Infrasound Microphone

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Abstract

My project was about building a microphone to be used to see infrasound noise present in LIGO's apparatus and this article describes the work I did to build it.

Chapter 1

Basic Ideas

The basic principles on which the microphone is based are easy to understand: first I tought to build my microphone using the same principles as common loudspeakers and microphones are built: a membrane fixed to a coil with a magnet inside, so that any air pressure variaton on the membrane induces a movement of the membrane itself and of the coil, and so a current on the coil itself.
However I should abandon this idea soon because I realized that my infrasound microphone had to work at frequencies below 20 Hz, or at wavelenghts above 17 m: too much compared with the displacement of the membrane, so that, at the first order, my apparatus couldn't see any pressure variation, because too weak. So I looked for another method, not based on any pressure variation on loudspeaker, but, better, based on the effective pressure on it. This method, that I eventually found, consists of this idea: there's a coil fixed to a membrane, as in the loudspeaker, but instead of a magnet inside the coil there's another coil above the first one and fixed to a retaining structure (in my case to the metal framework of the membrane), so that one coil is movable and the other one is fixed. Then the movable one carries an alternate (sinusoidal) current. In the other coil an induced alternate current appears, with the same frequency as the first one, but with an amplitude which depends (in first approximation) only on the distance between the 2 coils.
To be clearer, call A the fixed coil and B the movable one, also call z the mutual distance between the 2 coils, Φ_A the flux of the magnetic field in the fixed coil and i_A and i_B the currents that flow in each coil. Then it's easy to see that

$$\Phi_A = M(z)i_B = M(z)i_{0_B}sin(wt + \phi)$$

where $M(z)$ is a factor that depends only on the relative distance of the coils and on the geometry of the system. From the Faraday-Neumann law you have:

$$f.e.m._A = -\frac{d\Phi_A}{dt} = -\frac{dM(z)}{dt}i_B - M(z)\frac{di_B}{dt}.$$

The first term in the approximation of small variation of z is negligible compared to the second one, so that the current i_A in the movable coil as an amplitude that depends on the relative distance of the coils:

$$i_A = \frac{f.e.m._A}{R_A} = -\frac{M(z)}{R_A}\frac{di_B}{dt} = -\frac{M(z)}{R_A}\omega i_{0_B}cos(\omega t + \phi)$$

where R_A is the resistence of the movable coil and i_A is still a sinusoidal function with the same frequency as i_B.
With this in mind it's easy to understand that if there's any pressure variation on the membrane, then there will be an amplitude variation of current (and so of tension) in the fixed coil, and this variation can be detected by an electronic circuit, as the one described below. All this system had been fixed inside the lid of a metal barrel, isolating so doing a side of the membrane and improving the response of the apparatus to any external air pressure variation.

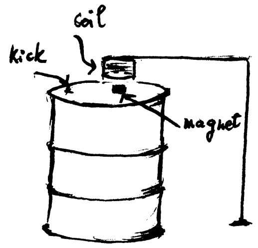


Figure 1.1: measurement of barrel resonances, as explained below

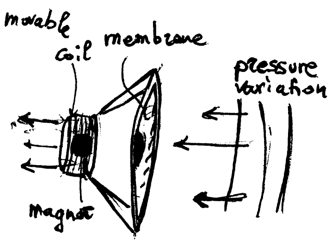


Figure 1.2: picture of the principle on which common loudspeakers are built

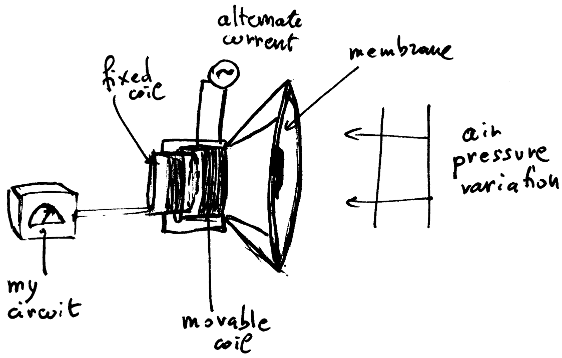


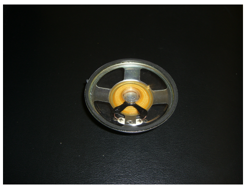
Figure 1.3: picture of the principle on which my loudspeaker was built

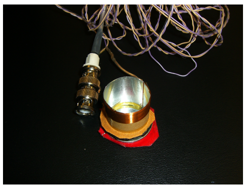
Chapter 2

Construction

To build my microphone I used two loudspeakers with the diameter of 10 cm and a metal barrel of size 60cm(diameter)·80cm(height), at the top of which, inside the lid, I fixed the membrane of one of the two speakers.

First I roughly measured the low-frequency resonances of the barrel to understand if I had to strengthen its walls, cutting so off all these resonances that could decrease the response of the membrane to the air pressure variation because of the additional response of the barrel's walls to the pressure waves. I did it using a little magnet fixed to the top of the barrel and a coil above it fixed through a rigid support independent from the barrel and linked to the ground. Then I hit the barrel on different points.





I measured the electric signal, induced by the vibration of the magnet in the coil, on an oscilloscope and I realized that there were some resonances at about $10 - 20$ Hz. Below there's a graphic representing one of these measurements, after having isolated the resonance vibrations.

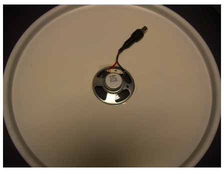


Figure 2.1: coil fixed in the lid of the barrel

Figure 2.2: barrel

I decided to cover the top and the bottom of the barrel with an aluminium beehive-shape material 1 cm thick and two more lids (like a sandwich), to make all more rigid. I then built my microphone based on the LVDT's method: I removed in one speaker, composed of a membrane and a coil fixed to it, its magnet and I pasted a second coil, taken from the other speaker, above the first coil, fixing it to the metal framework of the first speaker itself (LVDT method).
Then I did a hole on the top lid of the barrel and I pasted the whole structure in this hole, with one side of the membrane inside the barrel.

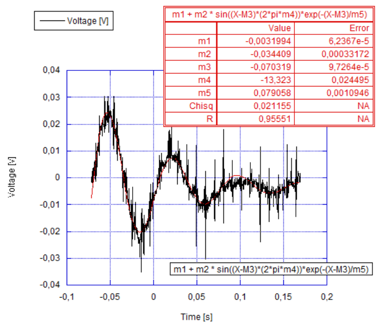


Figure 2.3: the blue and black line represent the relaxation curve of the membrane with the hole opened and closed

I also did a small hole on the lid to blow in, and so to measure the characteristic relaxation time of the membrane, understand if there could be some air losses inside the barrel, and, if so, understand if these losses could decrease the response of my apparatus to noise under 20 Hz. In fact I found out that (with the small hole closed)there were some losses that could be relevant at the noise frequency of the order of 10 mHz. Below it's possible to see the graphics of the membrane relaxations with open and closed hole.
To set my microphone I built a wood box bigger than the barrel, I put the whole system inside this box and I fixed a subwoofer at the top of it. Then I sealed the wood box to isolate my system and used the woofer to produce pressure waves, in order to test the response of my microphone to any pressure variations. All this analisys was done through an electric circuit used to detect any change of the current's amplitude on the fixed coil.

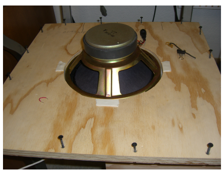


Figure 2.4: woofer

Figure 2.5: wood box

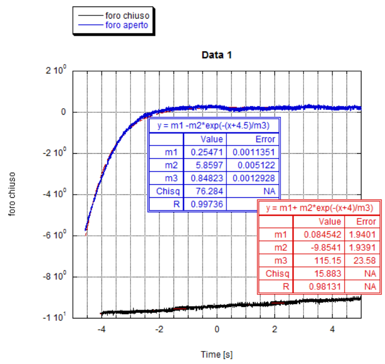


Figure 2.6: the blue and black lines represent the decay laws respectively for the opened and closed hole

Chapter 3

Electric Circuit and Measurement

With the LVDT method in mind I built a circuit with the aim of detecting pressure variations on the membrane of my microphone. Afetr having built it I soldered it in order to reduce some additional noise coming for example from the board
Each coil of my microphone had a resistance of 8 ohm and a maximum power dissipation of 2 W. I made a fixed current of frequency at about 10 khz and amplitude at about 100 mV flow in the movable coil. As already said, in the fixed coil an induced current appeared, with an amplitude depending on the mutual distance of the 2 coils. My circuit had in input both the signals coming from the coils, and was devided into 3 parts:

1. the two signals are amplified up to tensions of the order of Volts
2. the two signals are put in opposition of phase (sphasators) and then added (that is they are subtracted). So doing I get a signal whose amplitude variation is proportional to a pressure variation on the membrane. Then a time average of the modulus of this signal is taken through a diode and a bass-pass filter (with a cutting frequency at about).
3. the final signal is amplified once more, with respect to a tension reference, chosen so that without pressure on the membrane the resulting signal at the output of my circuit is 0 Volts

So doing I got at the end of my circuit a signal proportional to the air pressure variation on the membrane. The sketches below represent all that:

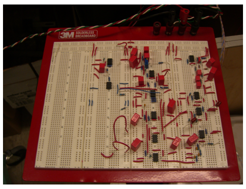


Figure 3.1: electric circuit

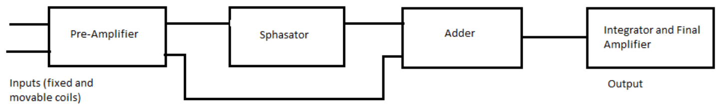


Figure 3.2: general sketch

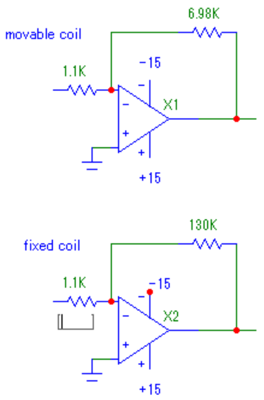


Figure 3.3: Pre-amplifier

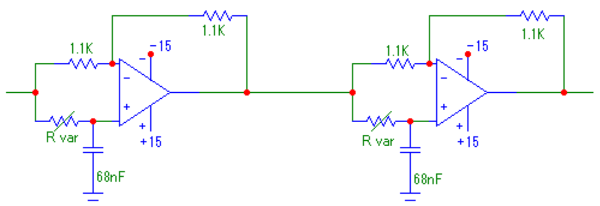


Figure 3.4: Sphasator

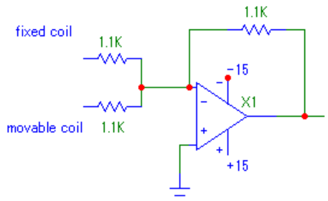


Figure 3.5: Adder

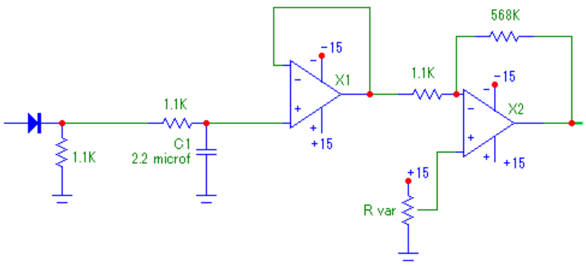


Figure 3.6: Integrator and final amplifier

Then I used the subwoofer, as said before, to test my microphone: I measured the response of my circuit to pressure waves of different frequencies produced by the woofer and at the end I plotted all that in a graphic getting the transfer function of my microphone. Below it's possible to see the signal sent in the subwoofer (constant in amplitude for all values of the frequencies used) and the response signals detected. For each of them I reported the real signal measured, its average over a period (trend) and its sinusoidal part, calculated by the real signal after having subtracted the trend part.

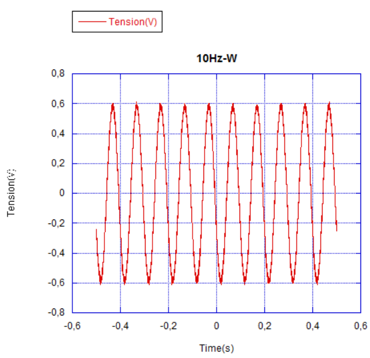
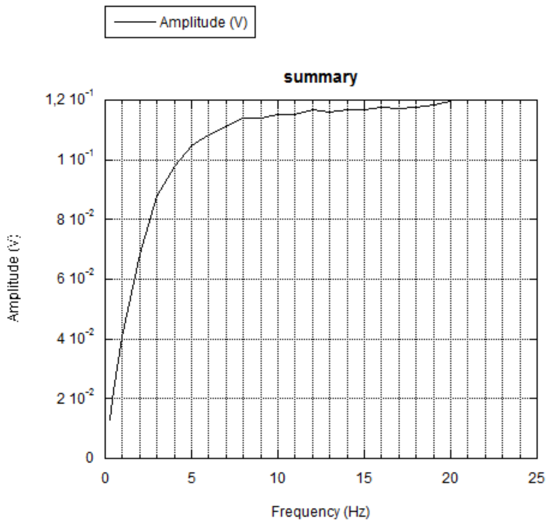


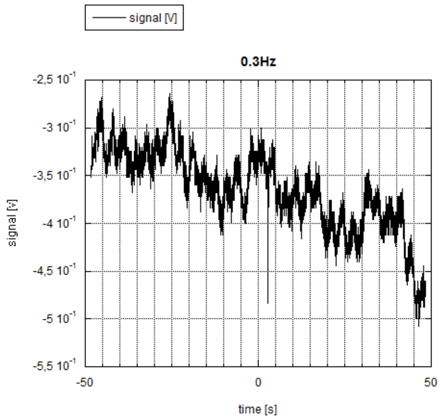
Figure 3.7: sample of woofer signal of 10 Hz frequency

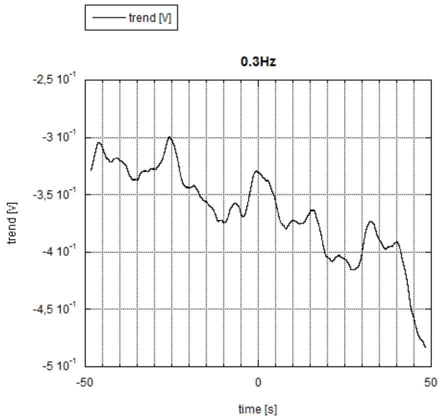
Chapter 4

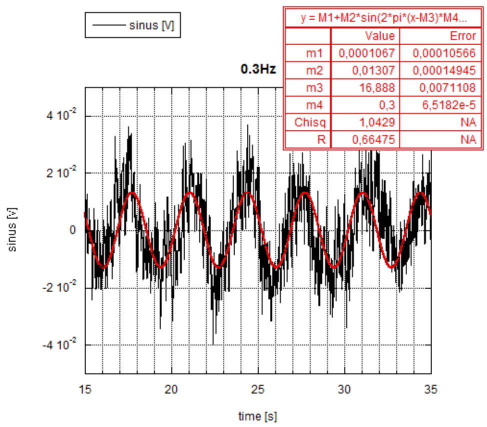
Conclusion

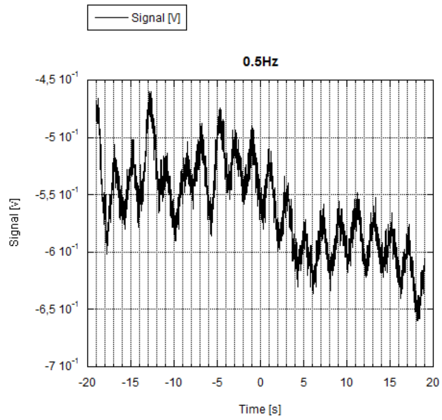
Below it's possible to see the plot representing the response of my microphone at different frequencies. In particular it's evident that there is a region, delimited by a cut-off frequency of about 2 Hz (the frequency at which the response is about one half the maximum response value), in which my microphone doesn't work well.

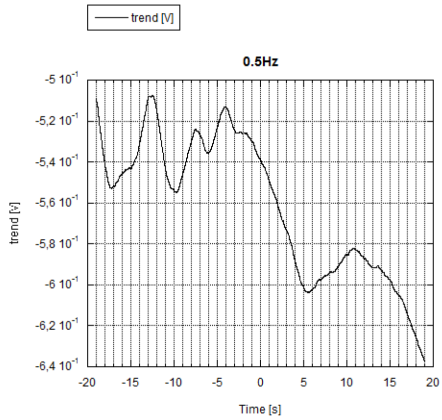


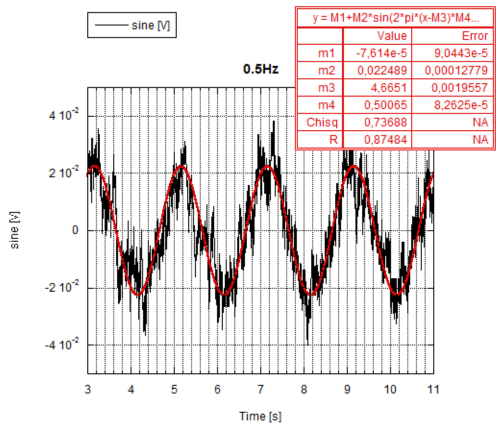

signal [V]
0.3Hz
-2,5 10^-1
-3 10^-1
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
-5,5 10^-1
signal [V]
-50
0
50
time [s]

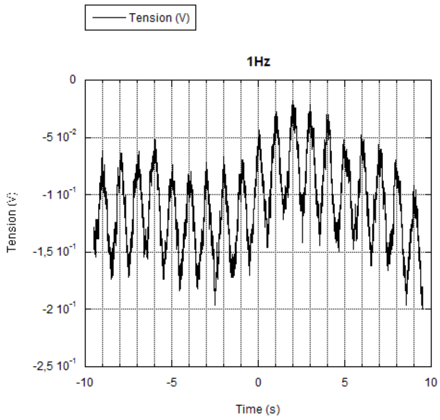

trend [V]
0.3Hz
-2,5 10^-1
-3 10^-1
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
trend [V]
-50
0
50
time [s]

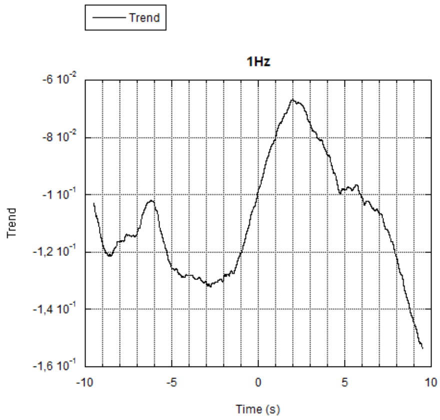

sinus [V]
0.3Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 0,0001067 0,00010566
m2 0,01307 0,00014945
m3 16,888 0,0071108
m4 0,3 6,5182e-5
Chisq 1,0429 NA
R 0,66475 NA
4 10^-2
2 10^-2
0
-2 10^-2
-4 10^-2
sinus [V]
15
20
25
30
35
time [s]

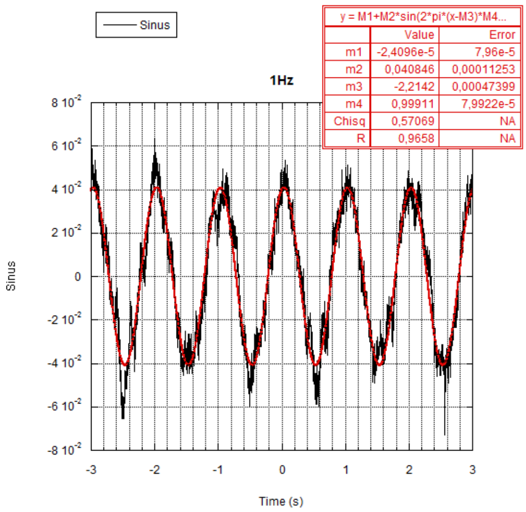

Signal [V]
0.5Hz
-4,5 10^-1
-5 10^-1
-5,5 10^-1
-6 10^-1
-6,5 10^-1
-7 10^-1
Signal [v]
-20 -15 -10 -5 0 5 10 15 20
Time [s]

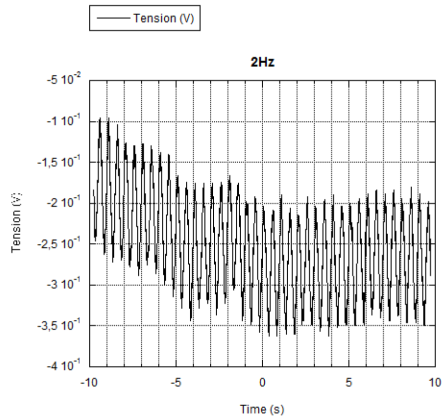

trend [V]
0.5Hz
-5 10^-1
-5,2 10^-1
-5,4 10^-1
-5,6 10^-1
-5,8 10^-1
-6 10^-1
-6,2 10^-1
-6,4 10^-1
trend [v]
-20 -15 -10 -5 0 5 10 15 20
Time [s]

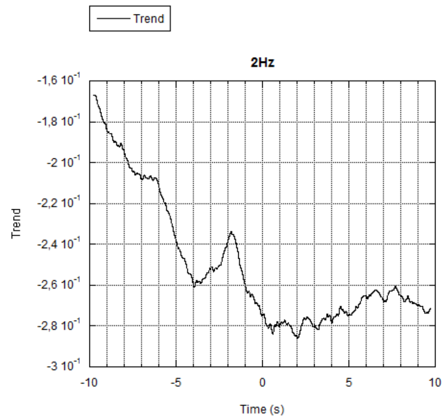

sine [V]
0.5Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -7,614e-5 9,0443e-5
m2 0,022489 0,00012779
m3 4,6651 0,0019557
m4 0,50065 8,2625e-5
Chisq 0,73688 NA
R 0,87484 NA
4 10^-2
2 10^-2
0
-2 10^-2
-4 10^-2
sine [v]
3 4 5 6 7 8 9 10 11
Time [s]

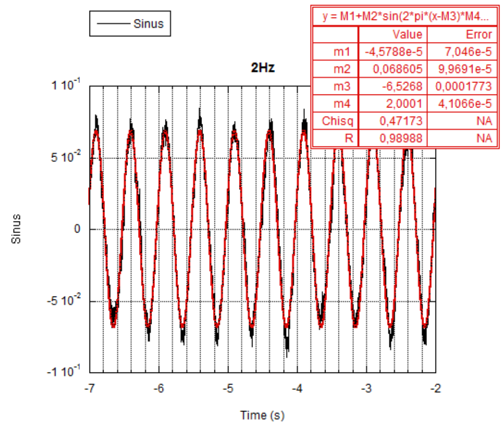

Tension (V)
1Hz
Tension (V)
Time (s)

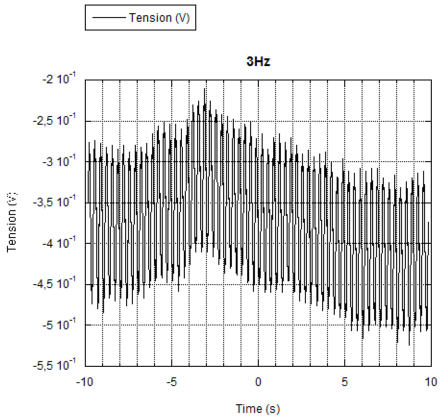

Trend
1Hz
Trend
Time (s)

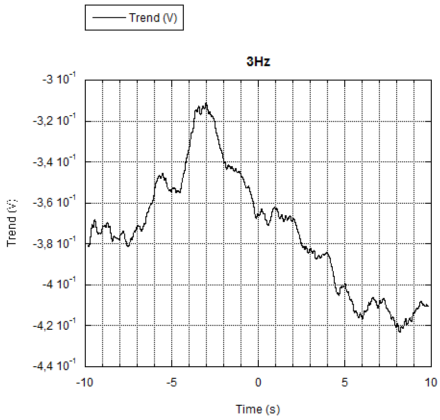

Sinus
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -2,4096e-5 7,96e-5
m2 0,040846 0,00011253
m3 -2,2142 0,00047399
m4 0,99911 7,9922e-5
Chisq 0,57069 NA
R 0,9658 NA
1Hz
Sinus
Time (s)

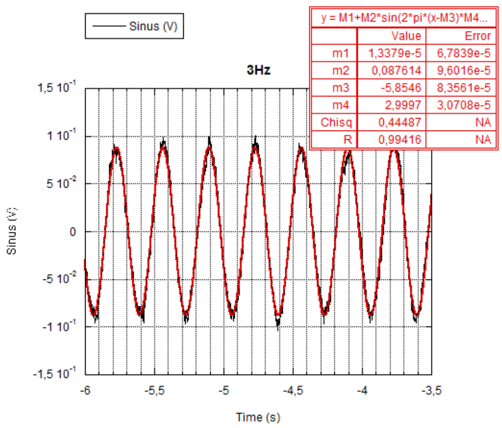

Tension (V)
2Hz
Tension (V)
Time (s)

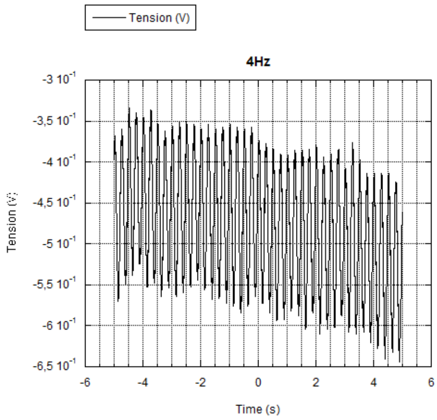

Trend
2Hz
Trend
Time (s)

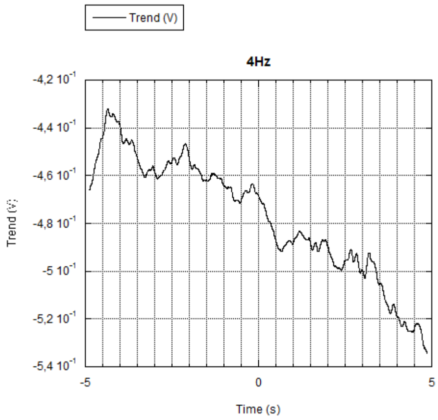

Sinus
2Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -4,5788e-5 7,046e-5
m2 0,068605 9,9691e-5
m3 -6,5268 0,0001773
m4 2,0001 4,1066e-5
Chisq 0,47173 NA
R 0,98988 NA
Sinus
Time (s)

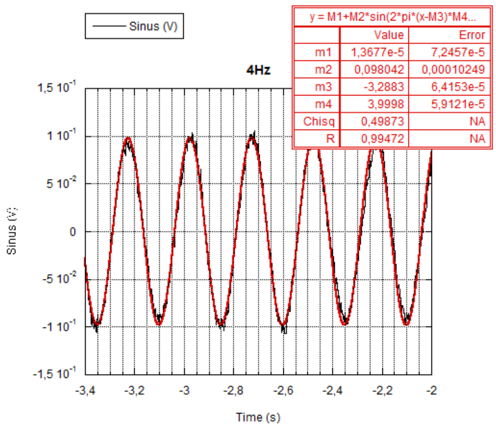

Tension (V)
3Hz
Tension (V)
Time (s)

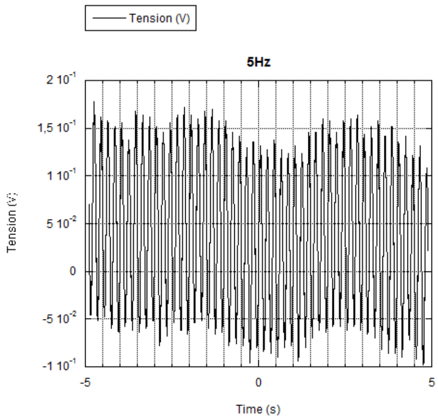

Trend (V)
3Hz
Trend (V)
Time (s)

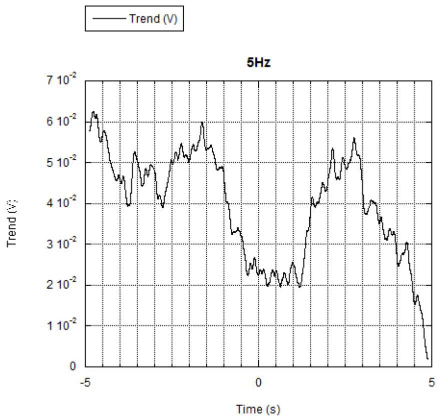

Sinus (V)
3Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 1,3379e-5 6,7839e-5
m2 0,087614 9,6016e-5
m3 -5,8546 8,3561e-5
m4 2,9997 3,0708e-5
Chisq 0,44487 NA
R 0,99416 NA
Sinus (V)
Time (s)

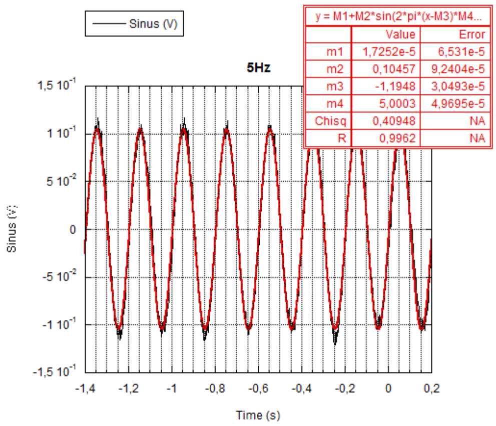

Tension (V)
4Hz
Tension (V)
Time (s)

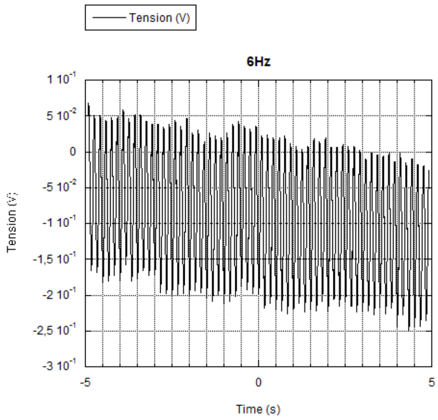

Trend (V)
4Hz
Trend (V)
Time (s)


Sinus (V)
4Hz
Sinus (V)
Time (s)
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 1,3677e-5 7,2457e-5
m2 0,098042 0,00010249
m3 -3,2883 6,4153e-5
m4 3,9998 5,9121e-5
Chisq 0,49873 NA
R 0,99472 NA

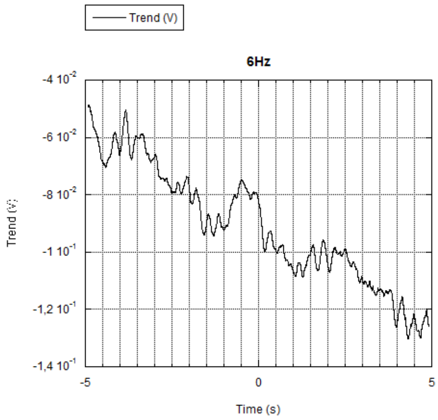

Tension (V)
5Hz
2 10^-1
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
Tension (V)
-5
0
5
Time (s)


Trend (V)
5Hz
7 10^-2
6 10^-2
5 10^-2
4 10^-2
3 10^-2
2 10^-2
1 10^-2
0
Trend (V)
-5
0
5
Time (s)

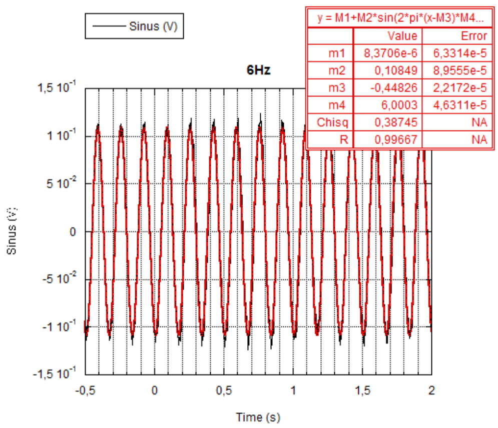

Sinus (V)
5Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value
Error
m1 1,7252e-5 6,531e-5
m2 0,10457 9,2404e-5
m3 -1,1948 3,0493e-5
m4 5,0003 4,9695e-5
Chisq 0,40948 NA
R 0,9962 NA
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
Sinus (V)
-1,4
-1,2
-1
-0,8
-0,6
-0,4
-0,2
0
0,2
Time (s)



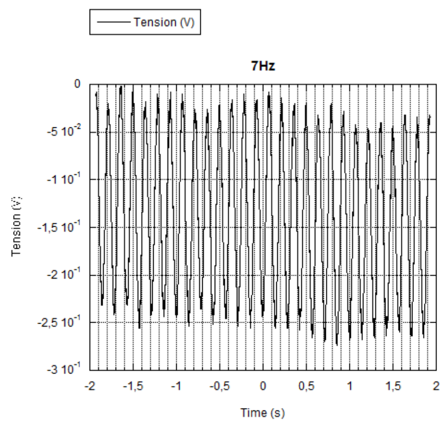
Tension (V)
6Hz
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
-2 10^-1
-2,5 10^-1
-3 10^-1
Tension (V)
-5
0
5
Time (s)

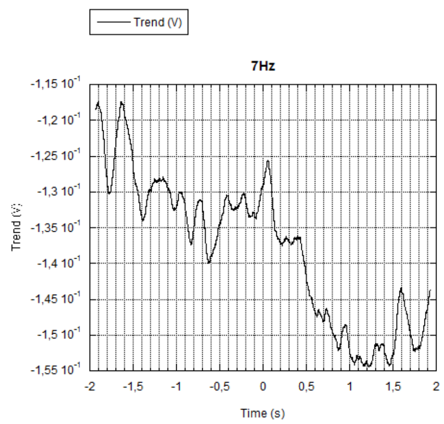


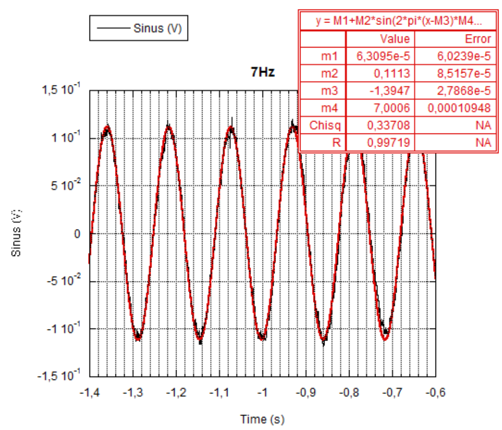
Trend (V)
6Hz
-4 10^-2
-6 10^-2
-8 10^-2
-1 10^-1
-1,2 10^-1
-1,4 10^-1
Trend (V)
-5
0
5
Time (s)

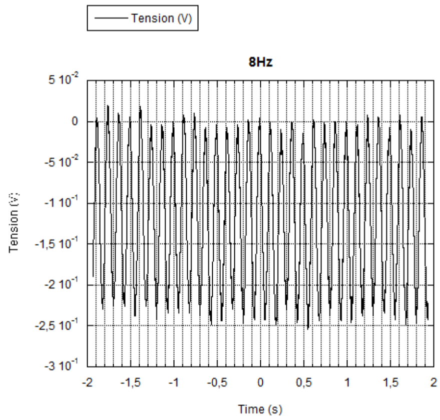


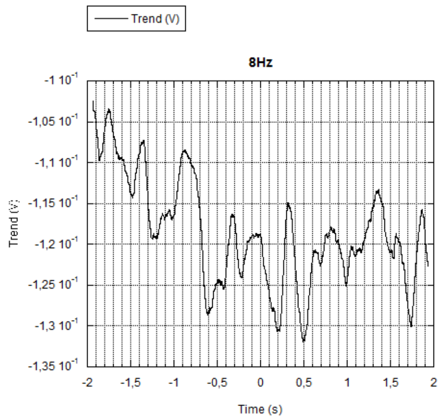
Sinus (V)
6Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 8,3706e-6 6,3314e-5
m2 0,10849 8,9555e-5
m3 -0,44826 2,2172e-5
m4 6,0003 4,6311e-5
Chisq 0,38745 NA
R 0,99667 NA
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
Sinus (V)
-0,5
0
0,5
1
1,5
2
Time (s)

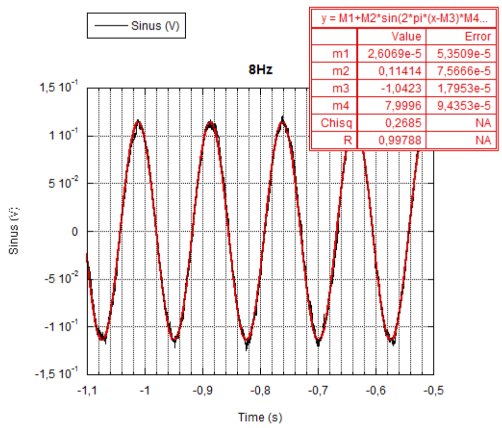

Tension (V)
7Hz
Tension (V)
Time (s)

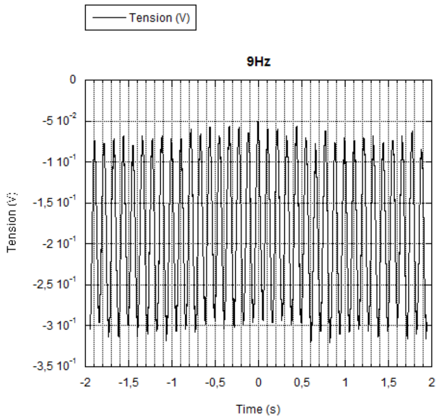

Trend (V)
7Hz
Trend (V)
Time (s)

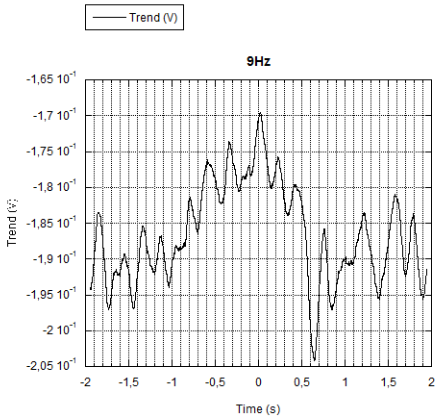

Sinus (V)
7Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value
Error
m1 6,3095e-5 6,0239e-5
m2 0,1113 8,5157e-5
m3 -1,3947 2,7868e-5
m4 7,0006 0,00010948
Chisq 0,33708 NA
R 0,99719 NA
Sinus (V)
Time (s)

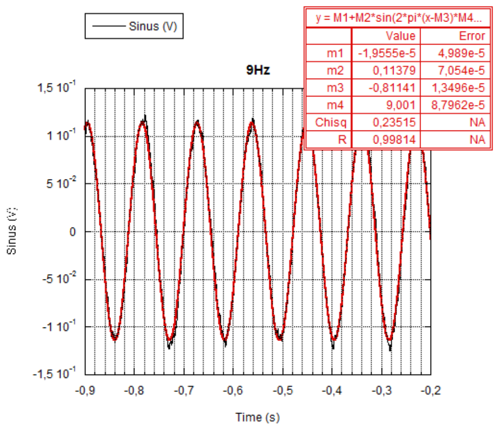

Tension (V)
8Hz
Tension (V)
5 10-2
0
-5 10-2
-1 10-1
-1,5 10-1
-2 10-1
-2,5 10-1
-3 10-1
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
Time (s)

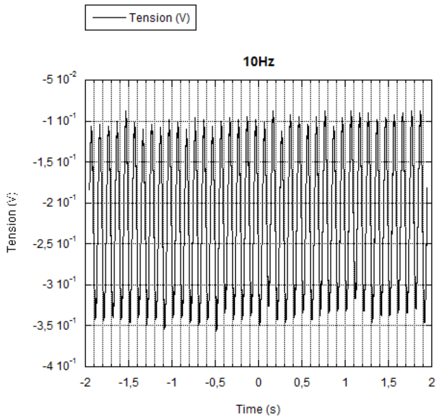

Trend (V)
8Hz
Trend (V)
-1 10-1
-1,05 10-1
-1,1 10-1
-1,15 10-1
-1,2 10-1
-1,25 10-1
-1,3 10-1
-1,35 10-1
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
Time (s)

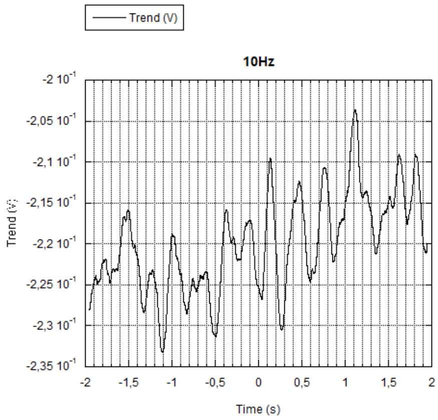

Sinus (V)
8Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value
Error
m1
2,6069e-5
5,3509e-5
m2
0,11414
7,5666e-5
m3
-1,0423
1,7953e-5
m4
7,9996
9,4353e-5
Chisq
0,2685
NA
R
0,99788
NA
Sinus (V)
1,5 10-1
1 10-1
5 10-2
0
-5 10-2
-1 10-1
-1,5 10-1
-1,1
-1
-0,9
-0,8
-0,7
-0,6
-0,5
Time (s)

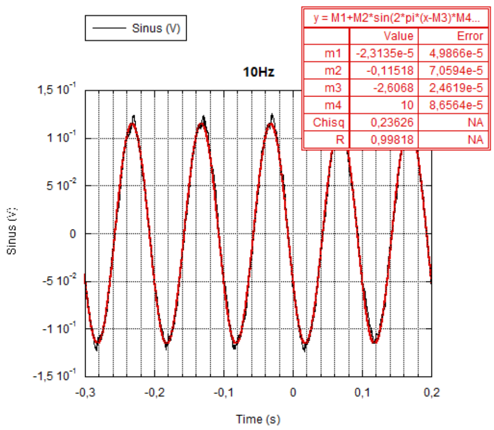

Tension (V)
9Hz
Tension (V)
Time (s)

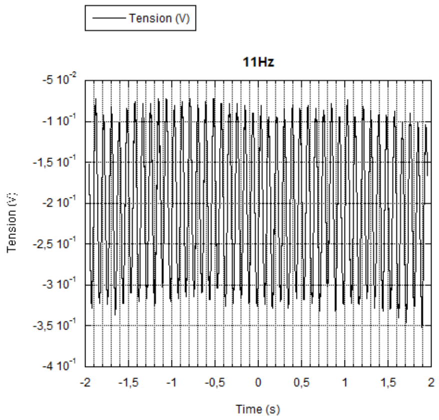

Trend (V)
9Hz
Trend (V)
Time (s)

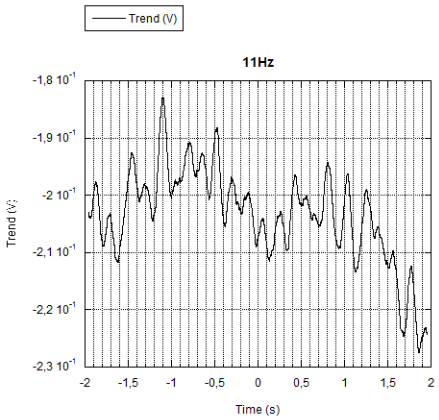

Sinus (V)
9Hz
Sinus (V)
Time (s)
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -1,9555e-5 4,989e-5
m2 0,11379 7,054e-5
m3 -0,81141 1,3496e-5
m4 9,001 8,7962e-5
Chisq 0,23515 NA
R 0,99814 NA

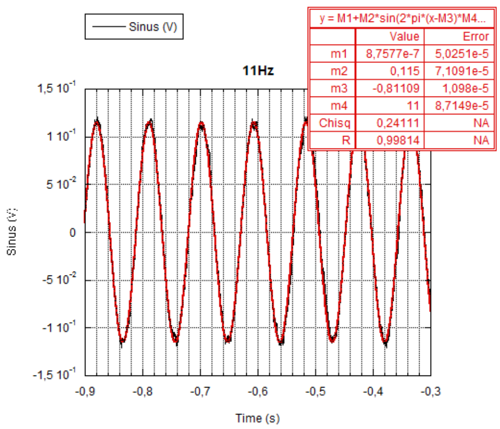

Tension (V)
10Hz
Tension (V)
Time (s)

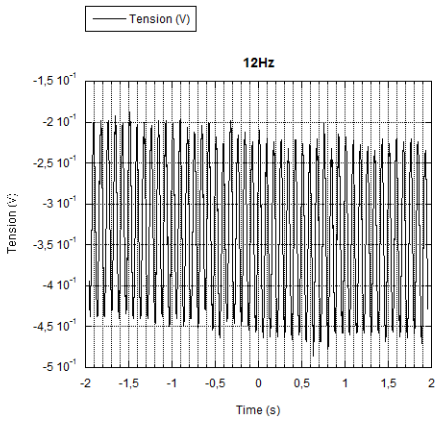

Trend (V)
10Hz
Trend (V)
Time (s)

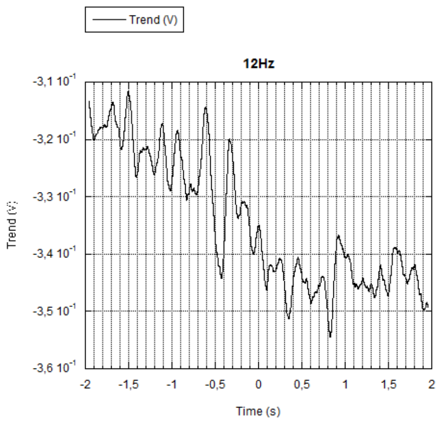

Sinus (V)
10Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -2,3135e-5 4,9866e-5
m2 -0,11518 7,0594e-5
m3 -2,6068 2,4619e-5
m4 10 8,6564e-5
Chisq 0,23626 NA
R 0,99818 NA
Sinus (V)
Time (s)

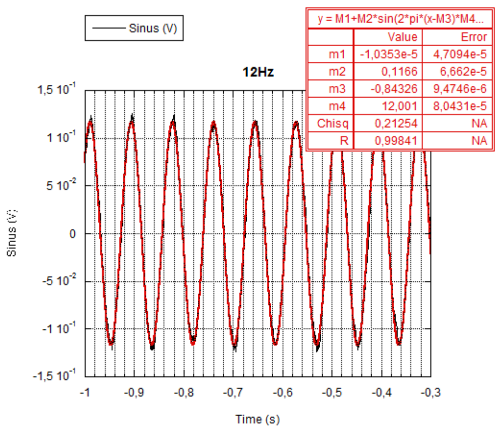

Tension (V)
11Hz
Tension (V)
-5 10^-2
-1 10^-1
-1,5 10^-1
-2 10^-1
-2,5 10^-1
-3 10^-1
-3,5 10^-1
-4 10^-1
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
Time (s)

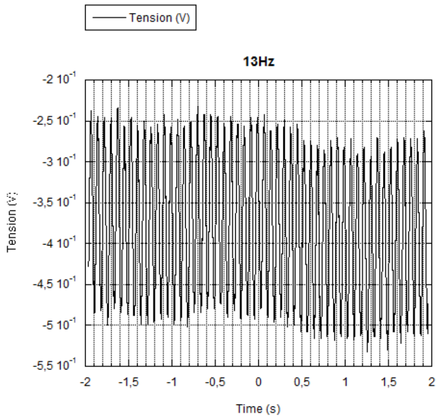

Trend (V)
11Hz
Trend (V)
-1,8 10^-1
-1,9 10^-1
-2 10^-1
-2,1 10^-1
-2,2 10^-1
-2,3 10^-1
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
Time (s)

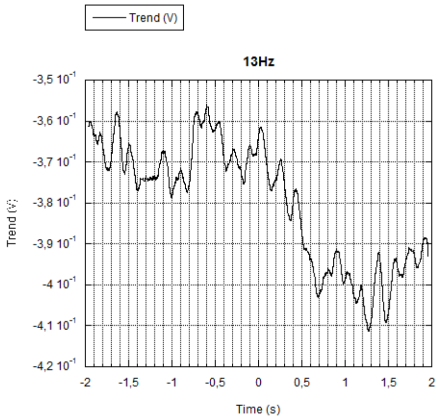

Sinus (V)
11Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 8,7577e-7 5,0251e-5
m2 0,115 7,1091e-5
m3 -0,81109 1,098e-5
m4 11 8,7149e-5
Chisq 0,24111 NA
R 0,99814 NA
Sinus (V)
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
-0,9
-0,8
-0,7
-0,6
-0,5
-0,4
-0,3
Time (s)

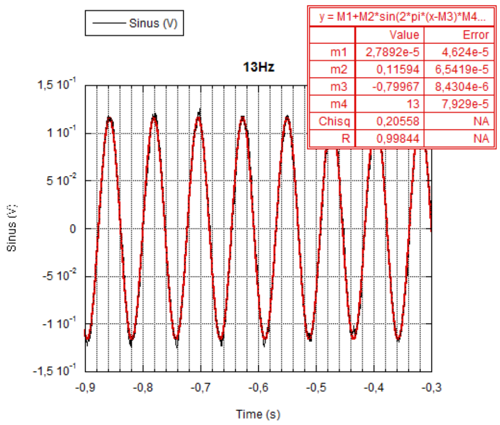

Tension (V)
12Hz
Tension (V)
Time (s)

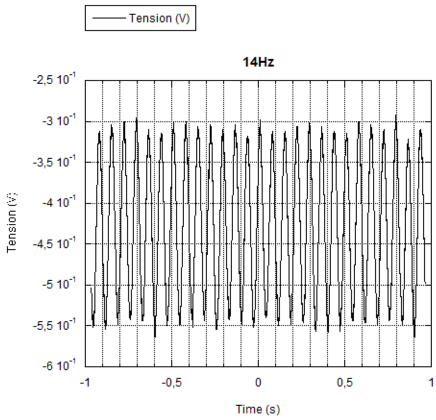

Trend (V)
12Hz
Trend (V)
Time (s)

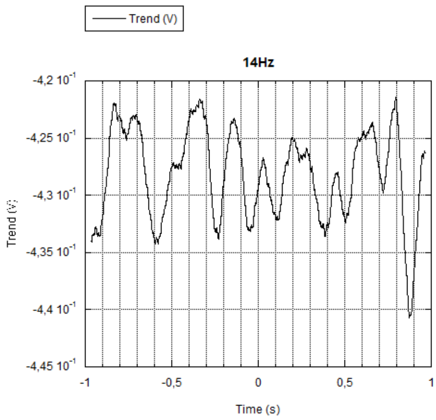

Sinus (V)
12Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -1,0353e-5 4,7094e-5
m2 0,1166 6,662e-5
m3 -0,84326 9,4746e-6
m4 12,001 8,0431e-5
Chisq 0,21254 NA
R 0,99841 NA
Sinus (V)
Time (s)

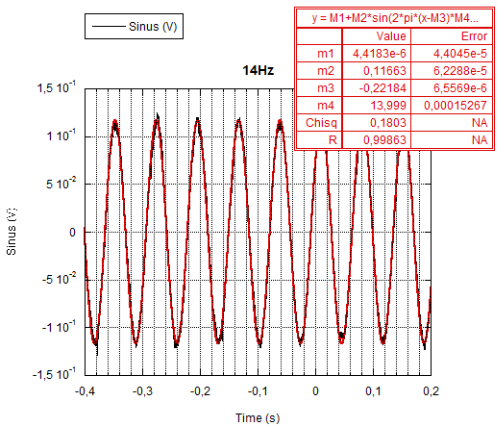

Tension (V)
13Hz
Tension (V)
Time (s)
-2 10^-1
-2,5 10^-1
-3 10^-1
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
-5,5 10^-1
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2

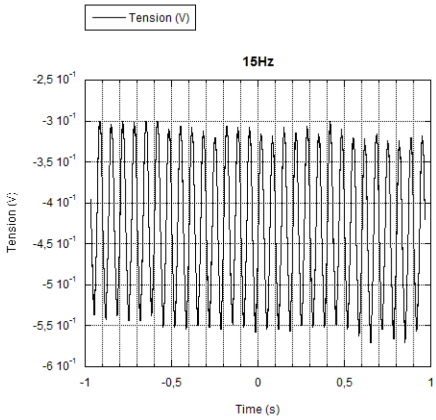

Trend (V)
13Hz
Trend (V)
Time (s)
-3,5 10^-1
-3,6 10^-1
-3,7 10^-1
-3,8 10^-1
-3,9 10^-1
-4 10^-1
-4,1 10^-1
-4,2 10^-1
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2


Sinus (V)
13Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value
Error
m1 2,7892e-5 4,624e-5
m2 0,11594 6,5419e-5
m3 -0,79967 8,4304e-6
m4 13 7,929e-5
Chisq 0,20558 NA
R 0,99844 NA
Sinus (V)
Time (s)
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
-0,9
-0,8
-0,7
-0,6
-0,5
-0,4
-0,3

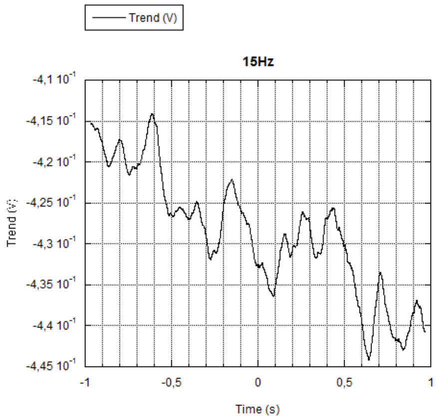

Tension (V)
14Hz
-2,5 10^-1
-3 10^-1
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
-5,5 10^-1
-6 10^-1
Tension (V)
-1
-0,5
0
0,5
1
Time (s)


Trend (V)
14Hz
-4,2 10^-1
-4,25 10^-1
-4,3 10^-1
-4,35 10^-1
-4,4 10^-1
-4,45 10^-1
Trend (V)
-1
-0,5
0
0,5
1
Time (s)

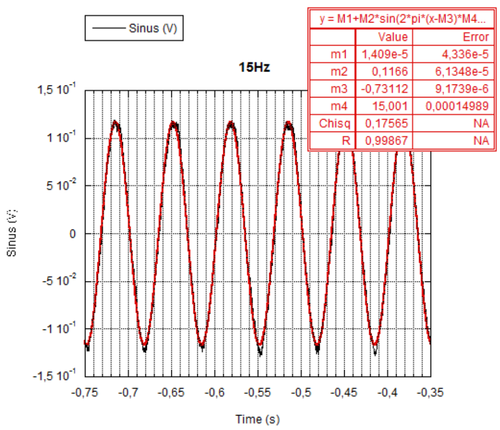

Sinus (V)
14Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 4,4183e-6 4,4045e-5
m2 0,11663 6,2288e-5
m3 -0,22184 6,5569e-6
m4 13,999 0,00015267
Chisq 0,1803 NA
R 0,99863 NA
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
Sinus (V)
-0,4
-0,3
-0,2
-0,1
0
0,1
0,2
Time (s)



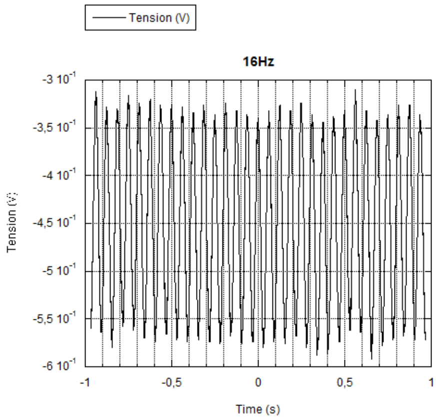
Tension (V)
15Hz
Tension (V)
Time (s)

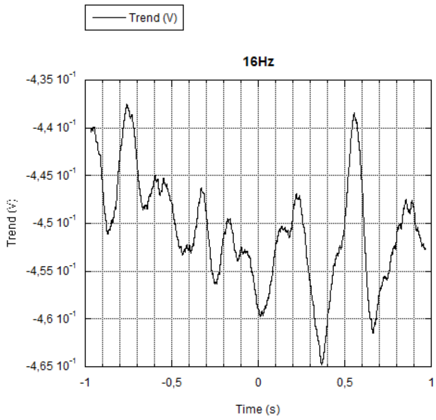


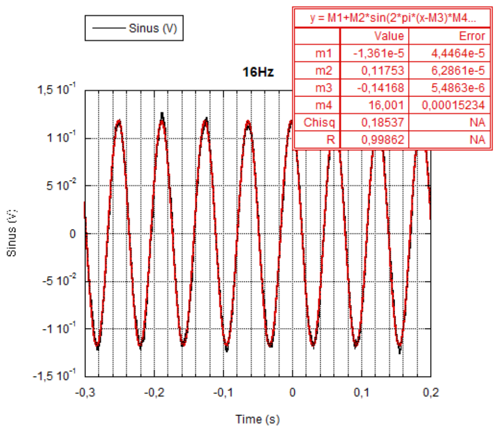
Trend (V)
15Hz
Trend (V)
Time (s)

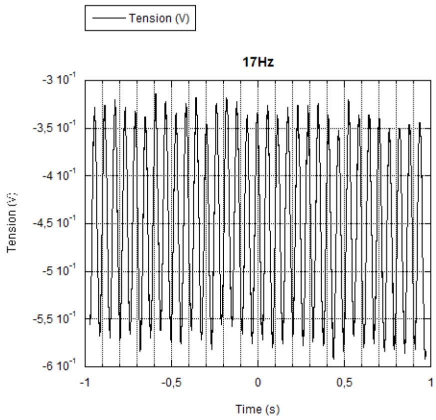


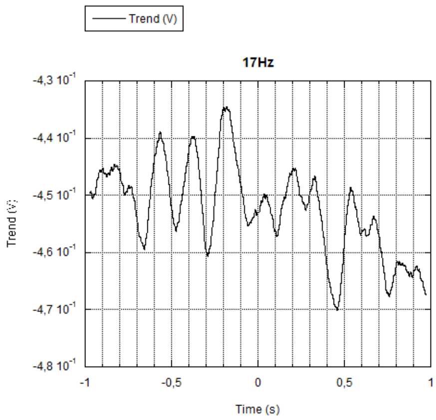
Sinus (V)
15Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
	Value	Error
m1	1,409e-5	4,336e-5
m2	0,1166	6,1348e-5
m3	-0,73112	9,1739e-6
m4	15,001	0,00014989
Chisq	0,17565	NA
R	0,99867	NA
Sinus (V)
Time (s)

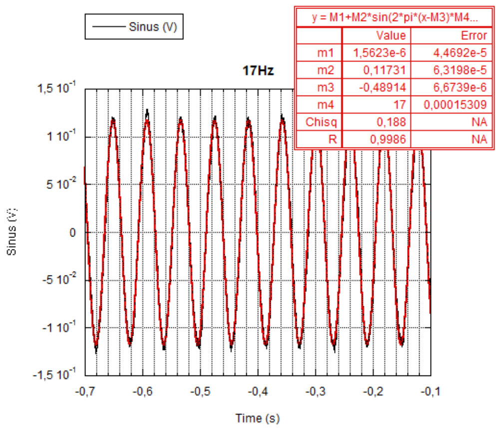

Tension (V)
16Hz
Tension (V)
-3 10^-1
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
-5,5 10^-1
-6 10^-1
-1
-0,5
0
0,5
1
Time (s)

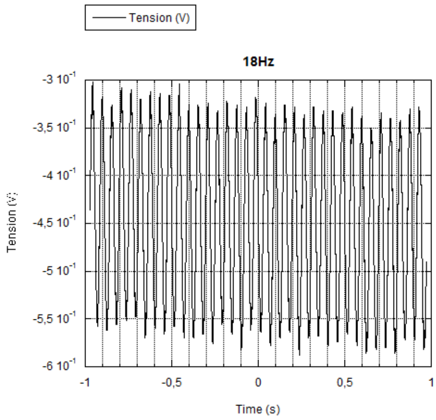

Trend (V)
16Hz
Trend (V)
-4,35 10^-1
-4,4 10^-1
-4,45 10^-1
-4,5 10^-1
-4,55 10^-1
-4,6 10^-1
-4,65 10^-1
-1
-0,5
0
0,5
1
Time (s)

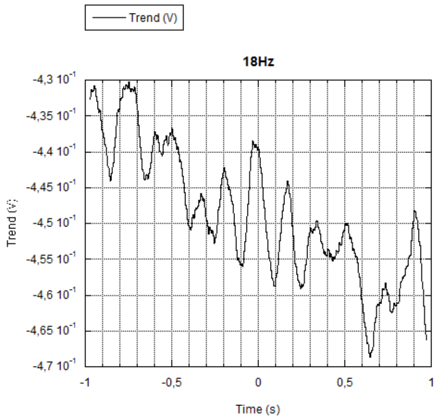

Sinus (V)
16Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -1,361e-5 4,4464e-5
m2 0,11753 6,2861e-5
m3 -0,14168 5,4863e-6
m4 16,001 0,00015234
Chisq 0,18537 NA
R 0,99862 NA
Sinus (V)
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
-0,3
-0,2
-0,1
0
0,1
0,2
Time (s)

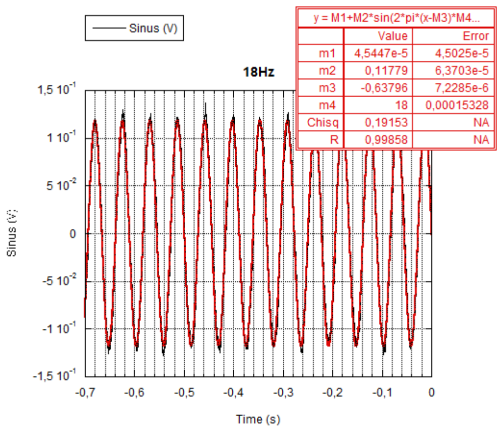

Tension (V)
17Hz
-3 10^-1
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
-5,5 10^-1
-6 10^-1
Tension (V)
-1
-0,5
0
0,5
1
Time (s)

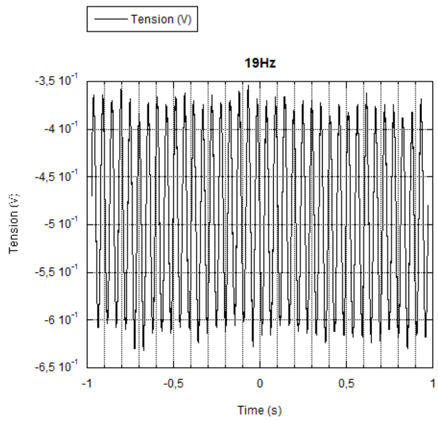

Trend (V)
17Hz
-4,3 10^-1
-4,4 10^-1
-4,5 10^-1
-4,6 10^-1
-4,7 10^-1
-4,8 10^-1
Trend (V)
-1
-0,5
0
0,5
1
Time (s)

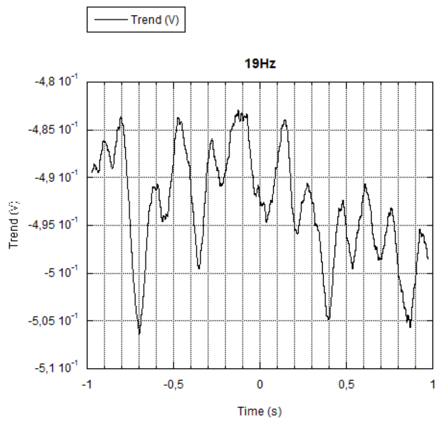

Sinus (V)
17Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 1,5623e-6 4,4692e-5
m2 0,11731 6,3198e-5
m3 -0,48914 6,6739e-6
m4 17 0,00015309
Chisq 0,188 NA
R 0,9986 NA
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
Sinus (V)
-0,7
-0,6
-0,5
-0,4
-0,3
-0,2
-0,1
Time (s)

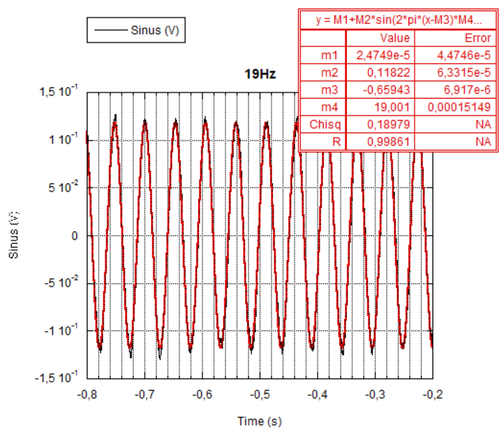

Tension (V)
18Hz
Tension (V)
Time (s)

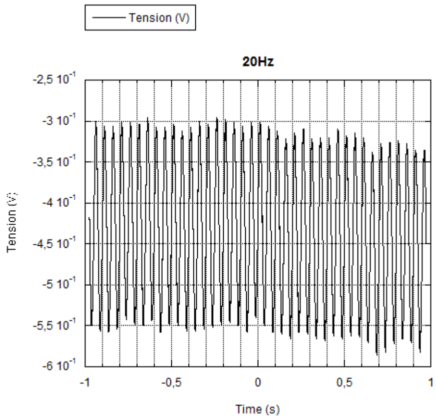

Trend (V)
18Hz
Trend (V)
Time (s)

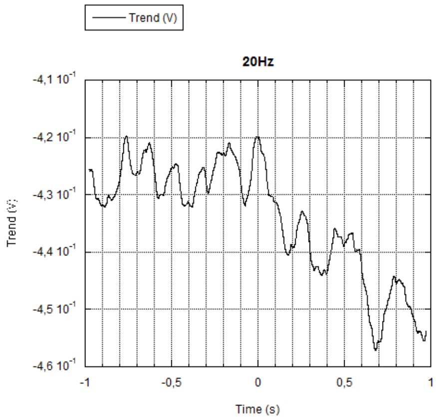

Sinus (V)
18Hz
Sinus (V)
Time (s)
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 4,5447e-5 4,5025e-5
m2 0,11779 6,3703e-5
m3 -0,63796 7,2285e-6
m4 18 0,00015328
Chisq 0,19153 NA
R 0,99858 NA

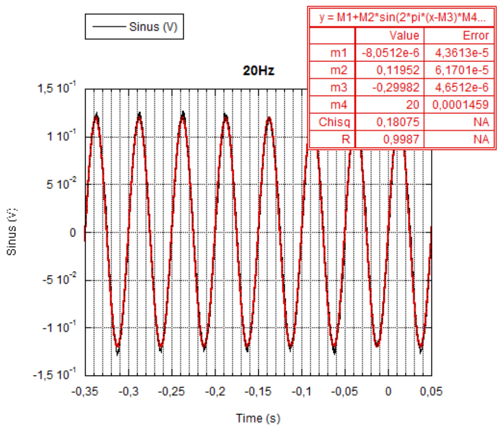

Tension (V)
19Hz
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
-5,5 10^-1
-6 10^-1
-6,5 10^-1
Tension (V)
-1
-0,5
0
0,5
1
Time (s)


Trend (V)
19Hz
-4,8 10^-1
-4,85 10^-1
-4,9 10^-1
-4,95 10^-1
-5 10^-1
-5,05 10^-1
-5,1 10^-1
Trend (V)
-1
-0,5
0
0,5
1
Time (s)


Sinus (V)
19Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 2,4749e-5 4,4746e-5
m2 0,11822 6,3315e-5
m3 -0,65943 6,917e-6
m4 19,001 0,00015149
Chisq 0,18979 NA
R 0,99861 NA
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
Sinus (V)
-0,8
-0,7
-0,6
-0,5
-0,4
-0,3
-0,2
Time (s)


Tension (V)
20Hz
-2,5 10^-1
-3 10^-1
-3,5 10^-1
-4 10^-1
-4,5 10^-1
-5 10^-1
-5,5 10^-1
-6 10^-1
Tension (V)
-1
-0,5
0
0,5
1
Time (s)


Trend (V)
20Hz
-4,1 10^-1
-4,2 10^-1
-4,3 10^-1
-4,4 10^-1
-4,5 10^-1
-4,6 10^-1
Trend (V)
-1
-0,5
0
0,5
1
Time (s)


Sinus (V)
20Hz
y = M1+M2*sin(2*pi*(x-M3)*M4...
Value Error
m1 -8,0512e-6 4,3613e-5
m2 0,11952 6,1701e-5
m3 -0,29982 4,6512e-6
m4 20 0,0001459
Chisq 0,18075 NA
R 0,9987 NA
1,5 10^-1
1 10^-1
5 10^-2
0
-5 10^-2
-1 10^-1
-1,5 10^-1
Sinus (V)
-0,35
-0,3
-0,25
-0,2
-0,15
-0,1
-0,05
0
0,05
Time (s)

Chapter 5

Acknowledgements

I would like to acknowledge Jan Harms and Vladimir Dergachev for their help and important suggestions, but I'm above all particular greatful to my mentor Riccardo DeSalvo, who helped me during all my work, and showed me for the first time in my life what to be a physicist means.