Tentative Magnetic Noise Limit for AdV compared with the estimated noise from High-Voltage power lines

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This note is meant to help in the definition of the maximum magnetic noise that AdV can tolerate. The limit holds in general both for internal and external sources. With “internal” sources we mean the Virgo infrastructure devices (buildings infrastructures, vacuum infrastructures, Virgo electronics). With “external” we mean sources external to EGO, among which a potentially relevant one are HV power lines. In Section 1 we present a rough evaluation of magnetic noise projection for AdV which is extrapolated from the measurements done in Virgo/Virgo+. In Section 2 we use a simple physics model to estimate the magnetic field noise from one 3-phase High-Voltage line, as function of distance from Virgo and as function of the electrical current and for different geometries.

1. Limit on magnetic noise for AdV

We want to define the maximum magnetic field spectral noise inside the Virgo experimental buildings which can be tolerated by Advanced Virgo. This value must be such to not to affect sensibly the AdV design sensitivity, that is to say should be a factor 5 to 10 below the AdV design.

The know mechanism of magnetic noise coupling to hrec is through forces exerted by the B field on the magnets glued on suspended mirrors which produce a displacement of such mirrors resulting in a length noise. We do not know at the moment other relevant mechanisms. We make a tentative projection using the formula [1]:

(Eq.1) $\tilde{h}_{mag}(f) = TF(f) \cdot \tilde{B}(f)$

Here “TF” measures the coupling of the magnetic field spectral noise to the strain spectral noise. And “B(f)” is the spectral noise of the magnetic field modulus which is sensed by the mirror. In practice “B” is measured by one external probe placed at some distance from the mirror. Eq.1 holds exactly in the hypothesis the magnetic probe and the mirror sense the same magnetic field, and this is true only if the magnetic field is not distorted by magnetic noise sources which are close (i.e. in the "near field") of the mirror or the probe, or, let us say, it is valid for magnetic noise from sources placed in the Far Field (FF) of both the mirror and the probe. The "TF" has been measured (B.Swinkels) injecting magnetic noise with one big coil placed as far as practically possible from both mirrors and the magnetic probe. This has been measured for the CB with Virgo payloads (eLog 22108). We can try to extrapolate this TF to the one expected for AdV in the CB. A comparison of magnetic injections done with a small coil in the proximity (inside the towers "oven") of input Virgo mirrors (NI and WI) and repeated with input Virgo+ mirrors (eLog 28260) allows to estimate the magnetic noise coupling reduction associated to the new dielectric Reference Mass (RM) in place of the old aluminum RM. This is estimated to be about a factor 5 (i.e. it is measured a factor 4 for the WI and 7 for NI). The same dielectric RM is at the moment foreseen for all AdV mirrors, and as well the same magnets actuation system is foreseen for AdV. In addition, the magnetic coupling is not expected to change with the arms finesse (F), while we expect the BS mirror coupling to reduce proportionally to the increase of Finesse. The TF for AdV central area could be thus extrapolated by reducing the measured Virgo TF by a factor 5. This is the TF we use in the following, although (as explained in comments at the end of this section) we believe this is likely to be an overestimate.

As for $\tilde{B}(f)$, we use the amplitude spectrum of magnetic field modulus measured in the Central Building (CB) by the *EnvMon* magnetometer triplet which is permanently located on the floor on the N side of the SR tower. The amplitude spectrum of the magnetic field modulus is computed taking the square root of the sum of the square of the spectral noise amplitude of the 3 axis components. Figure 1 shows this measurement (black line).

Also shown in Figure 1 is the lower noise measured when all CB electronic was moved for test from UPS to IPS (red line) (eLog 28474 25397). Our understanding is that the present magnetic noise in CB is due to noise of the UPS voltage which is radiated as magnetic noise by the several power supply of the front end electronics located close to the suspended mirrors in CB.

Also shown in Figure 1 are limits of magnetic noise from external sources proposed for the *Piano Territoriale di Coordinamento* of the *Provincia di Pisa* [2] ([*]):

(Eq.2) $\tilde{B}(f) < 0.5\, nT/\sqrt{Hz}$ at f=50Hz and harmonics, (dashed green line);

(Eq.3) $\tilde{B}(f) < 5\, pT/\sqrt{Hz}$ for frequencies between 50Hz harmonics (dashed blue line).

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[*] A preliminary version of this document exists (reference [1]) which defines the maximum noise levels that can be added at EGO from sources of seismic, acoustic and EM noises located in the territory. A final version of this document is under preparation. This new document, besides revising limits and measuring procedures, is also going to (following an explicit request by the *Provincia di Pisa*) set more manageable criteria for defining which activities or infrastructure works on the territory require attention. These criteria would be for example based on the type, characteristics of the source and its distance from EGO.

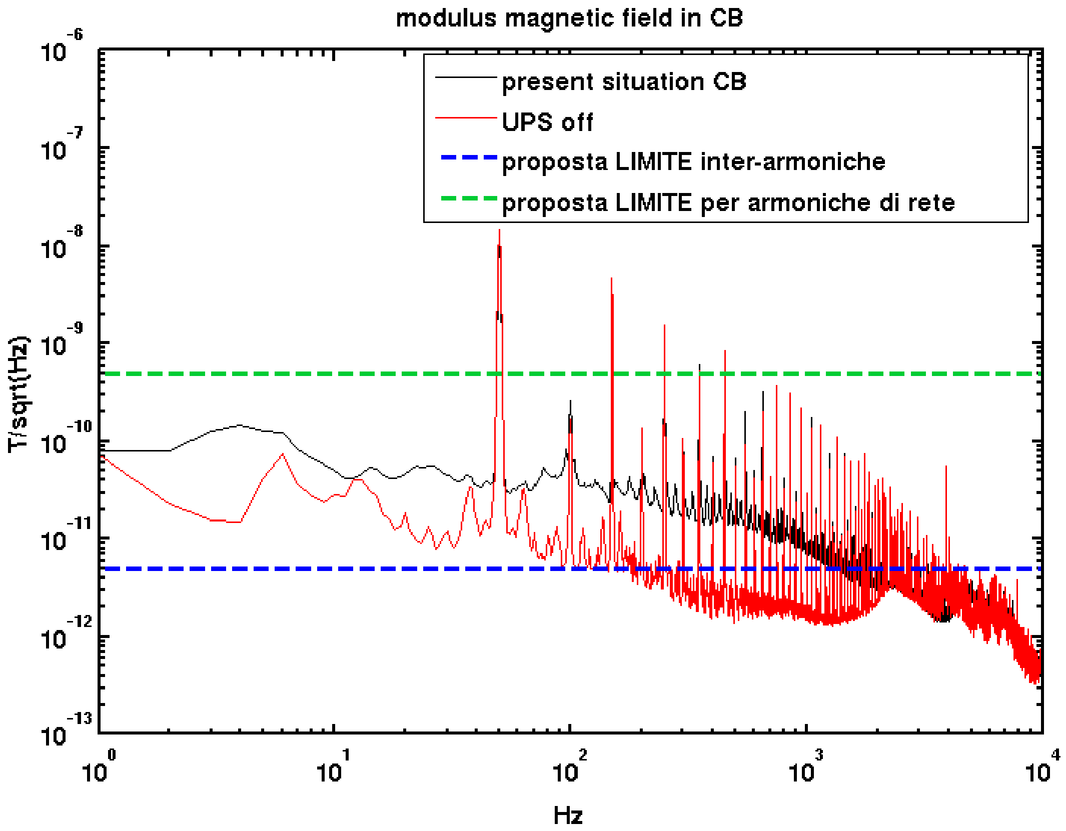

Figure 1. Amplitude Spectral Noise of Modulus of Magnetic field inside Virgo Central Building: present condition (black); when UPS electronics is switched to IPS power line (ENEL); proposed limits for PTC on 50Hz and multiples (green dashed) and for the inter-50Hz harmonics region (blue dashed).

Figure 2 below shows the projected h_{mag} noise of (Eq.1) corresponding to the different $\tilde{B}(f)$ noises of Figure 1.

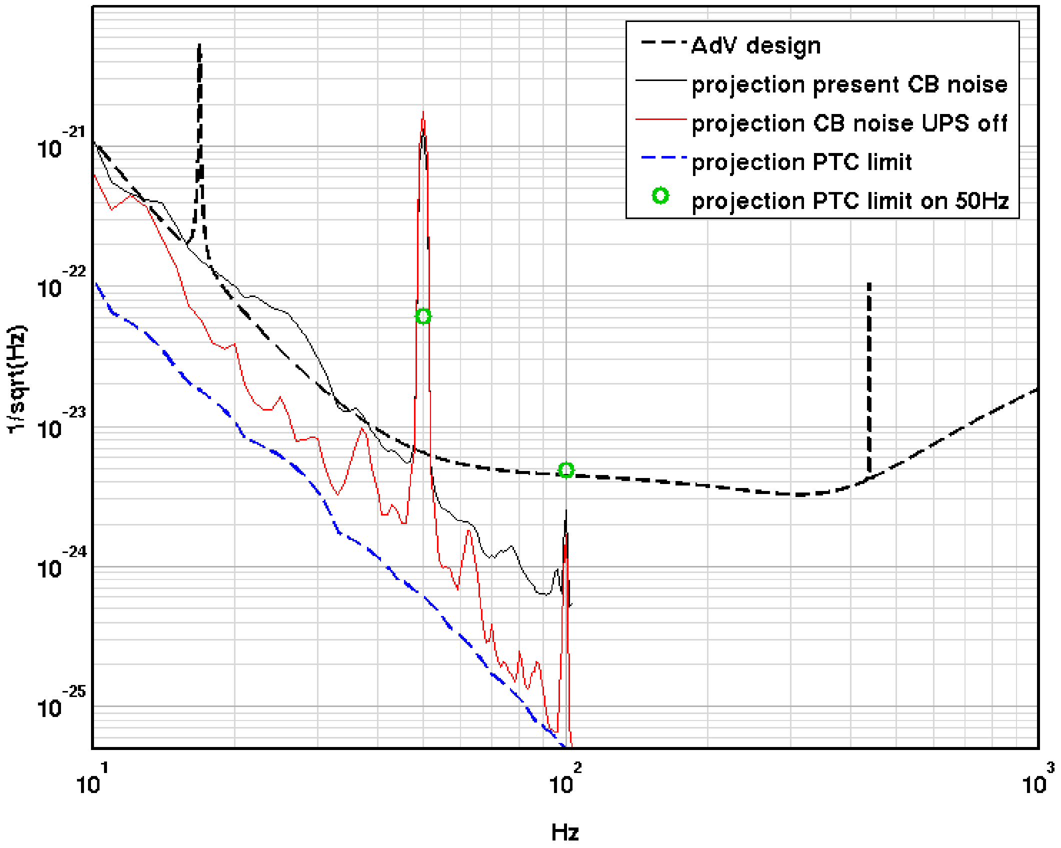

Figure 2. Advanced Virgo Strain noise. Fundamental noises (black dashed line) are compared with the noise contribution of the environmental magnetic field: (black continuous line) assuming the magnetic noise currently measured in CB; (red) assuming the CB noise contribution from UPS is eliminated (we comment on it below); (blue dashed) assuming the noise does not exceed the limit stated in (Eq.3); (green dots) at 50Hz and harmonics assuming the limit stated in (Eq.4).

Comments on the noise projections:

1) The shown projection has an uncertainly associated to the measured magnetic field. For both the TF measurement and the projection we used the field measured by the permanent probe in the CB. The error which affects the projection is given by the difference in the magnetic field measured by the probe and the (not measurable) magnetic field sensed at the mirrors. An estimate of this might be done by measuring the magnetic field in different positions in the CB which are “representative” of the mirrors position. The dispersion of these measurements provides an estimate of the “B(f)” uncertainty. To be noted that magnetic sources close to the mirrors have been removed as part of a mitigation campaign [3]. Remaining sources (i.e. power supplies in the racks…) are placed at a distance of at least 5m from each mirror. It is interesting to compare the field measured by the permanent probe with the field measured in a more

representative FF location which is on top of the CB balcony (actually were the big coil was placed for FF injection).

2) The shown projection is likely affected by a systematic error with overestimates it (i.e. it is too pessimistic) possibly by a factor 3 or so. This is because the TF measured in eLog 22801 was likely dominated by the coupling of the BS mirror (which still had large magnets at that time). We can attempt another estimate of the TF, using instead the TF measured with FF injections at the terminal buildings for Virgo (eLog 24987) and reducing it by the same factor 5 due to the replacement of the aluminum Reference Mass with the dielectric one, then multiplying by a factor 2 to account for the two input mirrors in CB (assuming coherent sum) and assuming that the BS will not contribute for AdV. A rough estimation based on plots in eLog 24987 indicates that projections in Figure 2 shall all be scaled down by a factor about 3.

Comments on the defined limits:

3) The limit set on inter-harmonics noise seems sufficient to protect AdV design sensitivity.
4) The limit on 50Hz harmonics seems a bit too large, especially on even-order harmonics. It can be re-discussed.

2. Magnetic field from High Voltage power Lines

Areal High Voltage electro-ducts work at typical voltages of 60kV to 150kV, more rarely 220kV, while 380kV are usually confined to underwater lines. They consist of three (or six) cables one per phase (which have relative phase of 120deg). Each cable carries a current which is typically around 400A for a 132kV line. The magnetic field radiated by a HV power line is a function of the current that flows in the cables and the geometric layout of the cables carrying the three phases [4]. Typical geometries are shown in the photograph above: for a 3-cable line the cables lay along a line or along a triangle, for a 6-cable line the cables lay along three rows carrying phases: R-T, S-S, T-R.

The magnetic field vector at distance "r" from a single infinitely long cable flowing an electric current "I" follows from the Biot-Savart law: $\vec{B} = \mu_0 \vec{I} \times \vec{r}/(2\pi r^2) \cdot \cos(\omega t + \varphi)$, where $\varphi = 0, +120, -120$ deg. is the phase angle. We take a (X,Y) location along a plane perpendicular to the cables and compute the total field summing the vector field of each cable accounting for its phase. The result is shown in Figures below. We assume a typical 132kV HV line and, according to numbers given in [4], we assume a typical inter-cable distance of d=5m, and a typical current I=400A per cable (I=200A per cable in case of a 6-cable line). Figure 3 shows intensity maps. Figures 4 and 5 show the decay profile of the RMS magnetic field intensity with distance from the cables barycenter. For a 3-cable configuration B decays as function of distance squared. Note that this holds also for three cables put very close together, as occurs for one underground cable. For a 6-cable configuration (phases being assigned as in Figure 3(right)) there is a more efficient compensation of magnetic fields from individual cables, and the total field attenuates as the cube of the distance.

At large (compared to "d") distance from the HV line the following simplified laws hold:

(Eq. 5) $$B_{rms} \cong \frac{\mu_0 I\, d}{2\pi r^2}$$ for a 3-cable

(Eq. 6) $$B_{rms} \cong 4\,\frac{\mu_0 I\, d^2}{2\pi r^3}$$ for a 6-cable

That is, for a given current and distance, the field intensity scales as the cable spacing; while for a given cable spacing and distance of course B scales with the current.

Figures 4 and 5 also tell us that, assumed the stated limit of 0.5nT on the intensity of 50Hz and harmonics, and assuming negligible the screening provided by our buildings, **HV power lines (assuming a current of I=400A per phase, as it is the one located close to Virgo CB, see below and reference [5]) shall be placed at a minimum distance of 1km if they are 3-cable type, or 250m if are 6-cable type.**

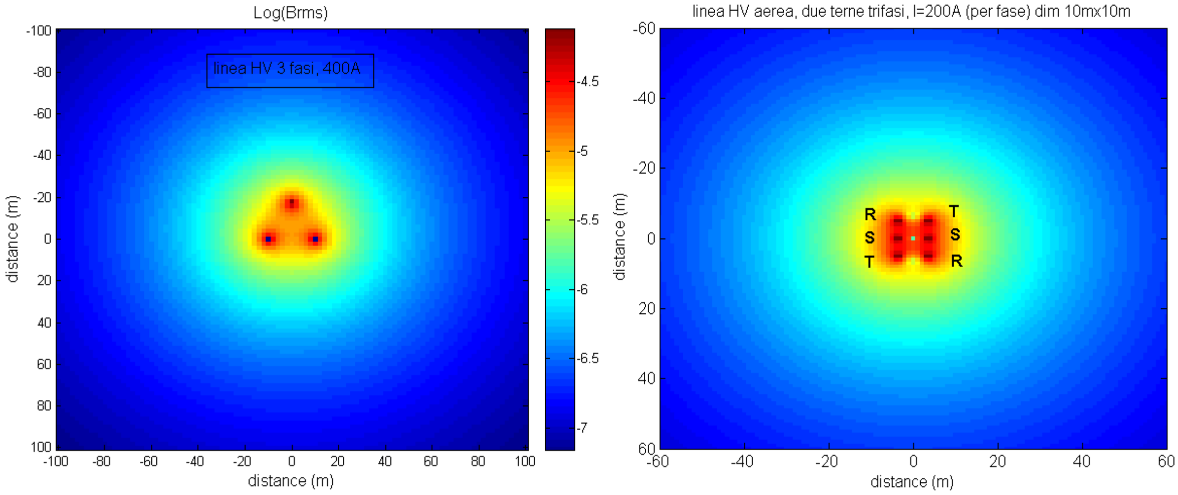

Figure 3. Intensity maps of the magnetic field in a plane perpendicular to the HV cables. LEFT: 3 cables carrying T,R and S phases, 400A each; RIGHT: six cables carrying phases as indicated and I=200A each.

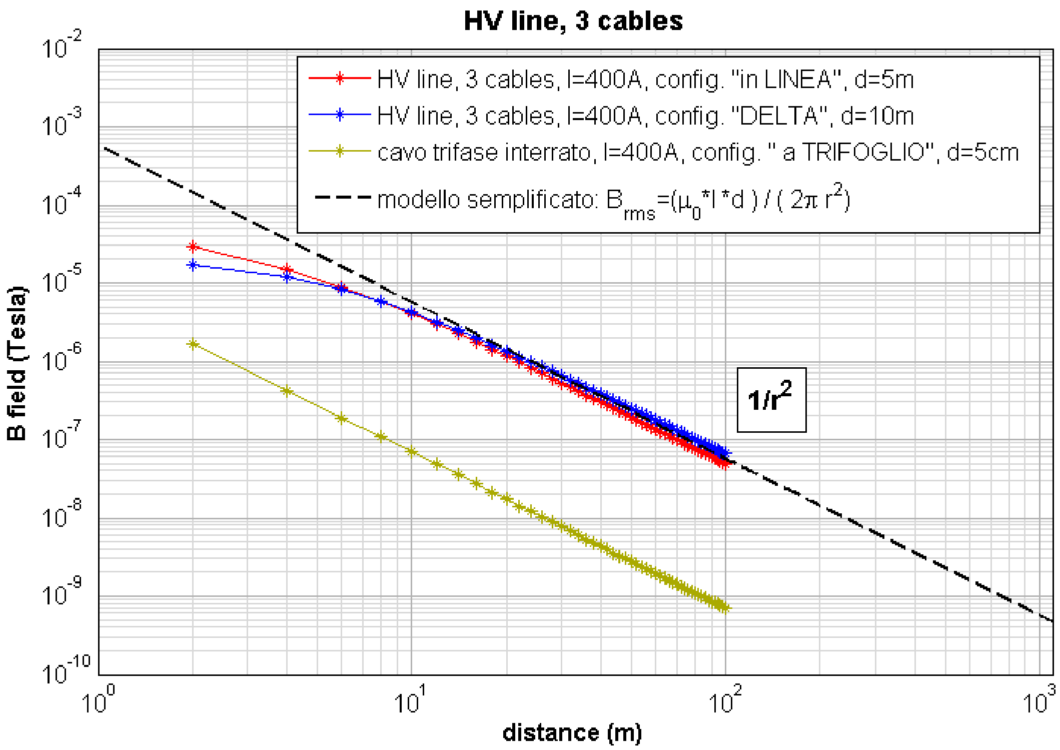

Figure 4. Intensity of RMS magnetic field with distance from the barycenter of one HV line with 3 cables. Three geometries are considered: (RED) the three cables are aligned and inter-spaced by 5m; (BLUE) cables lay at vertices of one equilateral triangle (also known as "DELTA" configuration) with a side d=10m; (YELLOW) very close cables in triangle-like configuration (typical configuration of underground HV cables) also known as "CLOVER" configuration.

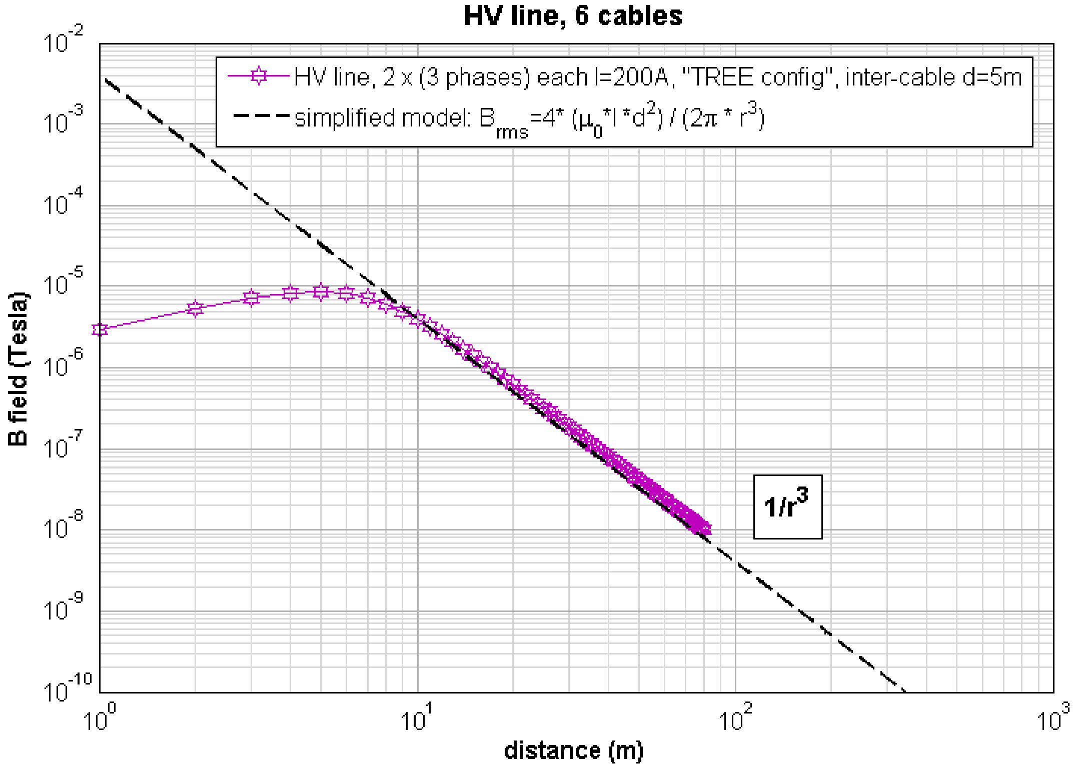

Figure 5. Intensity of RMS magnetic field with distance from the barycenter of one HV line with 6 cables whose phases follow the scheme indicated in Figure 3.

Indication for further studies

- To better define the magnetic noise projection for AdV, it is needed a better estimate of the TF of magnetic noise to the present V+ payloads which have the same dielectric RM foreseen for AdV. To this end, FF magnetic injections in the CB seem not useful since the CB coupling might be still dominated by the BS mirror (having large magnets). It seems instead that a cleaner estimate can be done by measuring the magnetic TF for one of the present V+ end mirrors (i.e. do FF magnetic injections in the end buildings).
- It seems useful to perform measurements of the magnetic field (i.e. with the portable flux gate 3-axis probe) in different position in the CB and on the balcony (see comment n.2 in Sec. 1).
- The shown noise projection indicates that the current magnetic noise level inside the buildings (in particular the CB) is critical. A mitigation of the noise seems mandatory. A significant reduction of noise might be achieved either or both (1) reducing the voltage noise of the UPS machines or (2) displacing away from payloads all the AC-DC power supplies of the front end electronics currently located on the platform. These actions seem indeed feasible as explained in the guidelines for AdV electronics edited by the EGO Electronic Group [6].
- High Voltage power lines (particularly 3-cables ones) are potentially relevant sources of noise of 50Hz and harmonics. One such line (132kV, nominal current I=334 A(summer) to 469 A (winter)

quoting numbers in the ARPAT report [5]) is located at a distance of about 150m from the MC building and at about 300m from the CB (shown in Figure 6). Our model (Figure 4) predicts the B field intensity produced by this line at the CB and MC to be of the order of 5 to 20nT. It is interesting to measure the B field noise it produces.

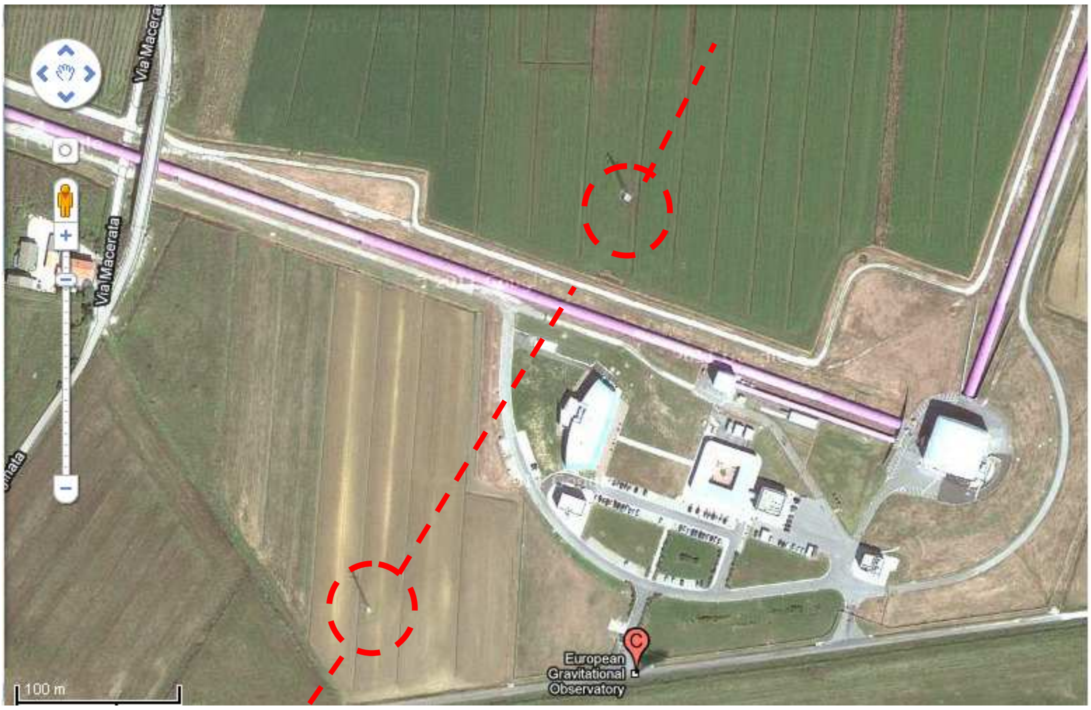

Figure 6: Areal view of EGO central area. Red line is the path of the electro-duct "R.F.I Cascina-Livorno".

References:

[1] B.Swinkels, Magnetic Noise Budget, Virgo Week VIR-0689A-09.

[2] EGO, "Inquinamento dell'ambiente da vibrazioni, rumore acustico e campi elettromagnetici: Limiti di compatibilita' con il funzionamento dell'antenna interferometrica Virgo", Relazione tecnica preliminare, Cascina, 12 ottobre 2004.

[3] D.Huet, "The hunt for magnetic noises: experimental facts", VIR-0874A-07, 2007.

[4] D.Capra, "Sorgenti ELF: nuove tecnologie e risanamenti", http://www.elettra2000.it/download/materialedidattico/ie/iem24_capra.pdf

[5] N.Colonna and G.Licitra, "Parere di conformità al DPCM 08.07.03 per l'edificio in progetto nell'area Virgo in Via E.Amaldi in S.Stefano a Macerata" , ARPAT, Prot. 1252 8 Feb 2005, EGO-EXT-29-2005.

[6] F.Nocera, F.Paoletti, R.Cavalieri, "Electronics for Advanced Virgo: Guidelines and Requirements for Electronics Installation", VIR-0737B-09