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) receiver application. Transistor, vacuum tubes, resistor and other devices exhibit a low-frequency phenomenon known as flicker noise, often called $\frac{1}{f}$ noise because the mean square density is proportional to $\frac{1}{f}$ $v^2$. Flicker noise poses serious problems for low-frequency application but Lock In modulation could be the answer.

Theory of Lock In Modulation and Demodulation

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 $f_{\text{chop}}$ and it must be upper knee frequency $f_{\text{knee}}$ (Fig. 2), where we have the crossing from $\frac{1}{f}$ noise region to white Gaussian noise region.

| $|v_0|^2$ | output voltage |
|-----------|----------------|
| 0         | $f_{\text{knee}}$ |
| $f$       | $b$            |

2 Knee frequency.
The Lock In modulation is also calling Chopping modulation, in fact it using Chopper amplifier. We know that translate 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 $\frac{S}{N} > 1$. 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:

\[
\begin{cases}
V_0 \cos \omega_1 t \text{ Signal In} \\
A \cos \omega_0 t \text{ Synchronous Reference}
\end{cases}
\]

Where $\omega_0$ is chopping pulsation and $\omega_1$ is the fondamental pulsation.

The demodulated signal is:

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

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](image)
2.2 Asycronism in Lock In Modulation.

The asycronism 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 asycronism 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 $\phi$ from signal to demodulate and the syncronous reference will give an error on the continuos component; this error is estimated to be:

$$V_{out} = V_s \cdot \left(1 - \frac{\Phi}{90}\right) \quad \text{with } 0^\circ < \Phi < 90^\circ$$

the wave form are in Fig. 4

![Wave form with asycronism](image)

4Amplitude and phase with asycronism

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 difference. In particularly we have the signal annulment at $90^\circ$ and his multiples, where the demodulated signal is not present. For the odd multiples of $180^\circ$ we have an inversion of the sign.
ANALOG DEVICE AD630 Balanced Modulator-Demodulator

We have choose for our examination the Analog Device AD630. It’s a high precision balanced modulator which combines a flexible commutating architecture 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 independent differential input stage and a precision comparator which is used to select the active front end. (Fig 5)

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 synchronus Modulator and one like synconous 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..

<table>
<thead>
<tr>
<th>Input signal</th>
<th>Offset</th>
<th>Freq.</th>
<th>V.ampl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin</td>
<td>0V</td>
<td>100 Hz</td>
<td>0.1-5V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modulated signal</th>
<th>Offset</th>
<th>Freq.</th>
<th>V.ampl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin</td>
<td>0V</td>
<td>1 KHz</td>
<td>5V</td>
</tr>
</tbody>
</table>

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:

$$G_{OL} = G \times B = K_{ost}$$
where \( G \) is the gain and \( B \) the band of applied 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 2\(^{nd}\) order Butterworth with \( F_t=150Hz \):

<table>
<thead>
<tr>
<th>OPAmp.</th>
<th>Approx</th>
<th>Order</th>
<th>( F_t )</th>
<th>Gain</th>
<th>Config.</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP77</td>
<td>Butterworth</td>
<td>2(^{nd})</td>
<td>150Hz</td>
<td>1</td>
<td>Invertente</td>
</tr>
</tbody>
</table>

![Circuit diagram](image)
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:

<table>
<thead>
<tr>
<th>Vin</th>
<th>Vnoise</th>
<th>Sign/Noise</th>
<th>G Amp</th>
<th>Demod.</th>
<th>Simulazione:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vpp</td>
<td>$\frac{V_{\text{eff}}^2}{Hz} (1Khz)$</td>
<td>$\frac{S}{N}$ (dB)</td>
<td>$20\log\left(1+\frac{R_2}{R_1}\right)$</td>
<td>Yes</td>
<td>Red=Input 100 Hz Green=Out Demodulated</td>
</tr>
<tr>
<td>1V</td>
<td>$1.26 \frac{V_{\text{eff}}^2}{Hz} (1Khz)$</td>
<td>-2 dB</td>
<td>6 dB</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>0.3V</td>
<td>$1.90 \frac{V_{\text{eff}}^2}{Hz} (1Khz)$</td>
<td>-16 dB</td>
<td>20 dB</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Vin Vpp</td>
<td>Vnoise $\frac{V_{eff}^2}{Hz}$ (1KHz)</td>
<td>Sign/Noise $\frac{S}{N}$ (dB)</td>
<td>GAmpl $20\log \left(1 + \left(\frac{R_2}{R_1}\right)\right)$</td>
<td>Demod.</td>
<td>Simulazione:</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------</td>
<td>-------------------------------</td>
<td>---------------------------------</td>
<td>--------</td>
<td>--------------</td>
</tr>
<tr>
<td>0.1 V</td>
<td>1.26 $\frac{V_{eff}^2}{Hz}$ (1KHz)</td>
<td>-25 dB</td>
<td>27 dB</td>
<td>Yes</td>
<td>Red=Input 100 Hz Green=Out Demodulated</td>
</tr>
<tr>
<td>0.01 V</td>
<td>1.26 $\frac{V_{eff}^2}{Hz}$ (1KHz)</td>
<td>-40 dB</td>
<td>40 dB</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
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© doesn’t exist one.
Now we pass to realize really 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: Synchronous reference for Modulator-Demodulator at 1 Khz
4:OUTPUT: Output of demodulated signal.

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

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

The not-inverted OpAmp OP27 gain is:

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

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:

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

The oscilloscope wave form are at Fig. 9, on the 1\textsuperscript{st} channel there is the modulated signal at 1 Khz, on the 2\textsuperscript{nd} 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 \( \frac{S}{N} \) 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 \( \left( \frac{S}{N} \right) \).

The carrying out of the circuit and the simulation haven’t permit to confirm the result of the software, we can recovering monocromatic signal only until \( \left( \frac{S}{N} \right) < -20 \) 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 \( \left( \frac{S}{N} \right) < -20 \) 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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Analog Device AD630 Data Sheet

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