INTERNATIONAL
PROJECT
HESSDALEN
WORKSHOP
MEDICINA, ITALY, JUNE, 17 2006

PROJECT AND REALIZATION OF A RADIOMETER PROTOTYPE FOR ULFO RECEIVER

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ABSTRACT: *In recent years, the scientific research and in particular the geophysics research regarding waves and radio fields, has been oriented towards the study of the lowest part of electromagnetic spectrum (ULF – Ultra Low Frequency) in relation to particular geophysical phenomena such as earthquakes precursors, the Schumann resonance and the Hessdalen phenomenon*.

The theories of structural phenomena as earthquakes and eruptions are based on the fact that during the micro fracture of rocks and consequent breaking of chemical bounds of material, electromagnetic waves are emitted in the band [0-20] Hz. The Schumann resonance theory says that the terrestrial surface, highly conductive, and the ionosphere, conductive but dissipative, are separated by a concentric spherical cavity. Inside this cavity, after electric changes, a magnetic field pulsing at

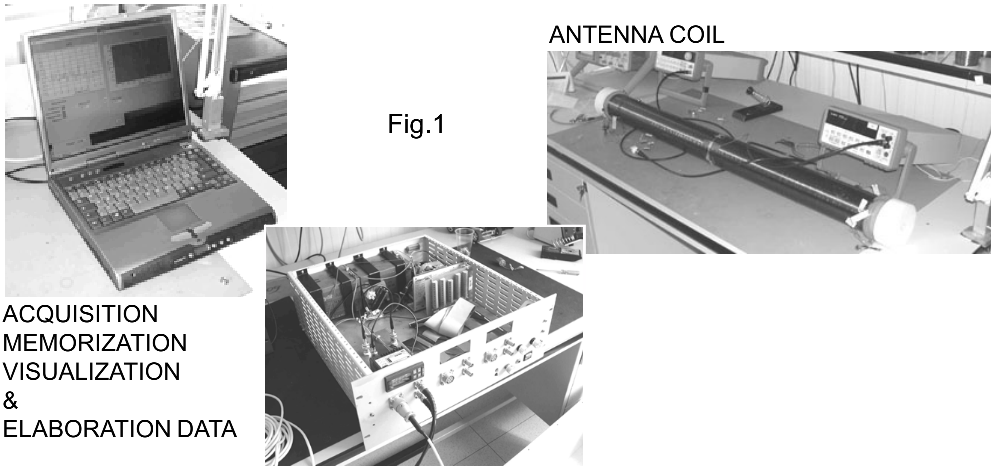

Fig.1

the frequency of about 10 Hz is created and propagated.
The aim of this project was to design and to construct an antenna coil prototype for ULF, which together a receiver, constructed in the same manner as a radio astronomical receiver, will form a system for the study of these geophysical phenomena. Consequently, dedicated software was required for the ULF receiver, including a user interface that permits the acquisition on the data coming from the

antenna and their extended arrays (Fig.1).
The project specifications for the antenna prototype were:

Band [0.1 - 30] Hz,
Central frequency 15 Hz (wave length = 20.000 Km),
Proceeding direction of a signal unknown,
Minimize the interferences (for example: power distribution lines, group of continuity, etc).

From these specifications, one derives that the antenna dimension must be much smaller than the wave length, must be not directive and must have a zero in a predefined direction to avoid the interferences. Furthermore the antenna must recognize the magnetic component. Therefore an electrically small loop was created. To create this type of antenna the induction electromagnetic law of Faraday-Lenz was followed. Applying this law to the loop with multiple windings, one can calculate the sensibility of loop:

$$\boxed{\frac{v}{H_0} = -2\pi f N A \mu_0 \mu_r \cos(\alpha)}$$

Where

- N is the number of windings,
- A is the loop area,
- H_0 [A/m] is the magnetic field,
- cos (α) is the corner between the axis loop and the magnetic field,
- 0[H/m] magnetic permeability of loop core,
- r magnetic permeability of vacuum.

In the formula (1) when the frequency tends to zero, the tension also tends to zero, so it is necessary to maximize the effective area and the magnetic permeability. Consequently it was decided to design a coil antenna. A coil antenna is a coil formed by some thousands of turns of metallic conductor wrapped around a ferromagnetic core with high magnetic permeability.
The first limitation was imposed by the high cost of material with high magnetic permeability. For core material $FeSi_4$ was used an appropriate compromise of low cost and high magnetic permeability. The $FeSi_4$ has a magnetic permeability between 3.000 [H/m] and 6.000 [H/m] and it has a low cost.
It was decided to work with a core formed by multiple smaller cores with single lower diameter, but to obtain a core with a diameter that was not available on the market (Fig.2). Through simulations it was calculated the length of the wire and the

number of the necessary turns. In the Fig.3 shows how the wire is wrapped around the core. Finally the coil antenna was constructed as shown in the photos (Fig.4, 5). After that the design of the coil was executed. The parameters which had to be measured were the sensibility and the pass band. Using the working of the transformer at vacuum with a primary composed by ten windings, a resistance and an inductance tending to zero and with a secondary formed by the coil, the system was characterized on the whole interest band. It has been verified that of the band met the project specifications.

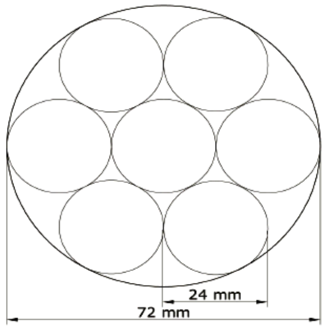

Fig. 2

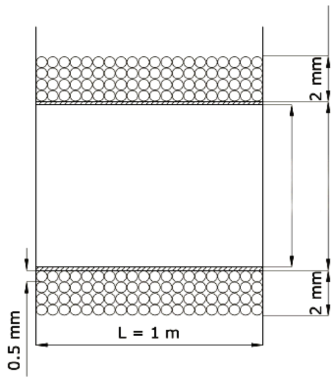

Fig. 3

Finally, the software was developed. The software had to manage the acquisition, the memorization, the visualization and the elaboration of the data coming from ULFO. The software is written in *LabWindows/CVI* and it is based on a multithreading architecture with a primary task for the acquisition.

In conclusion, the constructed antenna is a very good compromise between sensitivity, transportability and mechanical realization. Its functionality has been focused on the whole interest band where the frequency response is compatible with that simulated and requested in this project. The software is stable and efficient in its implemented functions and it satisfies all the requested specifications.

THE LOCK IN MODULATION IN ULTRA LOW FREQUENCY APPLICATION

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Abstract: The objective of this paper is to demonstrate the validity of Lock In modulation in ULF (0.1-30Hz Ultra Low Frequency) receiver applications. Transistor, vacuum tubes, resistor and other devices exhibit a low frequency phenomenon known as flicker noise, often called 1/f noise because the mean square density is proportional to $1/f_v v$ *” 1. Flicker noise poses serious problems for low frequency applications but Lock In modulation could be the solution.*

THEORY OF LOCK IN MODULATION AND DEMODULATION

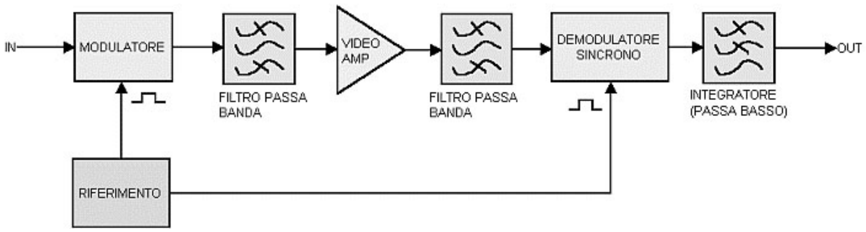


Fig. 1 - General scheme of Lock In ring

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 1/f noise (fig.2), where the instrumental noise or pink noise is prevailing. This frequency is like f_{chop} and it must be upper knee frequency f_{knee} (Fig. 2), where we have the crossing from 1/f noise region to white Gaussian noise region. [JL1]

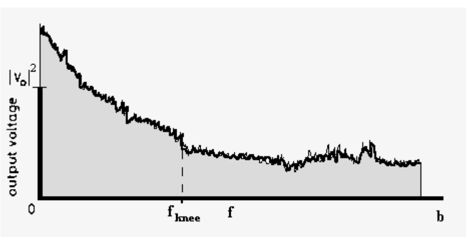


Fig. 2 - Knee frequency

The Lock In modulation is also calling Chopping modulation, in fact it uses a Chopper amplifier. [JL2]

We know that translating a signal frequency is similar to sampling it. Lock In modulation is like sampling at Fc frequency; we know from the Nyquist theorem that Fc must be twice of maximum frequency of the signal.

The process involves selecting the target signal, modulating ,enlarging, filtering with a pass band filter and demodulating in sync with the modulator. The demodulated signal will be enlarged to obtain a signal noise ratio S/N >1 . One advantage is that all the offset and the drift produced inside the Lock In are banished here. Now we can see the frequency response of a Lock In system with a time variant signal:

$V_0 \cos\omega_1 t$	Signal In
$A \cos\omega_0 t$	Synchronous Reference

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).

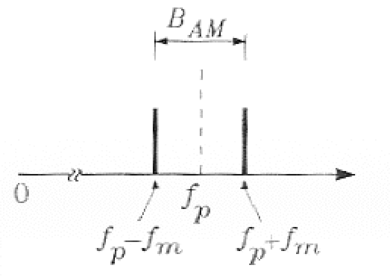


Fig. 3 - DSB-SC Spectrum

SYNCHRONISM IN LOCK IN MODULATION

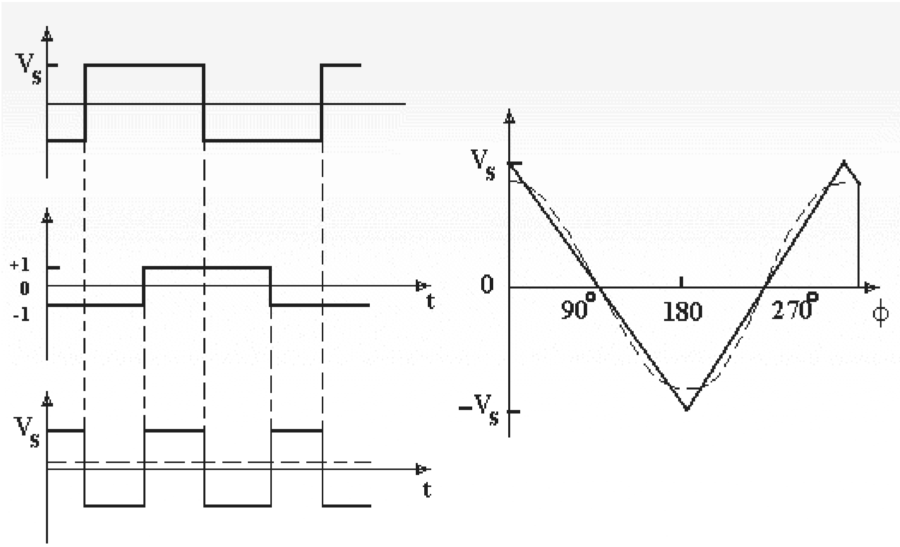
The synchronism in Lock in modulation/demodulation is one of the most recurring technical problems. In fact we must to give a very synchronous signal to Modulator and Demodulator. Often the cause of the asynchronism is the different propagation time from the synchronous signal generator and the modulator/demodulator devices.

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

$$V_{out} = V_S \cdot \left[1 - \frac{\Phi}{90}\right]$$

with: 0<Φ<90

the wave forms are in Fig. 4



Picture 4 - Amplitude and phase with asynchronism

The demodulated signals, for the phase displacement have a smaller amplitude. We can see that the amplitude is inversely proportional to the growth of phase difference. In particular 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 inversion of the sign [JL3]

ANALOG DEVICE AD630 BALANCED MODULATOR-DEMODULATOR

We have chosen 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 includes 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 stages and a precision comparator which is used to select the active front end. (Fig 5)

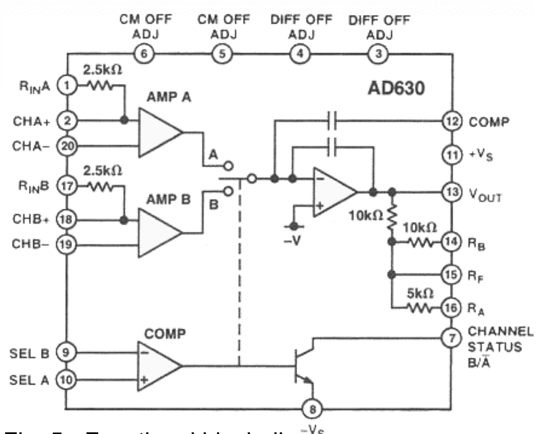


Fig. 5 - Functional block diagram

Lock In amplification is a technique which is used to separate a small, narrow band signal from interfering noise. A 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 consists of generating a Lock In ring with two AD630s, one being synchronous Modulator and one being a synchronous Demodulator

The data sheet says that AD630 should recover a small signal from 100 dB of interfering noise at 1 Khz. We want to verify if it is possible to recover small signal from noise at 100 Hz.

ELECTRIC CIRCUIT

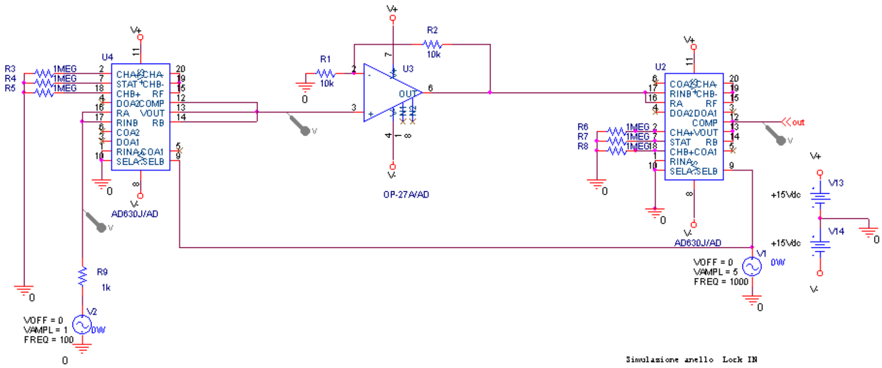


Fig. 6 - Wiring diagram

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

Input signal	Offset	Freq.	V.ampl.
Sin	0V	100Hz	0.1-5V
Modulated signal	Offset	Freq.	V.ampl.
Sin	0V	1KHz	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 guarantee a large gain bandwidth represented by:

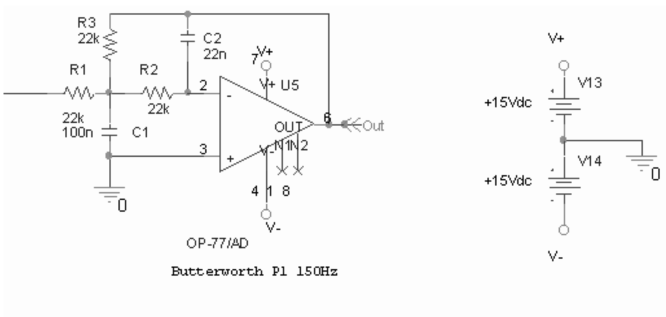
$$G_{OL} = G \times B = Kost$$

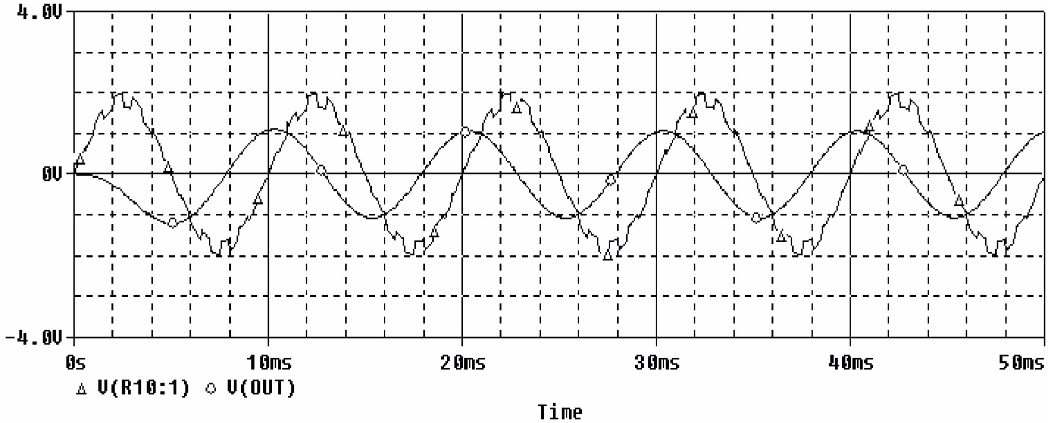
where G is the gain and B the band of applicated signal. For OP27 the gain bandwidth is about 8 Mhz ; we can have good gain (100, linear) for a signal with 100 Khz band. Last but not least the OP27 must have a very good noise figure.

FILTERING OF OUTPUT SIGNAL

The modulation of a signal by a sinusoidal wave generates some harmonic at nf_s, (for us f = 1kHz frequency, for this reason after demodulation the signal must be filtered with a LPF (low pass filter). The output low pass filter is a 2nd order Butterworth with Ft=150Hz:

OPAmp.	Approx	Order	Ft	Gain	Config.
OP77	0V	100Hz	0.1-5V	1	Invertente

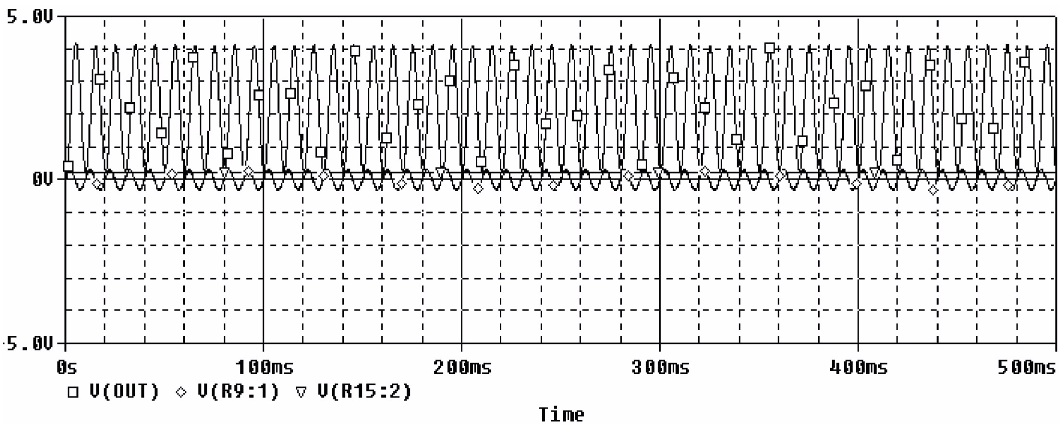




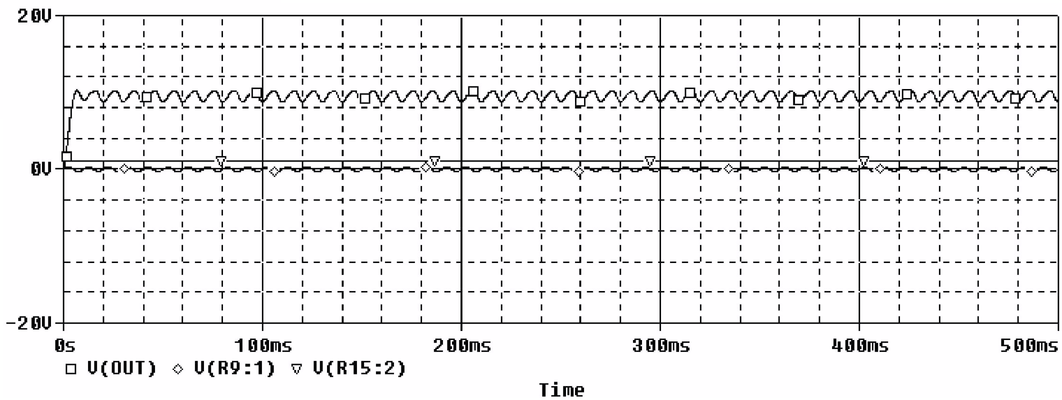
Now we start to simulate by Pspice© , all the Lock In ring. We have to add to input signal (Test signal) a white Gaussian variable noise source, than modulated by AD630 enlarging by OP27 and demodulate by AD630. We have to vary the test signal amplitude and to verify the correct recovery of the test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

In the follow table the most important result:

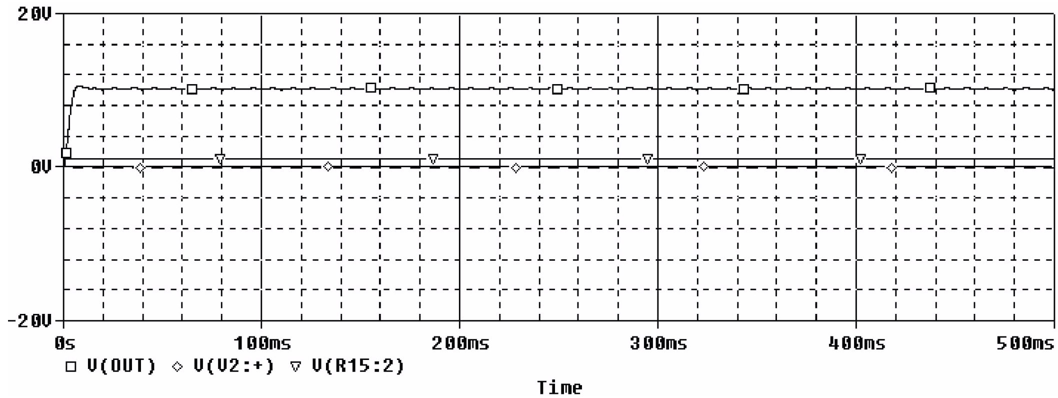
Vin Vpp	Vnoise $\frac{Veff^2}{Hz}(1Khz)$	Sign/Noise $\frac{S}{N}(dB)$	GAmp $20Log\left(1+\left(\frac{R_2}{R_1}\right)\right)$	Demod.
1V	1.26 $\frac{Veff^2}{Hz}(1Khz)$	-2 dB	6 dB	Yes



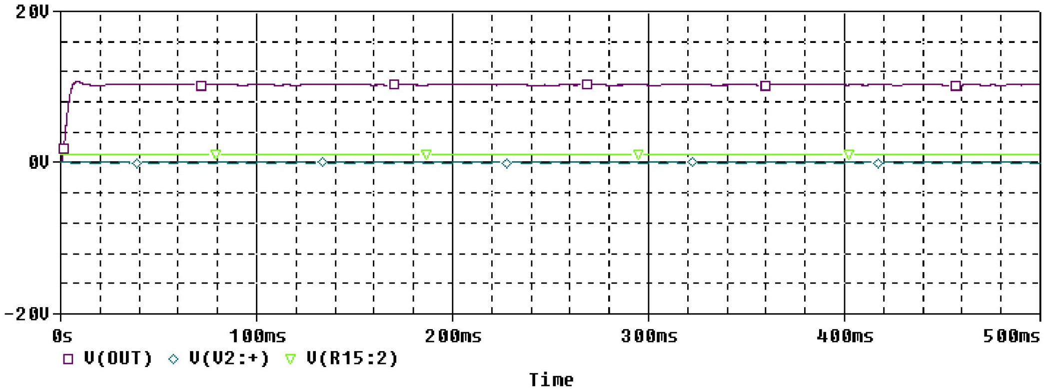
0.3V	1.90 $\frac{Veff^2}{Hz}(1Khz)$	-16 dB	20 dB	Yes



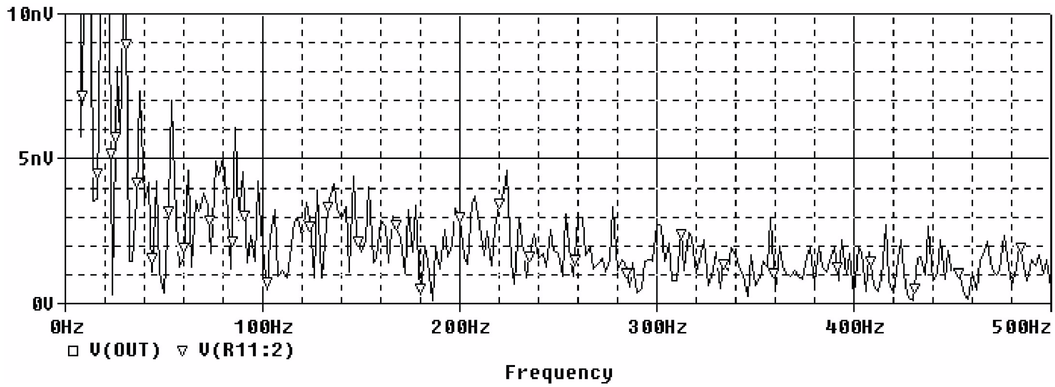
Vin	Vnoise	Sign/Noise	GAmp	Demod.	Simulation:
Vpp	$\frac{Veff^2}{Hz}(1Khz)$	$\frac{S}{N}(dB)$	$20Log\left(1+\left(\frac{R_2}{R_1}\right)\right)$		Red=Input 100 Hz Green=Out Demodulate
0.1V	1.26 $\frac{Veff^2}{Hz}(1Khz)$	-25 dB	27dB	Yes	



0.01V	1.26 $\frac{Veff^2}{Hz}(1Khz)$	-40 dB	40 dB	Yes	



Vin	Vnoise	Sign/Noise	GAmp	Demod.
Vpp	$\frac{Veff^2}{Hz}(1Khz)$	$\frac{S}{N}(dB)$	$20Log\left(1+\left(\frac{R_2}{R_1}\right)\right)$	
0.01V	1.90 $\frac{Veff^2}{Hz}(1Khz)$	-45 dB	46 dB	No



Although the Pspice© simulation yielded some important results, we can't confirm the Analog Device result obtained at 1 Khz; but we could satisfy our results for -45 dB (S/N [dB]) at 100 Hz.

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

Now we test really the same circuit simulated by Pspice© . The wiring diagram is at

Fig. 7 , we want to find a confirmation at what we have simulated is:

The circuit was made on a Bread Board, (fig.8)

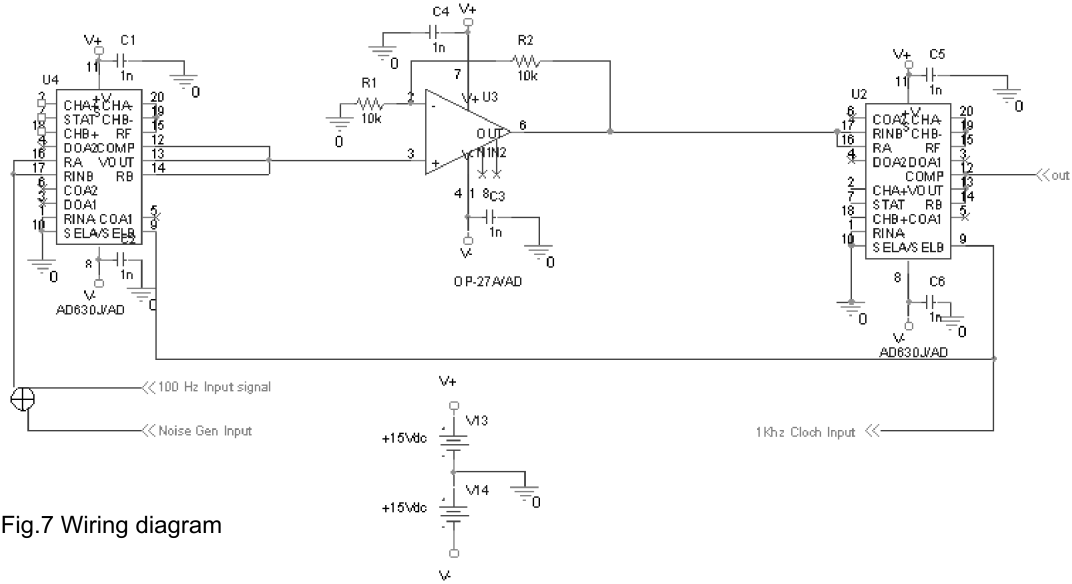


Fig.7 Wiring diagram

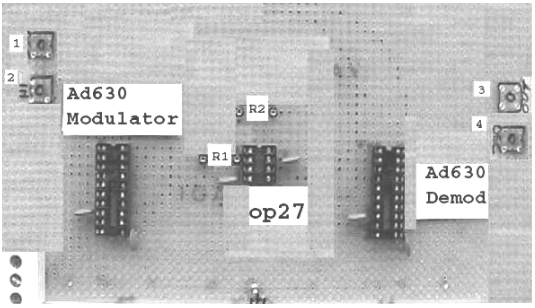


Fig.8 The circuit was made on a Bread Board,

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 tested every single circuit components and then all Lock In ring.

The not-inverted OpAmp OP27 gain is:

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

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

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 verified the correct signal recovery until: $\left(\frac{S}{N}\right) = -20dB$.

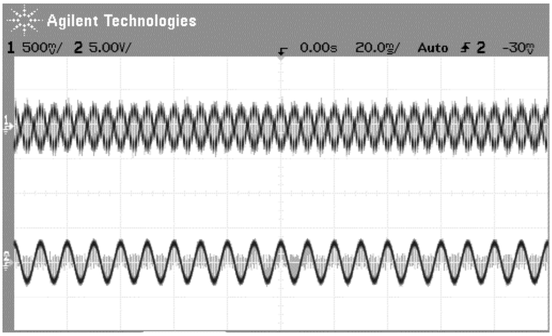
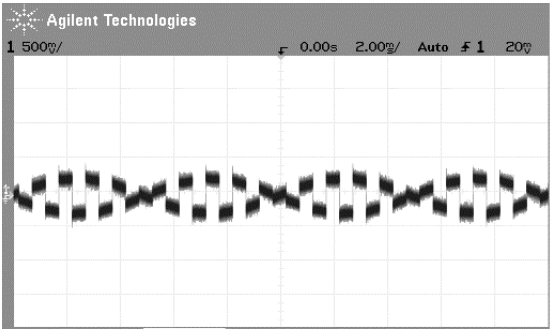


Fig. 9 - Modulated Vs Demodulated



Pig. 10 - Zoom of Channel 1

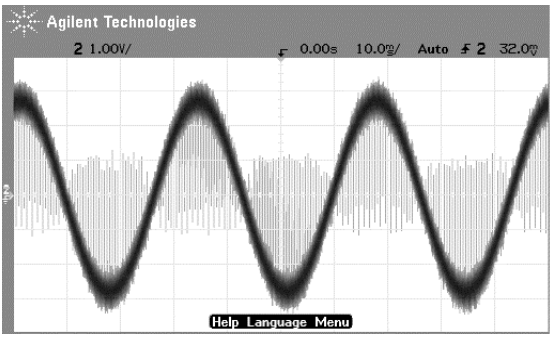


Fig. 11 - Zoom of Channel 2

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.

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

The object of our work is to find the maximum signal noise ratio (S/N) where the signal is correctly recovered.

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

The Pspice_ simulation confirms the superiority of Lock In modulation for U.L.F. application and gives a –45dB (S/N).

The execution of the circuit and the simulation haven't permitted us to confirm the performance of the software, we recover a monochromatic signal only until

(S/N) < -20dB.

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

In fact recovering a small signal in U.L.F band with (S/N) < -20dB is a great result, one impossible to obtain with other technical devices.

Another part of this material and some applications are on line at www.qsl.net/iw2lla.

Thanks a lot to Ing. Jader Monari and'Ing Marco Poloni from Istituto di radioastronomia CNR (Italian National Research Council) of Medicina (Bo) and Ing. Stelio Montebugnoli general manager of the istitute .

Bibliography

C. Vignali (I4VIL):Radio Rivista 10/2002-Ricevitori a rivelazione Sincrona

F.P.Panter:Modulation-Noise and Spectral analysis – Mc Graw Hill 1985

Monari-Guidi-Poloni : Circuito di riferimento per Mod/Dem Lock In
Marco Poloni: Tesi di Laurea

Analog Device AD630 Data Sheet