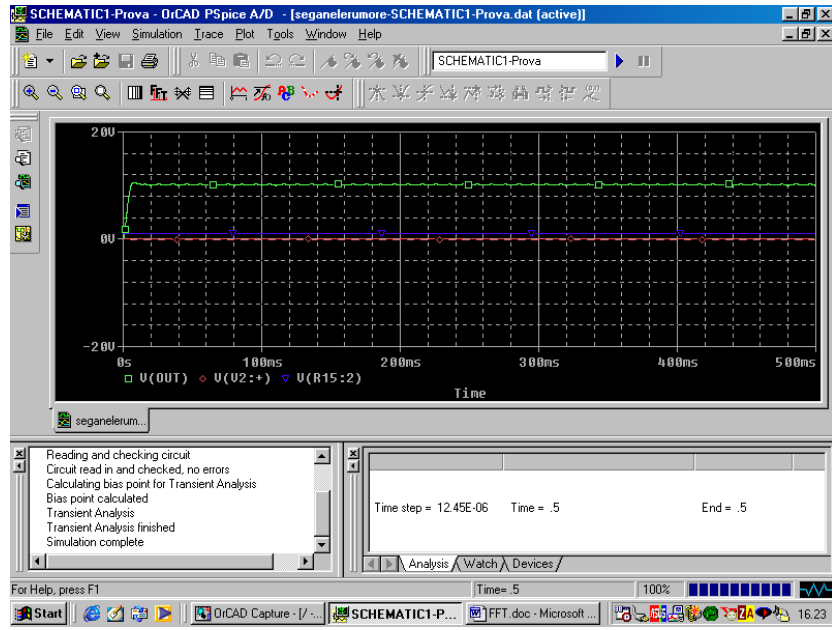In the follow table the most important result:

Vin Vpp	**Vnoise** $\frac{Veff^2}{Hz}(1Khz)$	**Sign/Noise** $\frac{S}{N}(dB)$	**GAmp** $20Log\left(1+\left(\frac{R_2}{R_1}\right)\right)$	**Demod.**	**Simulazione:** Red=Input 100 Hz Green=Out Demodulated
1V	$1.26\ \frac{Veff^2}{Hz}(1Khz)$	-2 dB	6 dB	Yes	
0.3V	$1.90\ \frac{Veff^2}{Hz}(1Khz)$	-16 dB	20 dB	Yes	

Vin *Vpp*	Vnoise $\dfrac{Veff^2}{Hz}(1Khz)$	Sign/Noise $\dfrac{S}{N}(dB)$	GAmp $20Log\left(1+\left(\dfrac{R_2}{R_1}\right)\right)$	Demod.	Simulazione: Red=Input 100 Hz Green=Out Demodulated
0.1V	$1.26\ \dfrac{Veff^2}{Hz}(1Khz)$	-25 dB	27dB	Yes	
0.01V	$1.26\ \dfrac{Veff^2}{Hz}(1Khz)$	-40 dB	40 dB	Yes	
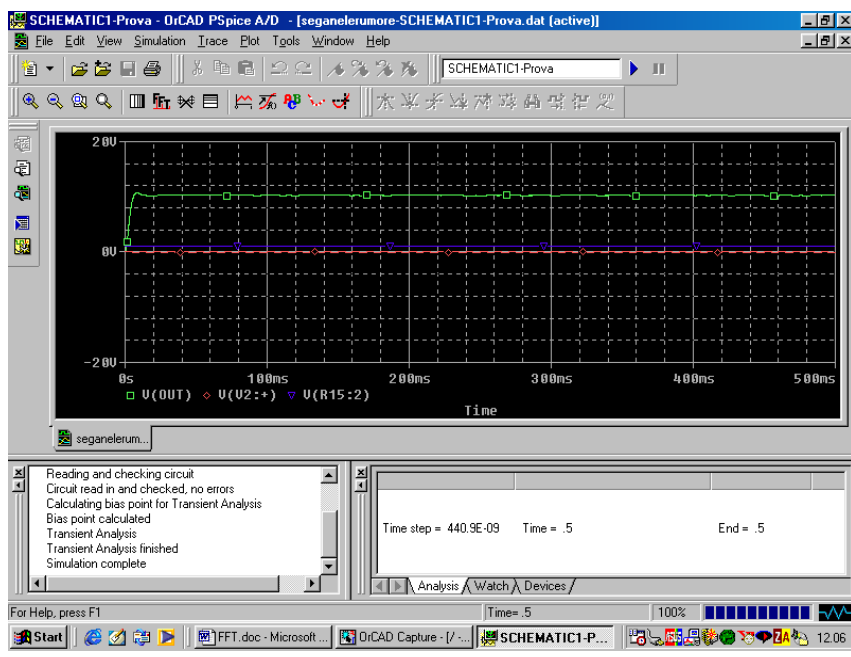
Vin	Vnoise	Sign/Noise	GAmp	Demod.	Simulazione:
Vpp	$\dfrac{Veff^{2}}{Hz}(1Khz)$	$\dfrac{S}{N}(dB)$	$20Log\left(1+\left(\dfrac{R_2}{R_1}\right)\right)$		Red=Input 100 Hz Green=Out Demodulated
0.01V	$1.90\ \dfrac{Veff^{2}}{Hz}(1Khz)$	-45 dB	46 dB	No	
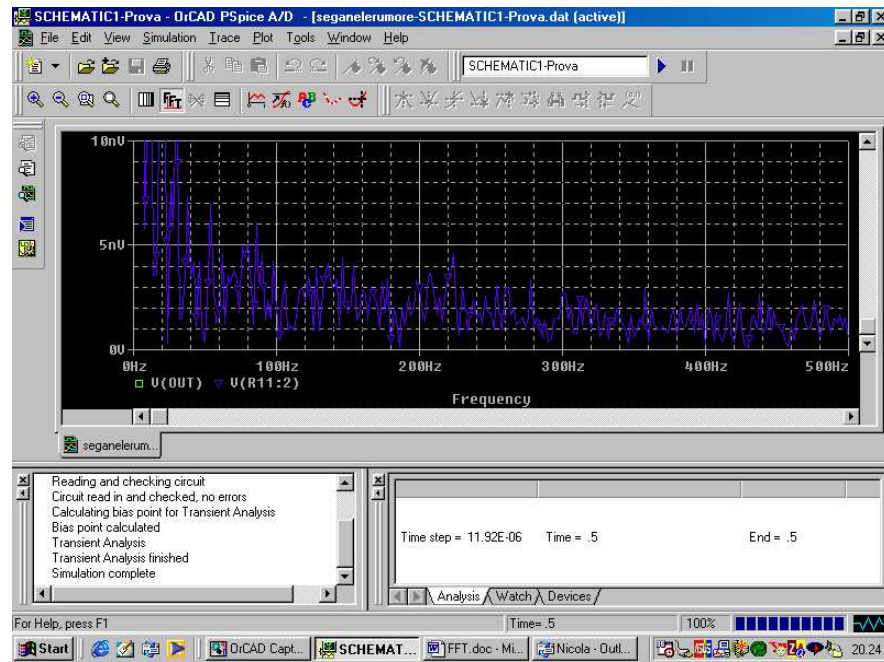
The Pspice© simulation given some important result, we can't confirm the Analog Device result obtained at 1 Khz but we could be satisfy for our -45 dB ($\frac{S}{N}(dB)$) a 100 Hz.

The Pspice© simulation is limited by the white gaussian variable noise source, we must to create a "ad hoc" device to generate suitable noise because in Pspice© dosn't exist one.

Now we pass to realize realy the same circuit simulated by Pspice©. The wiring diagram is at Fig. 7 , we want to find a confirmation at what we have simulate
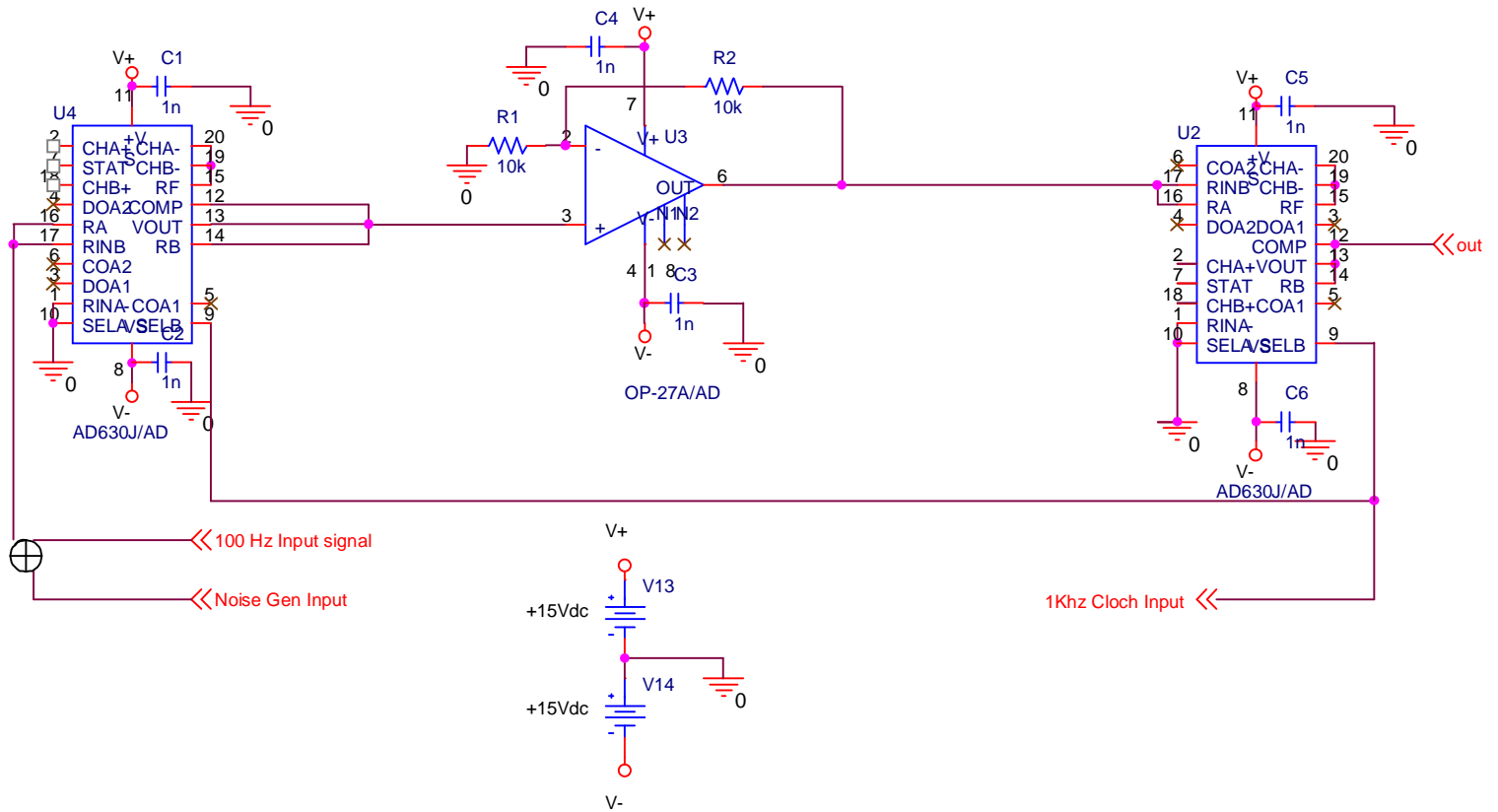
7 Wiring diagram

The circuit was made on a Bread Board , (Fig. 8).
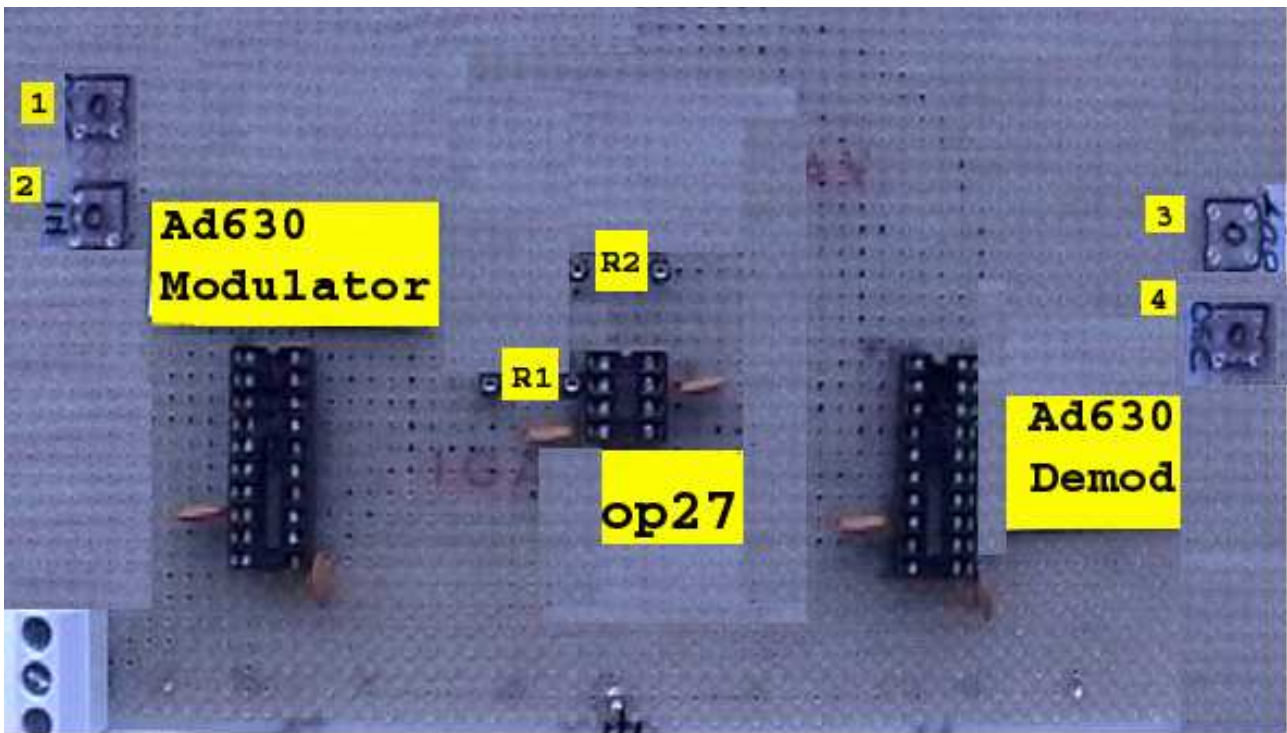
8 Components on the Bread Board

On the Bread Board we have four In/Out gate at 50 Ohm SMB connection.

1: NOISE: Input from noise generator

2:INPUT: Input 100 Hz test signal.

3:OSCILLATOR: Syncronous refernce for Modulator-Demodulator at 1 Khz

4:OUTPUT: Output of demodulated signal.

There is a dual power suply tower +15V –15V too.

We have test every single circuit components and then all Lock In ring.

The not-inverted OpAmp OP27 gain is:

$$G = 20Log\left(\ 1+\left(\frac{R_2}{R_1}\right)\ \right) = 20Log\left(\ 1+\left(\frac{1k\Omega}{100\Omega}\right)\ \right) = 21dB$$

The INPUT test signal was a 100Hz and the amplitude was varied from 500mV to down.

Then we varied noise source intensity and the test signal amplitude to verify correct recovering of the test signal.

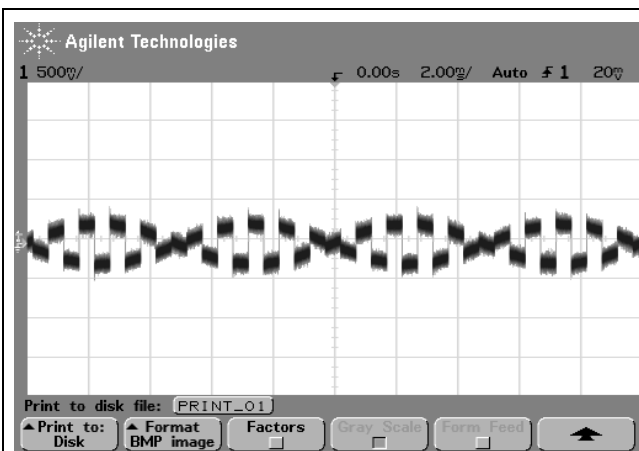We have verify the correct recovering of signal until:

$$\left(\frac{S}{N}\right) = -20d\text{B}\,.$$

The oscilloscope wave form are at Fig. 9, on the 1st channel there is the modulated signal at 1 Khz, on the 2nd channel the test signal correctly demodulated. and enlarging.
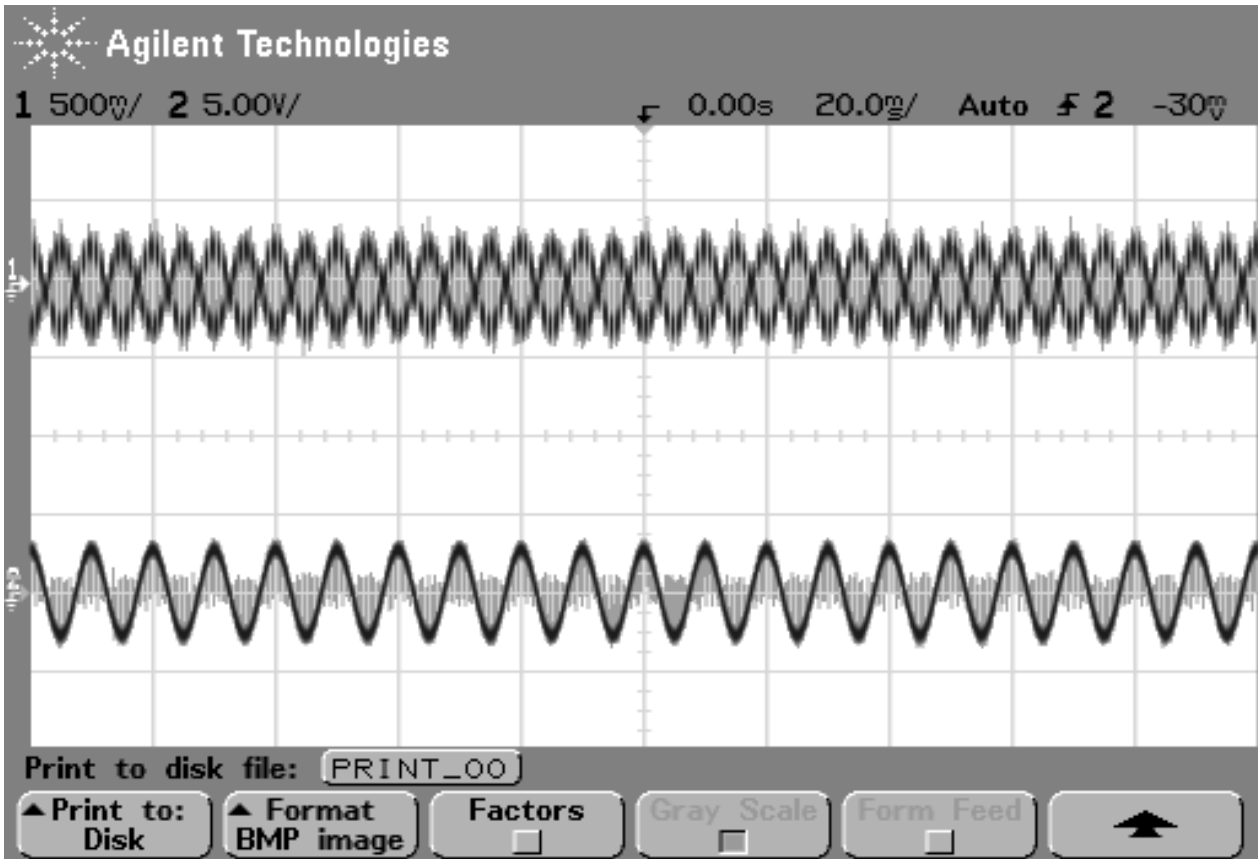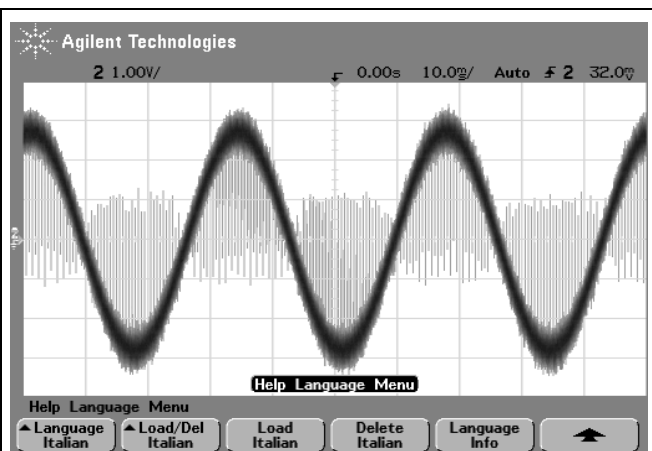

9 Modulated Vs Demodulated

The zoom of the oscilloscope wave form are in Fig.10 and Fig. 11.

10 Zoom of Channel 1

11 Zoom of Channel 2.

The object of our work is to find the maximum signal noise ratio $\left(\dfrac{S}{N}\right)$ where the signal is correctly recovery

The Analog device Data Sheet give a border of –100dB a 10 Khz.

The Pspice© simulation confirming the superiority of Lock In modulation for U.L.F. application and give a –45dB $\left(\dfrac{S}{N}\right)$.

The carring out of the circuit and the simulation haven't permit to confirm the result of the software, we can recovering monocromatic signal only until $\left(\dfrac{S}{N}\right) < -20 \quad dB$.

The experimental result is the worst but is at the same time more interesting.

In fact the recovering of small signal in U.L.F band with $\left(\dfrac{S}{N}\right) < -20 \quad dB$ is a great result impossible to obtain with other tecnical devices.

Another part of this works and some application are on line at www.qsl.net/iw2lla.
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Marco Poloni: Tesi di Laurea

Analog Device AD630 Data Sheet

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