1 Introduction

Virgo evolution towards maturity will benefit from some agreed interface “standards” that will simplify the installation and maintenance process of Virgo custom electronics.

For historical reasons, in Virgo there has not been so far an agreed upon strategy on how to handle low level, low frequency (say below 100 kHz) analog signal transmission. We are in a transitional phase in which differential and single-ended signals coexist, different kinds of cables are selected and dissimilar connectors are used.

The present situation is even more complex because in some instances it is necessary, temporarily or not, to interface either differential driving signals with single-ended receiving stages (for example, correction signals from DAC channels to various kinds of amplifiers) or single-ended monitor signals to differential input ADC channels. In both cases typically the connector of choice for the non-differential end is a classic BNC.

This document gives some background information and outlines some strategies adopted so far to cope with this peculiar condition.

Future upgrades will allow cleaning up this situation and in Virgo we will orderly migrate towards a status in which low frequency error, correction and monitor signals will all be differential.

This has consequences in terms of connectors and kind of cables selected for use in Virgo. The following considerations explain the rationale behind this choice[1].

2 Cabling low frequency signals

In the field of precision measurement, it is vital to eliminate or mitigate as far as possible causes and effects of electromagnetic interference (EMI) that can limit instrument performance. A series of measures can be adopted to increase the immunity of sensitive pieces of equipment – also known as their electromagnetic compatibility (EMC) – to external signals or fields while maintaining the ability to perform at design level.

2.1 EMI mechanisms

In order to have a potential EMC problem, it is necessary to have a noise source (“culprit”), a propagation path and a receptor (“victim”).

We focus our attention here only on proper cabling techniques with the goal of increasing cable (and receptor) immunity to all possible interferences.

Cables are typically the longest components of many electronic systems and therefore the more exposed to unwanted interference from the surrounding electromagnetic environment.

[1] for further details, see for example
1. Ott, Henry W. - Noise Reduction Techniques in Electronic Systems (Wiley-Interscience, 1988)
2. Morrison, Ralph – Grounding and Shielding Techniques in Instrumentation (Wiley-Interscience, 1986)

The coupling between source and receptor can be either through radiated (field) path or via conductive path.

The latter is also referred to in literature as common impedance coupling. In this case, noise and signal share at least part of the path (i.e., a conductor) to the receptor thus hiding the possibly weak signal in noise. The obvious way to avoid this transfer mechanism is to force signal and induced noise current to follow different paths.

In the category of radiated interference a further distinction can be made depending on the wavelength λ of the disrupting field, identifying a the near field region where it is possible to examine separately the effect of the magnetic (inductive coupling) and electric (capacitive coupling) fields, and a far field where instead it is necessary to consider electromagnetic coupling as a whole.

Various techniques are available to fight against these enemies. A prescription list of sound engineering practices that can be found in literature is reported below.

The following considerations do not assume that a specific kind of cable (coaxial, twisted pair – shielded or not) is used, but are of general applicability. Cable types, with their assets and liabilities, are concisely examined subsequently.

2.1.1 Coupling mechanism: capacitive

1. shield the signal carrying conductors and connect the shield to (a preferably very good) ground
2. a ***single*** connection of the shield to ground is sufficient when the cable length is below λ/20
3. the more critical (susceptible) end of the cable shield should be the one tied to ground: for low level circuits and signals this is typically the receiver end
4. when the cable length increases, it ***may*** be necessary to ground the shield at more than one point
5. ***never*** do that on a simple coaxial cable though[2], because in that case you create the much feared Ground Loop: a noise current will inevitably flow in the shield generating a noise voltage at the input of the possibly sensitive receiver circuit. This is even worse when the Common Mode Rejection Ratio of the system under consideration is inadequate

2.1.2 Coupling mechanism: inductive

1. the best way to protect the receiver from magnetic interference is to minimize the cross-sectional loop area whose perimeter represents the signal’s current path
2. non-magnetic shields around conductors grounded at one end only have no protection effect on the induced voltage on the inner conductor(s)
3. grounding the shield (used as a return path for the current) in two points would solve the problem **but**
4. this produces a noise voltage in the protected conductors due to the common impedance coupling mechanism mentioned at the beginning of the paragraph

Only a limited amount of protection from magnetic induced interference is then possible.

The remarks made about the capacitive coupling keep their validity for the electromagnetic case as well.

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[2] see footnote on page 4

In conclusion, in the low frequency range of interest for this analysis, it is possible to achieve good EMI immunity following these guidelines:

for electric coupling using an electrostatic shield and grounding it in one point

for magnetic coupling the only countermeasure available consists in minimizing the “receptor loop” area, defined as the cross-sectional area enclosed by the signal of interest’s current flow.

This is exactly what it is currently done, as detailed later on.

At this point, we can examine the kinds of cables available on the market that allow to implement these mitigation techniques.

2.2 Cables

The choice on which kind of cables to use for the type of transmission considered here is restricted among the following ones

1. coaxial cable
2. untwisted pair (shielded or unshielded) cable
3. twisted pair (shielded or unshielded) cable

Untwisted pairs have no technical advantages over twisted ones.

The multiple twists of the latter allow to ideally cancel the effect of inductive coupling interference because of the minimized loop area.

For twisted pair cables, the shielded version has obvious advantages when compared to the unshielded one in terms of immunity to capacitive induced interference. The shielded twisted pair (STP) emerges then as the best possible solution among the pair cables.

In conclusion, the real choice is then restricted between coaxial and STP cables.

Coaxial cables, grounded at one end[3], would offer good protection from electric pickup but could not mitigate the magnetic one; the right thing to do would be to ground both ends of the cable but, as explained before, while this solves one problem it does create another, introducing a ground loop.

A possible way around it would be to use a triaxial cable with the external screen used as a “magnetic” screen. This way signal and noise do not share a common impedance. This is exactly what happens to regular coaxial cables at high frequency, due to the skin effect.

Triaxials are much more expensive though than the only alternative left, the STP, which offers good performance in terms of immunity from all the considered mechanisms at a reasonable price.

In addition, the shield can be grounded at both ends because there is no return current flow in it and therefore no induced noise voltage on the signal path (in a perfectly balanced system).

[3] this is a purely academic hypothesis, of course; the shield of a normal coaxial cable is necessarily connected at both ends.

2.3 Connectors

The kind of mating connectors selected for our applications are three-pin LEMO circular metallic connectors of the B series; more in detail,

Receptacle EGG.0B.303

Fig 1: receptacle's picture (illustrative purposes only, the actual pin number is 3) and technical drawing (rear view) showing markings and pin numbers

Plug FGG.0B.303

Fig 2: plug's picture and technical drawing (rear view) showing markings and pin numbers

The basic reason for this choice is backwards compatibility: all Virgo electronic devices using them could still be used in the future, if needed.

To establish a naming convention, the single pins of each connector have been arbitrarily numbered in the order shown above. As typically done in industry, the numbers were chosen so that the mating pins share the same name. The numbers are the only "externally added" features: the other marking signs are actually present on each connector, to allow their proper assembly and use.

The common practice so far in Virgo, when dealing with differential signals, is to use the following mapping rule when connecting receptacle's pins to the boards

pin	signal
1	hot
2	neutral
3	GND

Whenever, as described above, the circumstances require to interface a single-ended [differential] transmitter with a differential [single-ended] receiver, it is necessary to somehow convert a three-wire cable in a two-wire (usually coaxial) one.

The solution selected is to make custom "adapting cables". The logic used to map signals so far is the following

BNC	LEMO pin number
central	1
shield	2
—	3

There are two options open here: it is possible to leave the third wire not connected (Fig. 3, left) or short it to pin 2 (Fig. 3, right).

Fig 3: two possible solutions for the adapter

The first one (pin 3 floating) is the right one for (temporary!) installation on the interferometer.

With this solution you **never** ground the cold leg of your differential stage, wherever it happens to be.

In case of a differential transmitter it would be wrong to do so because it would amount to short-circuiting its minus output to ground.

For a differential receiver instead, it would be an error because it would result in having a second ground point on the same cable (remember that pin 3 is tied to GND on the LEMO receptacle), creating a ground loop.

In conclusion, these 2-to-3 pin connector adapters, if used at all, should always have pin 3 not connected.