OPTIMIZATION OF AN INDUCTION COIL FOR ULF

This paper is to dimostrate how to is possible to optimize an induction coil for ULF band (0.1-30Hz). My realization was inspire to Hans Michlmayr project. My coil is a 70.000 turn of 0.3 mm enamelled copper wire (about 10 Kg). The coil former is a 800 mm length of 50 mm dia of PVC (orange kind) pipe. The end flanges are 50 mm (internal dia) and 85 mm (external dia) from 5 mm teflon sheet.

1. The coil

How is possible to arrive to optimize our induction coil? We know that:

$V_{out} = output\ voltage$

$A = Loop\ area$

$N = Number\ of\ turns$

$Q = \ Q\ of\ the\ Loop$

$H_0 = Applied\ magnetic\ field$

$\lambda = wavelength$

$\mu^I = \mu_{rod}\ X\ \sqrt[3]{L/D}\quad L = Length\ D = diameter\ of\ rod$

$\cos\sigma = \cos ine\ of\ the\ angle\ between\ loop\ axis\ and\ the\ field$

$$V_{out} = \frac{2\pi\ A\ N\ \mu^I Q\ H_0 \cos\sigma}{\lambda}$$

$$In\ ULF\ band\ we\ havea\ \ \lambda = \frac{c}{f} \cong 20.000 Km = 20 \times 10^3 m$$

From this equation we can immediatly understand that much important parameter are: N and A.

The product suggests a kind of merit of our coil that we can call Ae (effective aperture) give by the product between Area and number of turns so we have to maximizing it. In ULF we have a very big wavelength and large structures can give problems with dimensional stability and it is not too easy to screen out the large induced voltage at radio frequency.

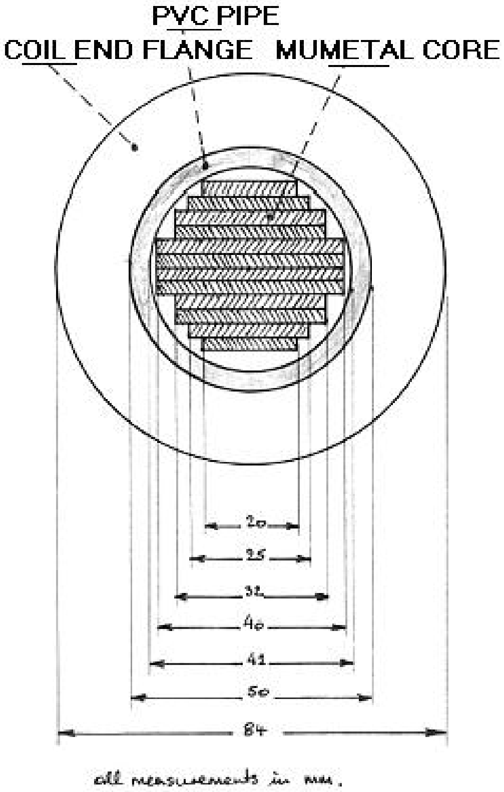
The Ae of my coil is: $A = \frac{\pi}{4}(D_{\max})^2 = \frac{\pi}{4}(0.085)^2 = 0.0057 m^2$

The number of turns is 70.000, and so the aperture is: $A_e = 70.000 \times 0.0057 \cong 400 m^2$

The experience says that the limit to receive Schumann resonance is around 1000 mq, how can we do to encrese it? We have now only other two parameter Q and µ. The Q is worst when the coil is concentrated in a small portion of the rod length, than to improve Q we have to wind the coil over the entire length of the rod. The µ , magnetic permeability, could be encrese by using a very high permeability material for our rod (µmetal, permalloy, ferrite). The same total flux (HxA) can be carried by cross section, this allow you to reduce the amount of wire for the same number of turns.

Material	B (Gauss)	Permeability µ	Cost
Soft Iron	0.1 Gauss	100	Low
Special steel	6000 Gauss	800÷1200	Med
Permalloy®	40 Gauss @60Hz	50.000÷65.000	High
Mumetal®	100 Gauss	70.000	High
Alloy48®	2000 Gauss @60Hz	50.000÷11.000	High

The best problem is the very high cost of this material, I resolve this to recover µmetal where it just was. In a little research I discover that all around of cathodic tube we can recovering about half a meter of µmetal. Be attention, not all cathodic tube but only which are used in measures device likes oscilloscope or spectrum analyser. Now we have to cut µmetal and building our core like in Hans Michlmayr project. Remember to insulate each from the other all sheep of µmetal to evitate to absorb a lot of signal from the coil.

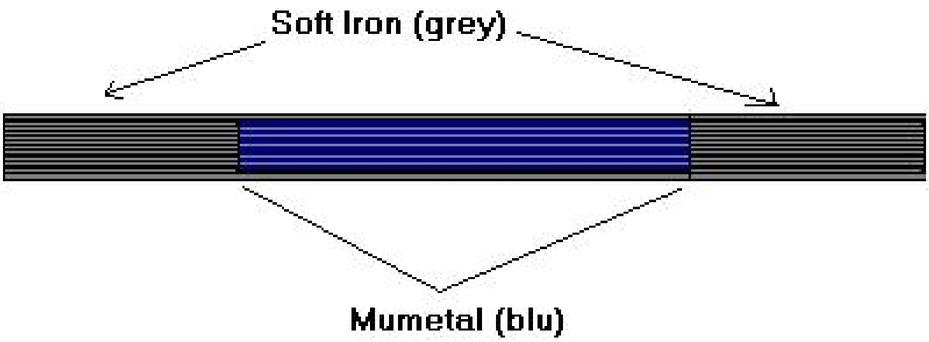


2. The core

With this expedient the effective area increases; another important parameter is the length of the core (L), to encrease we must have a long core at about 6 meter .

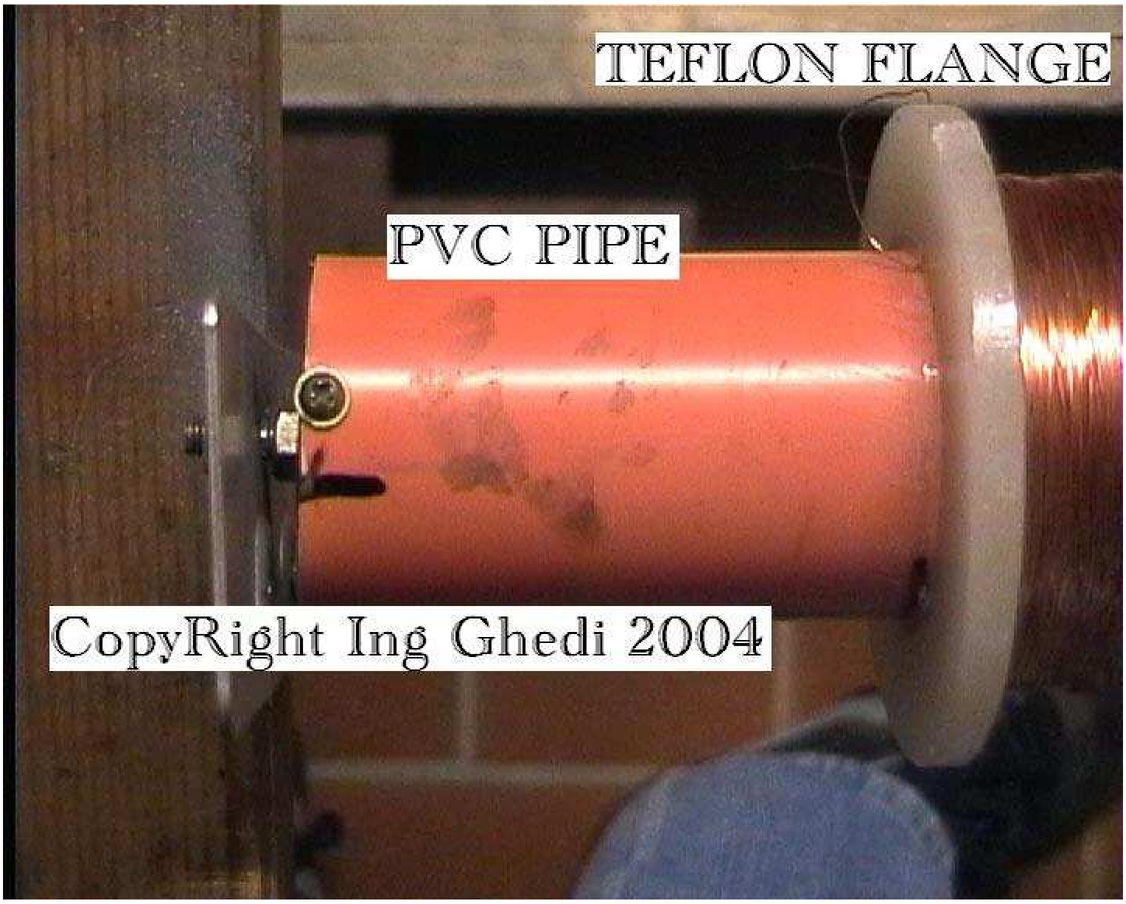
$$\mu^I = \mu_{rod}\ X\ \sqrt[3]{L/D}\quad L = Length\ \ D = diameter\ of\ rod$$

To resolve the expencivity of mumetal to realize a six meter core we can make like in figure:



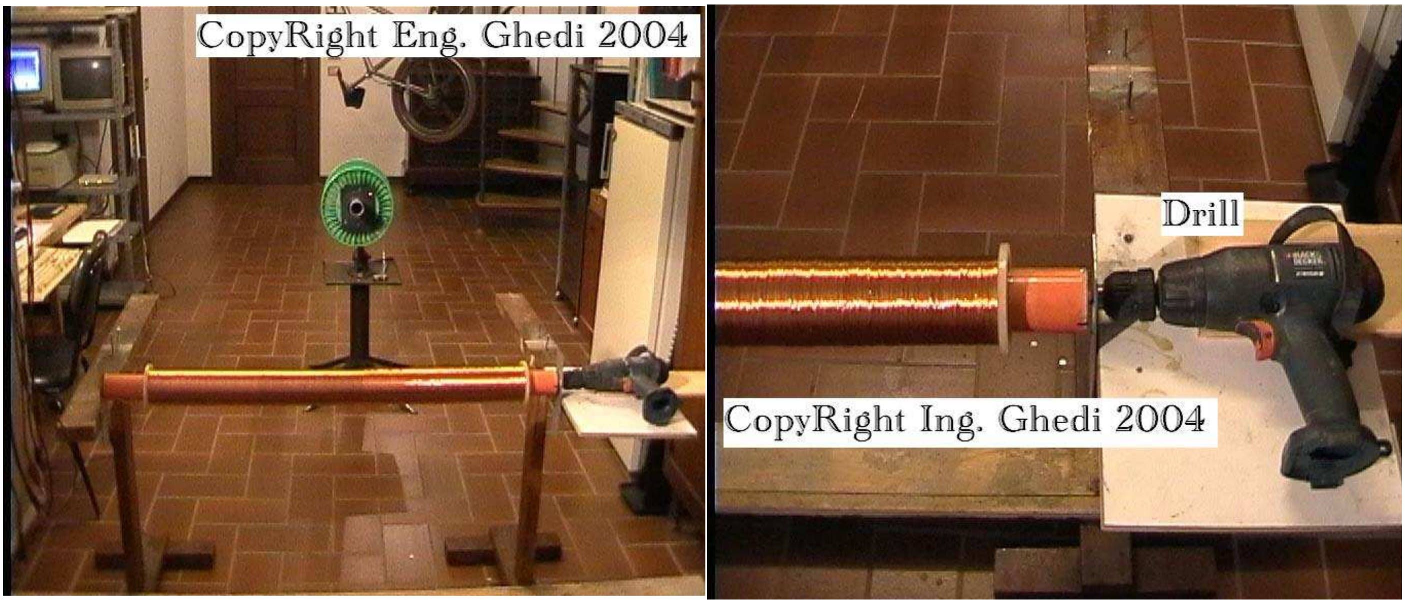
3. Core composition

You can using a small mumetal core (blu) inside the coil pipe and soft iron ends (grey) outside the coil to reach six meter length. This would keep the cost and the Johnson noise of the coil low.



4.

The practical realisation of the coil is not difficult but you need a lot of patient. The winding was controlled by a vel regulated drill and in the order of several hundred round per minute, every 5 layer of wire I put a DMD 0222 overcoating glue (incralac).



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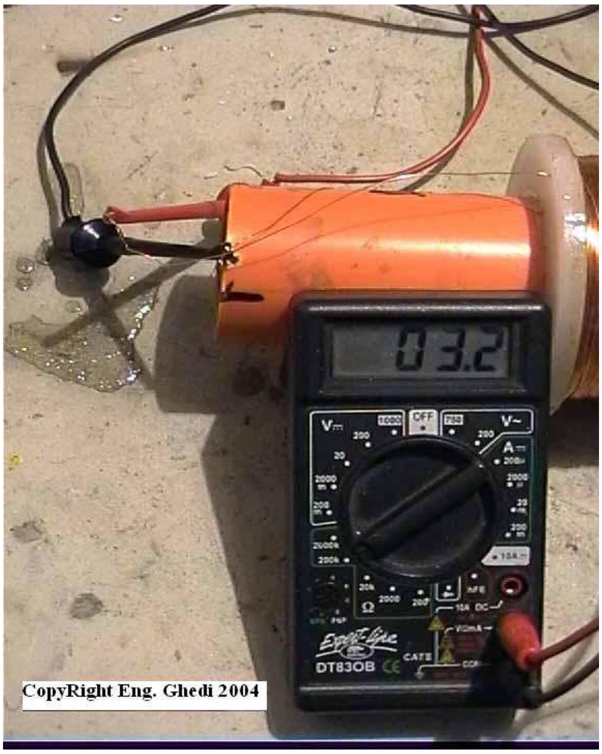


6. Final impedance is 3.2 KOhm and the inductance 11H

To guarantee an efficent shielding versus electrostatic and electric field is necessary to create a good shielding made by metallic of a tickness given by:

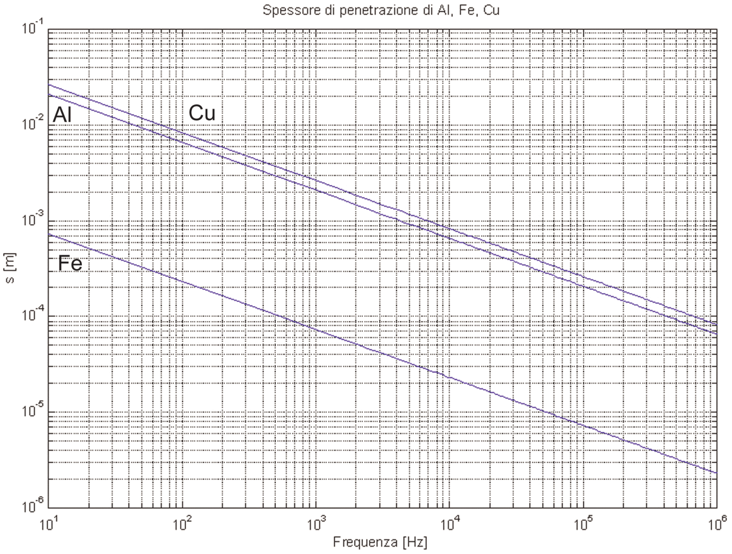
$$s := \sqrt{\frac{\rho}{\pi \cdot f \cdot \mu}} \quad [m]$$

f is the frequency [Hz]

ρ is electrical permeabilità of the shield [Ω m]

μ is the magneti permeabilità of the shield [H m^{-1}]

		ρ [Ω m]	**μ [H m^{-1}]**
Al	Aluminium	$27 \cdot 10^{-9}$	$1.257 \cdot 10^{-6}$
Fe	Iron	$105 \cdot 10^{-9}$	$6.243 \cdot 10^{-3}$
Cu	Copper	$17 \cdot 10^{-9}$	$1.257 \cdot 10^{-6}$

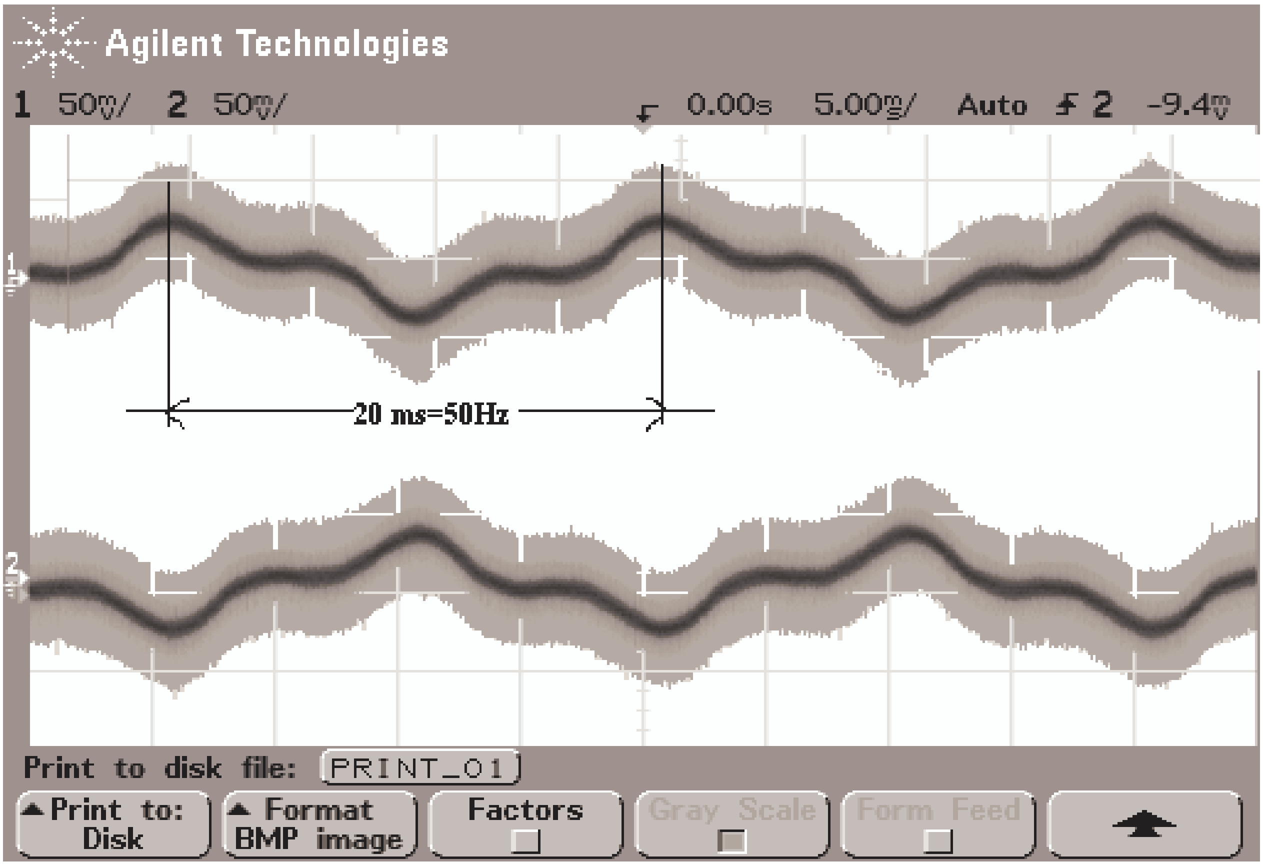


The shielding could be consider very good when the tickness is about 5s. From the table we can have that iron is the best but for is heaviness and corrosin is not very well than I deceding for aluminium.

$$s := \sqrt{\frac{27\cdot10^{-9}}{\pi\cdot15\cdot1{,}257\cdot10^{-6}}} \quad = 0.0214m$$

But unfortunaty 10 cm is to much for realizing my aluminium shielding!! The idea is winding iron net around the coil (Attention do not made short circuit with coil), connect the net shield to a aluminium box where the coil could be in. So I can overwork the good shielding quality of iron and the lightness of aluminium to reject eletrostatic charge .

We must to find onother solution to minimize EMI interference; if we put oscilloscope proble at the coil ends we can see a very strong 50 Hz signal, (Fig.7)



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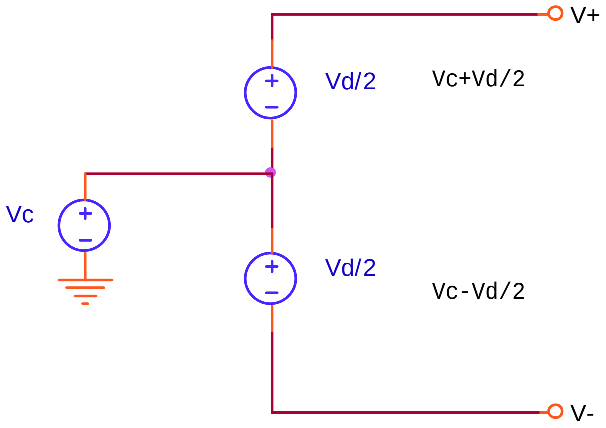
7. Differential signal at coil ends

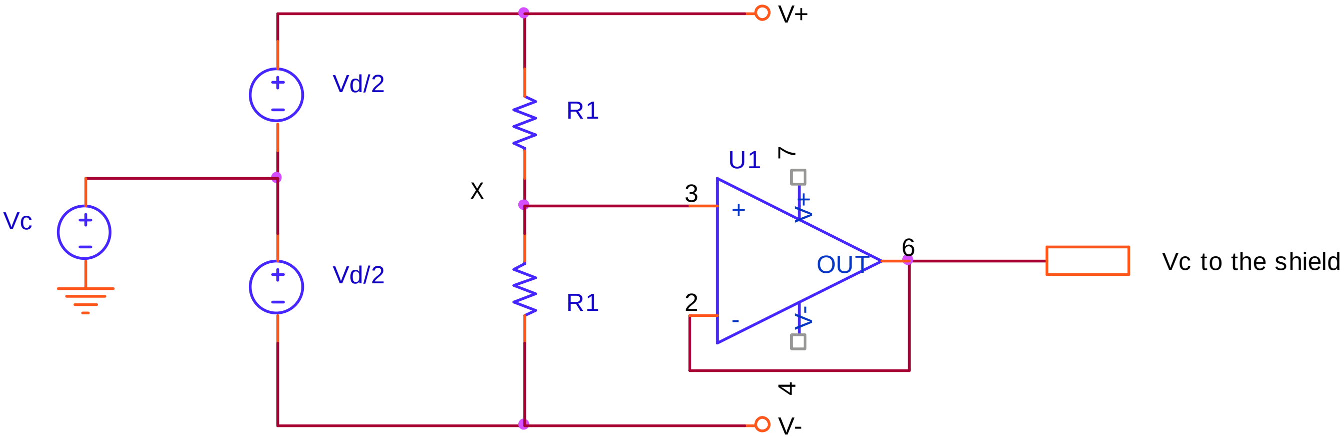
In fact our coil is plunged in the line voltage eletromagnetic field, we have a big common mode signal Vc (mV) and a little differential signal Vd (uV) on the differential amplifier input, pe like in the model fig. 8..



8. Coil electric scheme

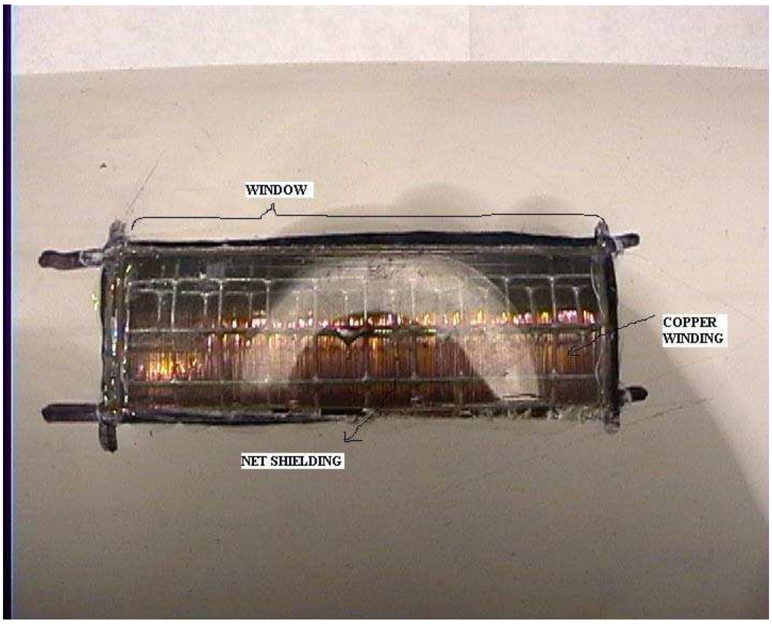
The CM (Common Mode) noise could be minimize with an hight CMRR (common mode reaction ratio) OpAmp (about 120dB) but if we put the shielding at earth ground we have some part ogf CM noise added to differential signal (parassite capacity) without the possibility to minimize it.

To solve this problem I realizing circuit (fig.9), in fact in X we have exactly Vc .

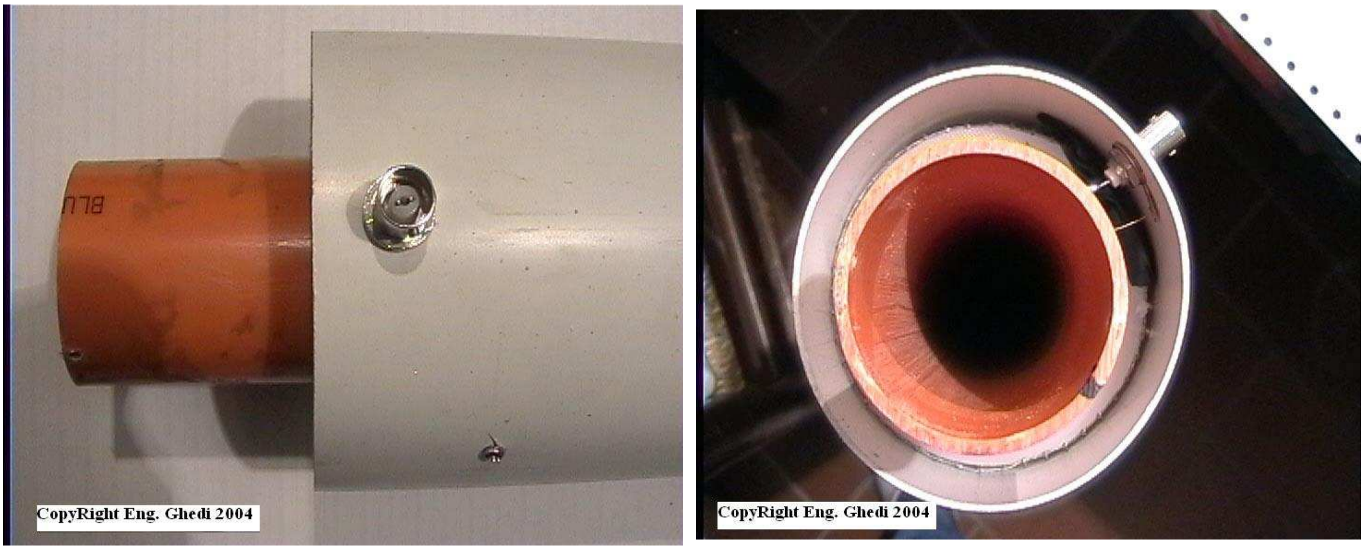


9. Vc circuit

The CM voltage could be connect to the shield by a buffer, is important to use shielding cable (STP Cat 5) to connect coil to differential OpAmp and link cable shield to Vc.



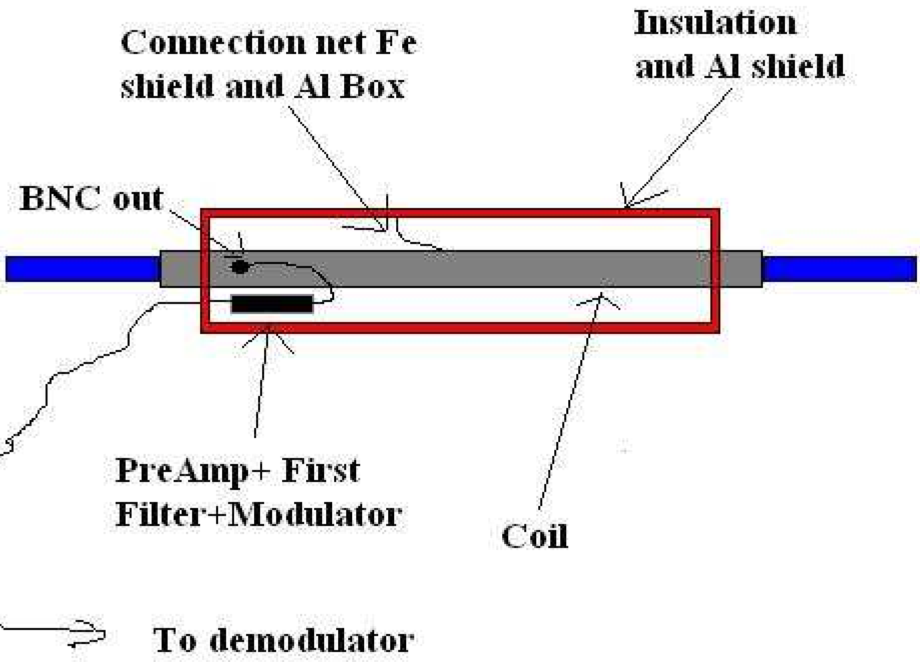
10.



11.

The antenna box could guarentee a little EMI shielding but is much important to reduce 1/f noise.My idea is to create a termical insulation between insulating panels inside the aluminium box, than like in ULFO receiver project insert the first amplification stage and the modulator in the box to guarentee to reduce the fknee of the devices out of the lock-in ring. To do that the antenna, the preamplifier and the first filter have been thermalized and all devices chosen in order to have the minimum 1/f noise and encrese low signal near DC.

For other kind of realization is possible to put all front end in to the box to minimize termical fluctation beetween coil and first amplification stage.



12. Final realization scheme and images

Aluminium Shield

Termical Insulation

Induction Coil