AdV Standard Feb 2nd 2011
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Electronics for Advanced Virgo: Guidelines and Requirements for Electronic Systems
-a proposal-

Introduction

This is the second of a series of three documents introducing a set of requirements and standards that electronics for Advanced Virgo shall comply with.
The overall plan is detailed in the first document of the series (VIR-0737B-09).

This second one deals with Electronic Systems; a System is assumed to be a level two item of the Advanced Virgo Work Breakdown Structure. In some cases it can actually be only a part of that and in this sense it would be probably better defined as a subsystem, but from the perspective at hand this aspect has no impact at all, since an electronic system is seen as whatever electronics used for a system to accomplish its task. No assumption about physical co-location or else has been made.

After describing the infrastructure constituting the environment in which electronic systems operate, it is now time to have a look at the requirements that systems themselves need to meet.

6. System

The word system in Virgo means a lot of different things: in what follows we will assume that an electronic system is a set of pieces of equipment designed and/or assembled to accomplish a given goal. It can be as simple as Virgo's Clock Distribution to the End Buildings System (single Eurocard board) or as complex as the Vacuum System, made of several different kinds of units spread over the entire site. This in turn can be split further in functional elements that can be considered as systems in their own right.

Once again in this second installment, we will look at the electronics as made of a series of black boxes; no matter what each box does specifically, they have to share certain characteristics to allow smooth integration and reliable operation over time. The goal here is to identify and list these common characteristics and suggest some standards every piece of electronics shall possess. Standards comply with vertical transmission, meaning they apply to lower tier items wherever applicable.

6.1 Power

The reference solution for powering electronic system is either to use the AC mains (with all the precautions listed in 5.1) or the ± 24 Vdc available at system level wherever needed.

In principle commercial equipment can be simply plugged in the available mains outlets, while custom designed boxes have also the option of choosing to use standard Advanced Virgo DC levels.

In both cases, the electronics downstream should be powered through one of the two chassis introduced in section 5.1, the Service Entrance Panel and the DC Distribution Box respectively.
They were both described with a fair level of details in section 5.1. In addition to that, specific points concerning the rationale behind the suggested solution will be detailed here.

Power Supply Systems can have an impact on electronics vulnerability in two main ways: directly through power disturbances and indirectly as a “sneak path” for energy to enter the system.

Power disturbances belong to the following classes: spikes (transients), sags/surges, and outages. Pushing the boundary a bit further, it is possible to include harmonic distortion as well, although this phenomenon typically has a stronger impact on wiring and distribution systems than it has on electronics itself, unless the high frequency harmonics drive into saturation the input stages of sensitive analog devices, causing rectification and masking the signal of interest.

The sort of effect that these undesired events can have on the victim systems depends both on the characteristics of the disturbance (amplitude, frequency content, time of the event) and on that of the “receiver”. Generally speaking, digital systems are more affected by spikes, because they can cause false triggers, while analog ones, almost immune to spikes, are prone to disruption caused by sags or surges (long term variation of the supplied power level, respectively towards lower or higher values than the reference one) that can introduce unwanted “modulation” on the signals of interest. Same consideration applies to power outages.

Power conditioning can solve most of these issues: transient protection devices (Zener diodes, MOVs) work against spikes; local regulation and filtering are effective against slow variations. In addition, as already mentioned before, the use of Linear Power Supply helps minimizing the risks affecting specifically analog systems.

6.2 Crates

Crates are intended as metallic cages whose purpose is to contain electronic modules and integrating, in the most general case, both a power supply and a backplane hosting a bus. They are also referred to, in technical literature, as subracks.
Their digital version is going to disappear in Advanced Virgo since the VME bus adopted in Virgo has been abandoned. The analog version instead (i.e., without a digital bus on the backplane common to all boards) very likely is going to be around longer.
It is known as Eurocard, which strictly speaking is only a standard form factor for Printed Circuit Boards (PCBs) that then are inserted in a Eurocard crate. Crate height is usually measured in “U” with 1U = 44.45 mm; this unit was silently introduced in section 5.4 when talking about rack height.
Eurocard board heights are either 3U or 6U, the latter being by far the most common in Virgo. Crate height (for vertical mounting boards) starts at 7U.

For analog crates the only purpose of the backplane is to conveniently distribute the DC power, which can be generated locally or not, to single boards.

In case the crate is AC powered, the principles to consider when selecting it and designing the system for the application under scrutiny are

- Avoid when possible to use switching regulators preferring linear power supply (see section 5.1)
- Minimize power consumption and avoid as much as feasible forced air cooling. For electronics located in close vicinity of the antenna, this is a must

while the following represent features every crate shall possess even when using the standard Advanced Virgo DC Power Distribution

- an on/off switch and a *green* LED clearly indicating the presence of power
- handles to allow easy removal and transportation

Additionally, it would be useful whenever possible for them to have the characteristics listed below as well

- a fuse on each power line
- a *yellow* LED in parallel with the fuse that lights on when the power is tripped
- one (or more) 851 00 JC 8-33 S 50 connector(s) to interface with the DC Distribution box

The back of any crate shall have an indispensable characteristic: the board-bus connections shall be hardwired through mating connectors rigidly mounted on either side.

In no event it can be possible for the crate assembler or troubleshooter to accidentally swap power supply pins reversing the polarity of the applied power. The backplane shall be rigid to act also as a mechanical support when inserting in or extracting out units with no need to open the back of the crate to complete the operation.

In general, crates host different kinds of modules and each of them in turn talks to different units that in the most general case can be located elsewhere. The principle mentioned in sub-section 5.5.4 that no metallic connection can leave a rack untreated shall be followed. This implies that there are two possibilities open; the first is for signals to go through an Interface and Distribution Chassis to be grouped first and then routed towards their destination(s) [or source(s)], the second one sees provisions for "point-to-point" connections (which, as we will see, in our case will be applied to RF and Field signals). In any case, rack panels cannot be penetrated by untreated cables.

6.2.1 Interface and Distribution Chassis

It is very difficult to conceive every possible configuration that can be encountered in Advanced Virgo and design a Chassis as generic as to cover all of them. The solution proposed is then to have two different basic Chassis that will cover a large fraction of all possible cases. Exceptions or modifications are of course contemplated and they will be handled on a case-by-case basis.

6.2.1.1 Interface and Distribution Chassis A

This model features the same connectors on its inputs and outputs. It is aimed at interfacing with new designs in which, as it will be detailed in section 6.3.2, a clear distinction between monitor and functional connectors shall be adopted.

The connector chosen to terminate the multi-pair snake cable selected (Belden's 1512c, 8 pairs, or equivalent) is the LEMO's FGG.3B.324.CYCD12 (crimp contact); its mating bulkhead companion is the LEMO's EGG.3B.324.CYM.

Fig. 19: receptacle and plug drawings of the selected 32-pin connector. Back (crimping side) view.
Markings that allow to identify pins are clearly visible.
Pin number assignment will be detailed later on.

The standard A model will be a 2U unit featuring 8 connectors on the back[⊗] and the same number on the front. The pin-to-pin connections internal to the chassis can then be implemented as preferred, going from a wire-wrapped solution to a dedicated pcb routing all signals reliably from input to output (best). The possibility of filtering at least some signals should not be ruled out.

6.2.1.2 Interface and Distribution Chassis B

The second model tries to address compatibility issues with Virgo or Virgo+ designs that could possibly be reused in Advanced Virgo. We will focus our attention only on a very general case; others can be adapted to it if needed (when a redesign is not possible).
In Virgo electronic boards have been designed, in general, adopting a dedicated connector for each signal on boards and chassis and these connectors are typically on the front panels. They can be either differential (LEMO's EGG.0B.303.CYM, referred to as 3-pin LEMO) or single-ended (in Virgo, BNC).

That is why on the front panel of the I&D Chassis B there will be one connector per signal.
To keep the same height (2U) the number of LEMO's EGG.3B.324.CYM connectors on the back[⊗] will be halved bringing it to 4 for a total of up to 32 differential signals, each of them with its own reference.
On the front panel therefore there will be 32 connectors (LEMO's EGG.0B.303.CYM).
Details on pin assignment will be given in section 6.7.1.

Every crate should have one or more of these I&D units associated to it to allow short local connections avoiding crossing cables and to simplify maintaining a clean installation. The solution proposed here has an obvious impact on cost.
A possible alternative to reduce the number of I&D units while still doing things properly is to eliminate cables going from the rack walls to the I&D boxes mounting those units directly on the side of the racks as shown in Fig. 20, right.

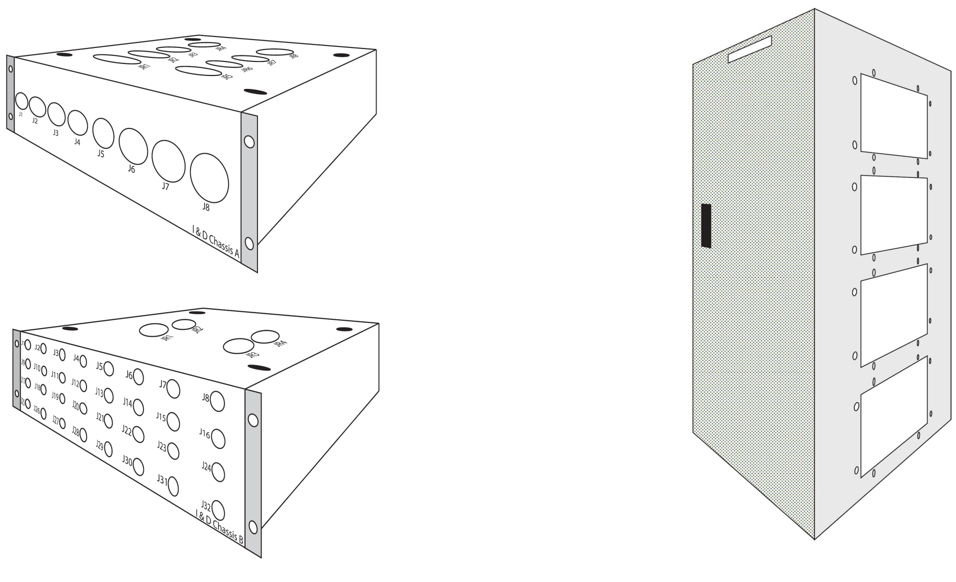


Fig. 20: 3D drawing of the I&D Chassis (version A on the top, B on the bottom).
It shows the connectors on the front panel and on the top.
On the right it is visible instead a modified version of a generic rack.
The side panel has been machined to allow the installation of 4 I&D Chassis.

⊗ an alternative, cheaper scheme sees these connectors placed on the top instead. Fig. 19 represents this alternative. See end of sub-section 6.2.1.2 for details. The same consideration applies to both versions of the I&D Chassis

The lateral wall has been machined to have a series of large holes only slightly smaller than the base of the 19'' chassis used to build the I&D boxes as shown in Fig 19. In this case the input connectors will be placed on the top of the chassis and not on the back. Other configurations are possible to increase the signal density per unit such as top-bottom instead of front-back (or, as explained, front-top), for example.

This allows to lower the number of interfaces and therefore of connectors, cutting cost.

6.3 Chassis

Most electronics will live in racks and the largest fraction of the custom electronics will be hosted in chassis; as for the crates described in the previous section, the following features shall characterize all of them

- an on/off switch and a *green* LED clearly indicating the presence of power
- handles to allow easy removal and transportation
- power connectors on the back, with a fuse on each power line
- a *yellow* LED in parallel with the fuse that lights on when the power is tripped
- one (or more) 851 00 JC 8-33 S 50 connector(s) to interface with the DC Distribution box

6.3.1 Mechanical Characteristics

The case containing the electronics shall be rack mountable (19" wide) to easy installation and maintenance. Generally speaking, all chassis shall be metallic. In principle, plastic containers could be used, as it is done in commercial pieces of equipment but using plastic suffers of two major limits. The first one is the absence of shielding effect and the second, more worrying from our perspective, is the (likely) violation of electrical safety codes and regulations.

The lack of shielding capabilities could in principle be overcome using thin conductive paintings, but this sort of approach represents an unnecessary complication for the typical number of units and applications we normally deal with in Virgo. To be fair, it must be noted that these coatings are effective at high frequency (remember the relationship between thickness and shielding effectiveness) and, speaking in the most general terms, do not offer adequate protection from low frequency magnetic fields, such as the one caused by power supplies.
As for the safety issues, things are even worse since is difficult to imagine the designer opting for a double isolation that prevents hazards caused by failures and short-circuits inside the box.

If RF shielding characteristics are required, care must be exercised in dealing with openings and joints of the chassis to the point that the adoption of EMI gasket might be unavoidable.

6.3.2 Functional Characteristics

For future designs, a novel approach shall be adopted, as briefly mentioned before.

This philosophy aims at standardizing the interfaces, and at limiting the probability of inadvertently affecting the performance of electronics systems. This is achieved keeping the functional connectors distinct from the monitor ones and distant from them as well.

Ideally the functional connectors shall be positioned on the *back* panel while the monitor ones shall be on the front, simplifying access and test. In addition different kinds of connectors shall be used for different functions. Both points are elaborated next.

Every chassis shall then have multi-pin functional connectors located on the back through which "Virgo's" signals (i.e., the real signals) leave the box to be routed, in the most general case, towards the associated I&D Chassis.

In principle, after the installation is completed there is no need to ever touch the cables dealing with functional signals again unless a spare unit has to be installed; debugging and troubleshooting, at least in their early phase, will rely on different provisions, as described in the subsection 6.3.3.1.

To simplify cabling and easy maintenance these connectors shall be the same kind of the corresponding ones on the I&D Chassis towards which the signals are routed before departing for their destination.

This allows to have a set of standard cables adopted in the largest by far number of possible cases. This implies that these receptacles can be either the standard 3-pin LEMO in case of single-pair signals or, for 8-pair signals, the LEMO's EGG.3B.324.CYM.
As usual other solutions can be considered when technical rationale supports them.

Labels clearly indicating unit names and, at least, connector identifiers shall be present on panels, consistently with what presented later on, and they have to be permanent (i.e., not stickers that can be removed or come off in time). A serial number would be good too.

6.3.3 Diagnostic Features

It is highly desirable to have an appropriate number of diagnostic tools to allow easy verification of electronics status and, in case, troubleshooting.

Different levels of diagnostics can be considered, going from a simple LED going off or blinking when something is wrong to an LCD with menus and submenus that can show relevant information.

6.3.3.1 Monitor and Test

There shall be two standard monitor and test connectors to make everything as foolproof and straightforward as possible; for all analog signals, inputs and outputs, the connector of choice is the BNC while for digital signals, inputs and outputs, a DB9 connector is suggested.

In both cases, the connectors mentioned shall be used ***exclusively*** for monitor purpose.
This means that no BNC or DB9 connector shall be ever used anywhere else for other reasons.

This choice makes it easy to interface with typical measurement or debugging tools. For analog signals, these are usually Dynamic Signal Analyzers, Oscilloscopes, Network Analyzers, Digital Multi Meters etc.

For digital signals instead, considering that nowadays is possible to find virtually in every recently designed custom electronic unit one or more modern programmable devices (FPGA, CPLD etc.), seems reasonable to have provisions to talk to them through the JTAG protocol not only for test but also to perform firmware debug and upgrades. Additional details on pin function for this specific case are given in section 6.6.2.

6.3.3.2 Display and Indicators

The presence of correct power levels and the absence of events that tripped the power have been already introduced previously, specifying the colors these indicators shall have.

Other LEDs can be very useful, indicating (for example) saturation of correction and out-of-range sensor signals. In case, LED of a color dedicated to these specific tasks shall be selected and the proposal is to reserve *Red* exclusively for this purpose.

6.4 Field Units

Field Units are electronic devices deployed in locations different from racks such as Optical Benches. Since in principle they can be used for a variety of different tasks, it is difficult to give requirements all of them must satisfy no matter what they specifically do.

Obvious examples of Field Units are Photodetectors (PDs), Quadrant Photodetectors (QPDs), Position Sensing Devices (PSDs), Faraday Isolators (FIs), Electro-Optic Modulators (EOMs), Motorized Waveplates, Flippers, Galvo Actuators, Piezoelectric Actuators (PZTs) etc.
While for custom design there is a set of common features that can be singled out and standardized, commercial devices need to be integrated somehow and the best way to do that has to be examined on a case-by-case basis, pressing to steer them towards the standards defined.
At the time of writing seems that a non negligible part of the Interferometer critical sensors and some actuators too will live and operate in vacuum. Since the list is still preliminary and technical challenges associated with this course of action need an assessment not yet available, this aspect will not be further discussed in this document.
Standard in-air units instead need to satisfy the list of requirements given below.

6.4.1 Field Unit Power

Active custom Field Units shall be powered using the Advanced Virgo DC Power Distribution, at least for the standard low-voltage levels introduced in section 5.1.2.
Since power dissipation needs to be kept under control and minimized, not to mention the fact that specific application may have more stringent requirements on power level stability, it makes sense to have “local” provisions to generate DC levels adequate to front-end ratings (typically, ± 18 Vdc).

Local in this context means, reasonably, one (or more) half-height rack placed in close proximity of the area it serves acting as interface between it and the rest of the experiment. Due to its vicinity to the interferometer, all electronics installed in these racks shall be as quiet, unintrusive, and linear as possible.

The solution proposed then consists in having a second type of DC Power Distribution Chassis with the same input of the first type but having 8 outputs each to be used to power the Field Units serving a given area (for example, an optical bench).

Since in general it is possible that additional DC levels are needed for other purposes (such as a +8 Vdc for biasing PDs or -5Vdc for ECL logic etc.) then these levels shall be made available on the output connector of these boxes. An umbilical cable shall then feed the units.

In few specific cases, “high-voltage” DC levels may be needed, for example to bias fast PDs or to drive PZTs. As a reference, based on Virgo experience, we will consider ± 120 Vdc.
In these cases all the precautions and definitions listed in section 5.1.3 apply. An additional detail worth mentioning is that whatever solution is adopted for the generation of these DC levels, the distribution chassis shall present output connectors used *exclusively* for this application and not compatible with any other connector used elsewhere. They are specified in sub-section 6.7.3.1.

6.4.2 Unit Essential Characteristics

Few common characteristics of possibly all field modules (including table-top units) can be mentioned.

Cases shall be metallic and ideally the mount should be one with the body, where it makes sense, and have provisions for the installation to avoid annoying mechanical resonances in the band of detection.

All boxes shall either sport a general power-on switch or the power supply line feeding them shall be selectively operable upstream without affecting any other line.

All units shall have test inputs and output monitors that, in principle, could be used to assess working conditions without necessitating removal. These diagnostic features could be operable from the Control Room, but this is not mandatory (nor necessarily feasible, for example for RF devices). Needless to say, those monitors shall obey the criteria set in section 6.3.3.1.

Indicators of presence of power (and, in case, additional diagnostic features) shall be present and ideally, shall be possible to power them off for normal operations to limit power consumption. Connector use shall be consistent with criteria specified elsewhere in this set of documents.

6.5 Cabling Class1 signals

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

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.

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. External cables offer then by far the most important way of either coupling energy into a system or radiating it outside it. To limit both effects, all elements of an electronic system have to be carefully specified and from the present perspective this means paying attention to selection first and installation afterwards of cables and connectors[♦].

Some elements about cables and cabling techniques have already been introduced in section 5.5. Here additional details pertinent to the system level design will be given, starting with some general considerations about best practice to reduce unwanted effect related to inappropriate selection or haphazard cabling methods when dealing with peculiarly sensitive signals.

In the previous installment of this series we have examined extensively the issues concerning cabling aspects of three out of four classes of signals (AC and DC power distribution and control signals) leaving out only the most sensitive one.

It is now time to examine appropriate cabling techniques for Class 1 signals that require special treatment and that will not, in general, be cabled using multi-pair snake cables: Field and RF signals.

6.5.1 Cabling Field Signals

With this definition we refer especially but not exclusively to low-frequency sensor signals, where the bandwidth does not typically go above the 100 kHz. Above this frequency limit we enter the region that Virgo considers as RF.

[♦] for details about definitions and some basics on EMI mechanisms and modes see Appendix B

Optimum shielding requires different techniques in these two regions. In the lower bandwidth the combination offered by a shield[○] that protects from unwanted electric coupling (and in which there is only noise current, not signal), a twisting of the information-carrying lines that limits coupling of magnetic interference and, with some help from the electronics designer, a good level of balance between the two lines can guarantee to these typically weak, precious signals all the care and protection they require. Additional details on balance will be given in section 7.5.

The standard solution for cabling this kind of signals (a typical example is represented by DC PDs and QPDs) is then to use shielded twisted pair (STP) cables, continuing with a practice already adopted in initial phase of Virgo.
The reference cable is Belden's 9501; it is a single pair cable, twisted and shielded with a foil whose electrical connection is made via a drain wire. The mechanical characteristics are exactly the same as the one for the cable mentioned in section 5.5.4 while the electrical ones differ slightly (pair impedance is 75 Ohm, the nominal capacitance between the paired wires is 40pF/ft).

Ideally these cables should run uninterrupted all the way to their destination. This would represent a violation of the code prescribing absence of untreated metallic penetrations inside electronic enclosures though; the choice has to be made taking into account additional circumstances dealing with the actual implementation but it would be wise to consider the alternative solution has as a fallback plan.

6.5.1.1 Which end to ground?

After the consideration of the previous subsection it is probably obvious that there is no issue of grounding when using STP cables, at least from the performance point of view. Nevertheless since in literature a great deal of attention is given to this topic, with detailed analysis of possible scenarios (source and receiver both referenced to ground, source floating and receiver grounded etc.) and workarounds in case of problems (like grounding one end through a capacitor so to have the shield floating at DC and referenced to ground at higher frequency), it is worth addressing it here as well reminding the grounding philosophy suggested in this work.

As clearly stated in section 5.2.2, the approach recommended is to ground everything as often as possible without worrying about ground loops and to design the electronics with the goal of being independent from the grounding scheme. If grounding the screens at both ends of a cable causes unanticipated problems, it is very likely that the root cause is a weakness either at the system level (incorrect termination etc.) or in the units design.

Every piece of electronics is then always referenced to ground locally. The drain wire of all STP cables used for field signals is then connected to ground on both ends.

All return currents have to be closely coupled to their own signals and, in principle, they should not be shared with other signal lines and especially with power lines. The solution indicated here obeys to all the principles mentioned.

6.5.2 Cabling RF signals

The most recent kind of twisted cables available on the market, even in their unshielded version[×] (such as Cat6 Ethernet cables) have excellent performance characteristics (as specified in EIA 568B-2 standard) which would allow, in principle, to use them also for Virgo RF signals (Cat6 can go up to

[○] to act as a screen, the shield needs to be connected to ground in at least one point (i.e., it can't be left floating)

[×] other considerations regarding immunity are not taken into account here

250 MHz) but above the traditional (and now outdated) limit of the 100 kHz, coaxial cables offer lower losses and more uniform characteristic impedance.

It would seem though that coaxial cables suffer from a major limitation when compared to STP from the point of view of immunity to magnetic noise pickup due to a violation of one of the principles mentioned earlier: there is no physical separation of noise and signal return current and therefore a common impedance path exists.
Although this is true in DC, the situation changes radically starting from around 1 MHz, where it matters, due to two concurrent phenomena.

The first one is the skin effect. When frequency increases, current in a conductor tends to migrate towards its outer edge reducing the cross sectional area through which electrons flow (therefore changing the effective resistance offered by the material).

The second effect is associated with its intrinsic inductance. As a matter of fact, the frequency at which the inductive reactance of wires starts to prevail over their resistance is lower than one could naively imagine.
The return path the current chooses to follow to go back to its source depends on the relative impedance offered by the various alternatives at its disposal; at high frequency the effect that dominates this choice is due to the existing mutual inductance between all potential couples of wires and since the minimum impedance to the return current is presented by the local return wire (i.e., the one constituting the minimum loop area with the signal wire), this is the path followed by the current to complete its loop.

The combination of these two effects explains why the apparent violation of the common impedance rule has no practical impact at the frequencies of interest when using classic coaxial cables: the signal current travels along the periphery of the central conductor due to skin effect, the return one moves towards the internal edge of the shield due to mutual inductance while the noise current occupies the most external layer of the shield. For all practical purposes a coaxial cable behaves then, in the MHz frequency region, like a triaxial one without having all the nuisances that the latter inevitably shows.

At this point, it is just a matter of selecting the most appropriate type of cable for our application. Many kinds of coaxial cables are readily available on the market, having different size, characteristic impedance, attenuation, and capacitance values to name only the most important features.

The proposed solution is to use RG174 U kind for RF signals. This specific type has characteristics♦ very similar to the RG58 C/U commonly used in measurement labs. The only difference is its diameter and, as a consequence, attenuation.

Cable	Outer Diameter (mm)	Attenuation dB/100 m @ 1MHz	Attenuation dB/100 m @ 6 MHz	Attenuation dB/100 m @ 10 MHz	Attenuation dB/100 m @ 80 MHz
RG174 U	2.54	2.71	6.66	8.61	24.57
RG58 C/U	5	1.46	3.59	4.64	13.36

This aspect starts to play a significant role when the cable lengths are important, but the plan is to use this solution only for "local" connections (not more than 40 meters or so) while for longer runs the right thing to do is to use fibers.

Naturally, there is no possible doubt about whether or not grounding the shield when dealing with coaxial cables.

♦ RG174U (Z = 50 Ω, C = 101 pF/m, insulation material PE, velocity factor = 0.66c, overall diameter = 2.54mm)

6.6. Cable identification and labels

The first, obvious goal of cable labels is to identify uniquely and unequivocally each cable and, wherever possible and meaningful, signal.
From this point of view then a simple alphanumerical tag would be sufficient.
Very often though other pieces of information can be of help when operating in the field and a quick and intelligible way of finding some additional amount of details to correctly identify the topology of the system, and occasionally troubleshoot it, is extremely useful.

With this in mind, a structured way of labeling cables is suggested.
The code structure is made of four fields. Within each field, information is separate by a dot (.).

The basic purpose served by Field number 1 and Field number 2 is to allow a system view approach; the information they contain would appear on a detailed system wiring diagram, showing block names, number, and nature of connections between blocks.
Field 3 in its simplest form is used to identify uniquely any cable in the interferometer with the minimum amount of information necessary.
Field 4's purpose is to give an easy first level guide to the system assembler, to make swapping units straightforward when necessary, and to offer a reliable reference to troubleshooters.

Not necessarily all fields or all information contained in a field must be present on every cable. In addition, since it is not practical to have tags too long, it makes sense to have one tag per field present. When there is more than one tag, they shall be positioned along the cable starting from Field 4 closest to the terminating connector and then, moving away from it, all other tags in reverse field order.
The minimum information available on the cable shall clearly indicate where each cable is supposed to be plugged, and this is explicitly shown in Field 4 (always present). Some examples help clarifying the matter. In what follows specifics such as connector numbers are, of course, purely indicative.

Field 1 – *System designation*

WBSLevel1.System.Subsystem

examples:
SAT.F7 VAC.CRY.DET TCS.NI.WS DET.PhaseCamera PSL.FreqStab

Field 2 – *Signal identifier*

SignalID.SignalFrequencyCharacteristics

examples:
CoilCurrent.DC LaserHeadTemp(erature) PDout.AC QPDSum SSFS_Corr.HP

Field 3 – *Cable marking*

CableClassID.CableDataBaseID.OverallSN

examples:
Class1.1STP-2010-5m-025.2894 Class2.Coax-2010-5m-025.13101

Field 4 – *Architecture identifier*

UnitLocation.ConnectorID

examples:
LAS2.C4.InjRampeAuto.J7 BS.C7.B3.Coil Driver.J2 DET3.C12.SSFS.J12 EIB.BMS.FF QPD.J3

Some extra details about how the field UnitLocation can be specified can help in understanding its use and the examples above; UnitLocation identifies the unit reached by the cable in question specifying its position completely.

If it is in a rack, it would require expressing the rack unique identifier, crate position in the rack and board position (and possibly name) in the crate before indicating the connector (BS.C7.B3.Coil Driver.J2).

If it is in a rack but it is a chassis instead of a board, after identifying the rack it shall specify the chassis's position (and name) inside the rack and, of course, the connector on the panel (DET3.C12.SSFS.J12).

If it is on an optical bench, then bench name, system and subsystem of pertinence and device identifier shall precede connector's identifier (EIB.BMS.QPD-FF.J3).

Finally, it could specify a flange; in this case Tower, Flange position and identifier shall be present.

As a result of this policy, couples of labels such as the ones reported below may be found on the opposite extremes of cables once the installation is complete.

Field1	Field2	Field3	Field4
SAT.F7	AccH1out	STP8-2010-5m-025.2	BS.FlangeX.ConnB
SAT.F7	AccH1out	STP8-2010-5m-025.2	BS.R12.C3.I&DvB.J9
DET.PhaseCamera	PDout.RF	Coax-2012-15m-031.3721	EDB.PD3.Out
DET.PhaseCamera	PDout.RF	Coax-2012-15m-031.3721	DET1.C7.Demod.Jxz
DET.Galvo	Xchannel	STP1-2013-6m-02.9912	WEB.Galvo1.J1
DET.Galvo	Xchannel	STP1-2013-6m-02.9912	WER2.I&DvA.J7
DET.RFPD	RFPDOut.RF	C1.Coax -2011-18m-01.1999	EIB.PD4.RFOut
DET.RFPD	RFPDOut.RF	C1.Coax -2011-18m-01.1999	DTR2.C4.B6.Demod.J7

6.7 Connectors

To avoid clerical errors is best to assign univocally to every pin of any kind of connector used numbers and functions so that different pieces of electronics designed by engineers belonging to different groups will not suffer of compatibility issues.

6.7.1 I&D Chassis Connectors

In Advanced Virgo there shall be no patch panels. This solution has shown all its limits during the initial phase of Virgo, especially from a reliability point of view.

The plus side of patch panels, provided there are a sufficient number of spare channels installed since the beginning, is their ability to offer a standard interface between distant areas of the experiment that allows integration upgrades with a modest amount of additional work and without affecting existing systems.

Trying to maintain this positive feature and improve reliability and EMC at the same time, the solution proposed sees the use of "enclosed patch panels". The connectors selected guarantee an excellent stability over time and against accidental actions. Their part numbers are reported below for clarity.

It is worth noting the pin assignment for the multi-pair connector; the goal is to isolate as much as possible every signal form the other ones sharing the same cable with it. This is possible only to a limited extent unless the price of dedicating a number of extra pins to GND connections is accepted.

pin	Signal
14	Ch1+
1	Ch1-
15	Ch1_GND

pin	signal
16	Ch2+
3	Ch2-
2	Ch2_GND

pin	signal
4	Ch3+
24	Ch3-
17	Ch3_GND

pin	Signal
18	Ch4+
5	Ch4-
6	Ch4_GND

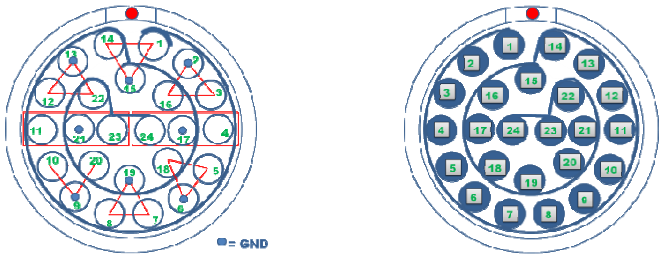


Fig. 21: LEMO's 24-pin connectors. Back (crimping side) view.
Pin number assignment for receptacle (EGG.3B.324.CYM, left) and plug (LEMO's FGG.3B.324.CYCD12, right)

pin	signal
7	Ch5+
8	Ch5-
19	Ch5_GND

pin	signal
10	Ch6+
20	Ch6-
9	Ch6_GND

pin	signal
11	Ch7+
23	Ch7-
21	Ch7_GND

pin	signal
12	Ch8+
22	Ch8-
13	Ch8_GND

Depending on what solution is preferred for the I&D Chassis internal realization, other possibilities could be considered more advantageous when it comes to pick the receptacle. Among them, there are the ECG.3B.324. CLN (straight contact for printed circuit) and ECG.3B.324.CLV(elbow contact for printed circuit). Both are back panel mounting connectors.

Details about the LEMO's 3-pin used for single differential signals are given in section 6.7.4.

As possible alternatives to the "regular" 3-pin receptacles mentioned there (EGG.0B.303.CYM), it is worth considering its twin options ECG.0B.303.CLV (fixed receptacle with 90° elbow contact for printed circuit), ECG.0B.303.CLN (fixed receptacle with straight contact for printed circuit), and EPG.0B.303.HLN (90° elbow receptacle for printed circuit). The first two are both back panel mounting connectors. Here too the final choice depends on the way the designer decides to implement the I&D Chassis.

6.7.2 Monitor and Test Connectors

6.7.2.1 Analog Signals

There is no need to give a long list of technical details about the very well-known BNC connectors proposed here as a sole analog monitor connector.

Nevertheless, since a plethora of variants of this very common connector exist on the market, some specific points about apparently negligible details can be helpful. For our present perspective what is relevant is the selection of the most appropriate ones for our panel mount application.

Although it does not have any practical implications in our case, it is advisable to use 50 Ω (and not 75 Ω) connector type. A couple of possible alternatives are presented here; the first one is the isolated bulkhead solder jack kind (instead of the panel mount) and compatible with a D shape panel cutout such as the one below.

Fig.22: Tyco's 5227726-3 BNC bulkhead connector details. Lengths in mm [inch]

This choice allows to cable first and then mount easily the coaxial connector inside the box and to have a mechanically stable connection that does not rotate when mating.

The second possibility is represented by the non-isolated bulkhead jack where it is possible to crimp directly an RG174 cable (if one chooses to use it also for the cabling internal to the chassis) such as Tyco's 5413771-3 (commercial type) or 5225398-7 (MIL type, better dielectric polytetrafluoroethylene (PTFE) also known as TEFLON® instead of polymethylpentene)

In all cases the cutout on the panel would have the same D-shape (but slightly different dimensions).

6.7.2.2 Digital Signals (JTAG Interface)

Details on JTAG are readily available for free on the web, so there is no point in reporting them merely copying them from some source. A good introduction, although a bit dated, is *IEEE Std 1149.1 (JTAG) Testability —Primer* by Texas Instruments (document ssya002c.pdf)

pin	signal
body	GND
1	TRST
2	TDI
3	TDO
4	TMS
5	TCK
6	GND
7	GND
8	GND
9	GND

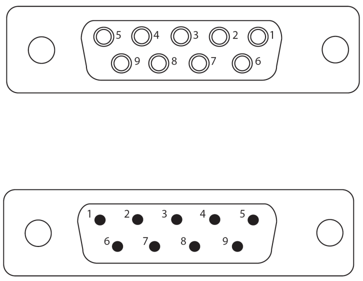


Fig.23: DB9 connector: pin number and function assignment. Front (mating side) view. Pin number assignment for receptacle (FCI 865709S065TLF or equivalent) on top and plug (FCI 865709P065TXLF or equivalent) on bottom.

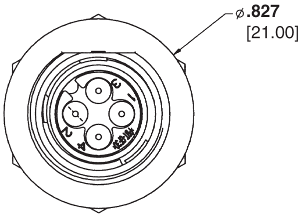
6.7.3 Unit Connectors

Criteria used in selecting connectors for Field Units are not exclusively technical in the strictest sense, but they considered an additional essential aspect which is the use of real estate on the unit box with the goal of minimizing it for both power and signal.

6.7.3.1 Power Connectors

For devices requiring "High-Level" DC voltage, both Power Supply Chassis and the Units they fed shall adopt the same connectors. The family of connectors endorsed here is Tyco's Miniature Circular Plastic Connectors (CPC) in its smallest shell size, 8, that fits up to 4 contacts. This choice combines a minimum use of precious panel surface with high electrical isolation between pins and a "*Unique contact pattern for each position size helps prevent accidental mating with other position sizes*".

On the unit side there shall be the panel mount receptacles while the plugs are on both sides of the connecting cables.
Pin assignment is reported below, together with the outer diameter in mils [mm] of both connectors.



pin	Signal
1	Positive High Voltage
2	Negative High Voltage
3	GND
4	GND

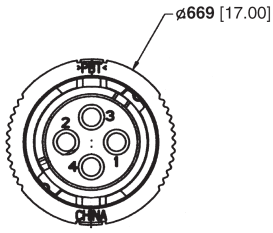
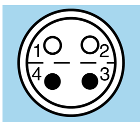


Fig. 24: Tyco's Miniature CPC 4-pin connectors. Front (mating side) view.
Pin number assignment for receptacle (1445421-1, left) and plug (1445390-1, right)

A possible choice for the cable to use with these connectors is represented by Belden's 9552 (outer diameter 9.34 mm) or equivalent.

An alternative worth considering for small units such as PDs or the like, where the overall size can represent an important factor, is offered by the Lemo's family 1S, which shall be adopted for low level DC as well as explained below.

More in detail,



pin	Signal
1	Positive High Voltage
2	GND
3	Negative High Voltage
4	GND

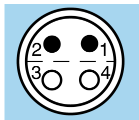
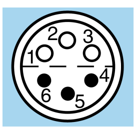


Fig. 25: LEMO's 4-pin hermaphroditic connectors. Back (soldering side) view.
Pin number assignment for receptacle (ERA.1S.304.CLL, left) and plug (LEMO's FFA.1S.304.CLAC62, right)

A cable that suits this choice is Belden's 9502 (outer diameter 5.64 mm) or equivalent.

Note the different assignment for pin functions when compared with the connector for the other solution proposed for the same application just above, which allows a more rationale use of the cable pairs.
For Regular DC levels instead the choice is to opt for hermaphroditic connectors where one section is used for ubiquitous ± 18 Vdc while the other one can be used for additional levels with the only constraint of not swapping the assigned polarity (i.e., on pin 4 there cannot be a negative voltage level).
DC Power Distribution chassis shall clearly indicate output voltage levels.



pin	Signal
1	+18
2	-18
3	GND
4	PositiveExtraVoltage1
5	NegativeExtraVoltage
6	PositiveExtraVoltage2

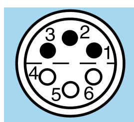
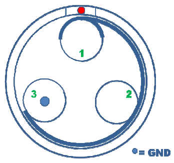


Fig. 26: LEMO's 6-pin hermaphroditic connectors. Back (soldering side) view.
Pin number assignment for receptacle (ERA.1S.306.CLL, left) and plug (LEMO's FFA.1S.306.CLAC62, right)

In this case the cable can be Belden's 9503 (outer diameter 5.89 mm) or equivalent.

6.7.4 Field Signal Connectors

There is not much to add to what already said, just assigning functions to pins.



pin	Signal
1	Ch+
2	Ch-
3	Ch_GND

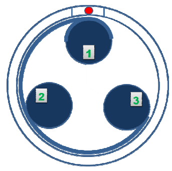
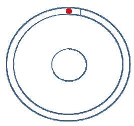


Fig.27: LEMO's 3-pin connector. Back (soldering side) view.
Pin number assignment for receptacle (EGG.0B.303.CYM, left) and plug (FGG.0B.303. CYCD42, right)

The associated cable has been described at length elsewhere in the document (Belden's 9501, outer diameter 3.96 mm).

6.7.5 RF Signal Connectors

Adopting the solution mentioned earlier for the RF cable directs us towards the selection of connectors that go with it which will be LEMO's well-known 00.250 series.



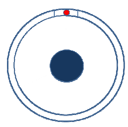


Fig.28: LEMO's single pin connector. Back (soldering side) view.
Pin number assignment for receptacle (ERX.00.250.NTL, left) and plug (FFA.00.250.CLAC29, right)

A possible choice for this kind of cable is Belden's 8216 (outer diameter 2.794 mm).

It is worth noticing that, as far as the cable is concerned, there are a couple of mechanically compatible alternatives to RG174U.

The first is RG316U, with a slightly larger external diameter (2.6 mm vs. 2.55 mm) but a better quality dielectric (PTFE instead of polyethylene[⊗]) and attenuation (6.35 dB/100 m @ 6 MHz, 8.20 dB/100 m @ 10 MHz, 23.41 dB/100 m @ 80 MHz).
The second is LMR-100A, having exactly the same diameter and dielectric insulator (solid PE) of RG174U but lower losses (5.73 dB/100 m @ 6 MHz, 7.41 dB/100 m @ 10 MHz, 21.26 dB/100 m @ 80 MHz)

This concludes the set of standards regarding electronic systems, i.e. the ones whose scope ends on electronic panels and boxes. Next installment will deal with what is inside those boxes and therefore with the electronics itself.

[⊗] PTFE has an higher melting point, higher than typical solder tip temperature, and that therefore does not melt when soldering cable central conductor or shield. This does not apply to polyethylene (PE).