Modifications to the ISC TDR chapter after February 1st review

1) Benoit: Page 2, last paragraph of the introduction: The fourth modulation is explained, while the three first one are not yet introduced. May be this part could be put later, or we should introduced the other modulation frequencies.
Last paragraph modified in:
"Optical simulations of thermal effects and mirror defects inside the \ac{PRC} showed a large impact on radio-frequency sideband aberrations. A risk reduction strategy to have error signals less sensitive to \ac{PRC} defects and aberrations is proposed. It will help in the first commissioning and locking steps (sec.~\ref{sec:high-frequency-modulation})."

2) Fulvio: Your chapter is stating a lot of requirements that will drive the activity of several other subsystem. These numbers are collected in tables but not all of them. I suggest to collect all the informations and (even if it is boring) to copy them in dedicated table grouped at the end or at beginning of the document.

3) Benoit: The interface section is very longue and duplicates some part of the text. One option could be to keep a much shorter version focusing only on the "assumption" used to do the various ISC computations and move the summary of consequences (or requirements) on the other subsystem and then end of the chapter. This would be a actually a better conclusion that the current one which do not bring really information.
5) Benoit: Should the interface section be at the end of the chapter since it gives constrains to other sub-system?
6) Benoit: Page 2/3: It may be good to first explain the goal of each of the three modulation frequencies before giving the constrains (resonant or not in the various cavities).
Section on interfaces with other subsystem is moved to the end of the document. A new section named "Inputs to the sub-system and assumptions" was added.
Following Fulvio's suggestion, as agreed during the review, all requirements are repeated in the last section with full details.

8) Luciano: Section 1.2.5, pag. 6: "…This poses stringent limits on the OMC filtering capabilities." : Could you give specifications on this limits?
The specifications in terms of isolation shown at the review meeting were added to the document.

9) Luciano: Section 1.2.6, pag. 7. At which frequency is intended the requirement for the RIN (10^-8 Hz^-1/2) in the power recycled case?
A more detailed table was added.

10) Fulvio: Please clarify the meaning of the sentence at the end of the paragraph 1.2.4

Sentence was modified to:

"Since the angular requirement is pretty tight, it was considered important to try an optimization of the telescope design to reduce the coupling from bench angular motion to spot displacement on the quadrant. This would relax the requirement on the bench angular motion. We can even afford some worsening on the coupling from bench translation to spot displacement on the quadrant, since the bench requirement with the present telescope is not very tight."

11) Benoit: Page SBE requirement: The Telescope offer little margin for optimization. It will be discussed this week and the last sentence might be drop and numbers updated after the telescope meeting.

65) Benoit: Section 1.7.7: It would be good to give the specifications before the telescope and may be leave the optimization in the DET section, especially since the telescope tuning does not seems easy.
As agreed during th review meeting, the requirement is also expressed in term of beam motion on the mirror (better explained with beam axis translation):
"Spot position (DC) signals will be used to control two angular degrees of freedom. Their required accuracy gives limits on the spurious signal created by bench motion, which should give a contribution not larger than what would be equivalent to a beam translation inside the arm cavity of the order of 20~μm."

14) Benoit: Section 1.2.8 (SAT): Why not setting a goal on the improvement of the inertial damping?
An estimation of the present Virgo performances in term of RMS motions have been added to give a reference, both in the "input" section and in the "interfaces" section.

15) Luciano: Section 1.2.7. DAQ – It looks like, according to DAQ sub-system, we won't be able to design a DARM control loop with a good phase margin. It is also written that we don't expect "huge improvements" from further studies. So we won't be able to lock the interferometer in a stable way?

If this is the case, you should stress this point in the conclusions. I don't think this is the case and possible point of mitigation for the total delay are indicated, for example, in the following section (1.2.8). In my opinion, this point should be better clarified.

16) Fulvio: In the case of SR configuration the requirement to extend the bandwidth up to 400 HZ could have an impact on the payload design. In fact it is not so eay to have mechanical resonances of large plates coupled to the payload infrastructure higher than 400 Hz. This point requires a deeper analysis and it is connected with the remark b).

A deeper discussion on the consequences of having 400 Hz of band-width has been added in section 1.3.6:
"The need of significantly increase the band-width of the DARM loop has strong consequences on the design of the real-time control system and of the payload. Indeed, the present design of the DARM loop is compatible with a total delay in the control chain of 50~μs (assuming the phase margin must be larger of 30 degrees). This seems very difficult to achieve. On the payload design side, the structure that will hold the coils used to apply the control forces should not have structural resonances inside the active bandwidth of the loop, otherwise they could get too excited by the control itself. Having all structural resonances above 400~Hz seems very difficult. Both DAQ and PAY considerations triggered the need of a more deep study of the DARM control. It seems feasible to reduce the band-width to 200~Hz, even if a detailed design is not available yet. In this way the total delay requirement would be relaxed to 100~μs and the resonance requirement to 200~Hz."
A summary of these considerations have been added to the DAQ and PAY interface sections:
PAY: The need of increasing the DARM loop band-width poses stringent requirements on the minimum possible frequency of internal resonances of the structure holding the actuation coils. The present design of the DARM control foresee and band-width of 400~Hz. Having all resonance above this frequency seems very difficult, therefore it is necessary to re-consider the design of the control. It seems feasible, although not yet designed, to reduce the band-width to 200~Hz.
DAQ: Such delays might play an important role only in the case of the DARM loop for dual recycled configuration, which has a unity gain frequency of about 400~Hz \cite{lsc-note}. This would impose a requirement on the total delay of about 50~μs which according to the DAQ subsystem would be difficult to reach. Therefore it is necessary to re-consider the design of the control. It seems feasible,

although not yet designed, to reduce the band-width to 200~Hz. This would relax the delay requirement to about 100~μs.

17) Benoit: Section 1.2.9: I'm not sure if it is really a requirement.
18) Benoit: Section on lock acquisition: We should give the specification for the forces, instead of not providing a number, even if the final design of the payload is not yet available and leave to choice of the magnets to PAY.
An estimate of the forces in newtons has been added:
"A rough estimation indicates that the maximum force used in Virgo+ was of the order of 3~mN per coil-pair. Keeping some safety margin, we can expect to reduce this by a factor 5-10. The exact value is still to be decided and depends on the mechanics of the new payload and on the amount of sensor noise during the lock acquisition."

19) Benoit: Section 1.2.10: This is maybe so obvious and easy that it is not needed to add it
Section has been re-written with more informations.
"In the terminal stations, the space for auxiliary laser benches must be allocated near the minitower and on the same concrete slab. We need to check with the infrastructure group the safety issues, as we will be placed on the roof of the clean room. We may also need an acoustic enclosure and we may be able to reuse the one installed around the end arm optical tables."

20) Benoit: Page 5: In the old Virgo naming convention, the PO beam is probably B4 instead of B5.
21) Benoit: Table 1.10: (and alignement section) Why not using the Virgo names "B1,…) for the beam?
All names I could find were changed to the Virgo-like convention, as recently decided by Giovanni.

22) Jerome: In GEO, to tune the SRM position we change the sidebands frequency used to lock the SRC (for example by 100 Hz). Will it is be the same for Advanced Virgo ? I am asking that because MICH and SRCL share the same sidebands (table 1.6), so does the tuning of SRCL will affect MICH?
23) Benoit: Section 1.3: There are different possible choice for the SR detuning. What are the impact for the ISC point of view? A sub-section addressing explicitly this would be usefull
Added in the "input" section the following:
The Advanced Virgo detector in dual recycled configuration is expected to work with different tunings of the \ac{SRC}. In the design of both angular and longitudinal control systems only the one which optimizes the sensitivity for NS-NS inspirals has been considered. The \ac{SRC} tuning will be controlled changing the offset added to the \ac{SRCL} error signal. The available linear range is about double of the tuning corresponding to the NS-NS-optimized configurations. The effect of using different tunings on the control loops and on noise couplings has not been studied yet.

24) Benoit: Page 11: The modulation index is set to 0.1. It would be nice to know why and even better, it would be nice to have a sub-section somewhere discussing the modulation index optimization.
Added a comment in the "input" section:
The present design of the INJ sub-system foresee the ability of delivering a modulation index of 0.1 for all main modulation frequencies.

25) Jerome: It could be good to remind in the paper how the CARM feedback is applied, more precisely how to divide the feedback between NE/WE and the laser frequency (frequency range / actuation range).
Added at the end of section 1.3.1:
In addition to these ``mechanical'' degrees of freedom one should consider the laser frequency

stabilization loop, which locks the laser to the mean length of the two arm cavities with typical band-widths of few tens of kHz (sec.~\ref{sec:ssfs}). The laser frequency will follow the motion of the arm cavity mean length, called CARM in the previous equations. The typical motion of the CARM degree of freedom, if left free, would correspond to thousands of Hz. To avoid such large fluctuation the CARM mechanical mode will be controlled, acting on the end mirrors, using an error signal coming from the reference cavity \cite{ssfs}. This is the same strategy adopted in Virgo+ and allowed also to extract complete position information to be used for the \ac{GIPC} system.

27) Jerome: It could be good to explain where the 80 mW of power for the MICH/DARM offset comes from, since it is a very important number.
28) Benoit: DC offset. Actually, there is a section here, which gives good justification of where to put the offset, but do not discuss its value beside the one of top of page 13 (it is say that it is 80mW, but without too much explanation).
29) Jerome: I do not see any reason why the LO at the dark power must be constant when the power changes from 25W in input to 125W ? I would think the DARM offset is constant but not the power at the output. When the input power is increased 5 times, the junk light that the 80mW has to dominate will be 5 times larger (optimistic case), so the safety margin will be reduced.
Explained in the "input" section that this is an input from DET.
Added also in the interface section with DET:
"DET sub-system fixed the DC-read-out offset value in order to have a carrier power at dark port of 80~mW. From the point of view of ISC, it would be better to reduce as much as possible the offset. As explained in \cite{darm} the larger the offset the more coupled the angular sensing matrix becomes."

30) Jerome: P15, just above 1.3.5. "Alternative schemes are being considered [11]". Could add in one line the alternative schemes and still keep the reference.
Added:
"such as controlling the CARM loop directly using the OMC error signal."

34) Benoit: Section 1.3.5, second paragraph: The assumption made is the power fluctuation of the sideband is 2%. But later, in the alignment section it is 0.1%. This should be made more consistent or the difference explained.
35) Benoit: 1.7.3: Where the 10**-3 requirement on power fluctuation is coming from? What would be the consequences of changing this number by an order of magnitude (both ways)?
Added in the angular requirement section:
The choice of a factor 10^{-3} for maximum tolerable power fluctuation is an educated guess that starts from the consideration than in Virgo+ we could reach 1\% of stability of the carrier field. Since Advanced Virgo is aiming to have ten times better sensitivity, the goal for angular stability was also tightened by the same factor. More solid estimates might be computed once a proper simulation tool to compute the effect on sensitivity of a mirror mis-alignment will be available.
The requirements are driven by the carrier field fluctuations. Choosing the same requirements for the sidebands might at first seem in contrast with the assumption of 2\% fluctuations made in sec.~\ref{sec:omc-requirements}. However it is known from Virgo and Virgo+ commissioning experience that sideband fluctuations are very sensitive to any interferometer defects, mainly aberrations in the \ac{PRC}. Since it is not possible as of today to properly estimate such effects, it was considered safe to compute the angular requirement on a tight basis, and assume a Virgo-like fluctuation to compute OMC requirements.

38) Benoit: Still section 1.3.6: It would be nice to give a short description of the design process and what are the filters obtained and sensing matrix used. BTW, I'm not sure it is wish to write that "There

is no more room for filter optimization", at least without explanation.
Added the following discussion:
"The filter optimization is a balance between having high gain below 2-3 Hz to be able to reach the accuracy requirements and string enough roll-off at higher frequencies (above 10 Hz) to avoid re-introducing control noise in the detector sensitivity. The stability of the control loop imposes some limits on the possible optimization. The present design is barely fulfilling the requirements with the minimum acceptable stability margins (30 degree of phase margin and less than a factor 2 of gain margin). Further optimizations in the present scheme are not possible. Any increase of the sensing noise or of the payload motion would result in the longitudinal control being no more complaint with the design."

39) Jerome: P20, Table 1.7. Could you give a comparison of the SB relative amplitude noise given to what has been achieved with Virgo+. I would like to have an idea if the noise required is critical or we could have such level without too much special care.
Added a cross-chapter reference
"Refer to [INJ chapter, section 1.6.4] for a comparison with the expected performances."

40) Fulvio: In the section 1.3.8 can you specify better what it the meaning and the implications of the phase noise requirement " at the mixer input"?
Added to the document a better explanation:

"Modulation noises enters in the photo-diode output signal following two paths. The first one is through the noise at the level of the modulation, which is transmitted to the laser beam and enters on one of the inputs of the mixer. The second path is through noise introduced by the local oscillator distribution system, which enters on the other input of the mixer. The requirements given here apply to the total of the two contributions."

41) Jerome: P21, In the text, to follow the logic it is better if the part about the power recycling appears before the dual recycling case.
Done

42) Jerome: 1.3.10. In case of no etalon, what should be the requirement on the transitivity matching of the 2 arms ? to know if it is achievable or an etalon in the ITM is mandatory.

Added the following sentence:
"To meet the sensitivity requirements, in the power recycled case losses asymmetries must remain below 20~ppm and finesse asymmetry below 1\% to be able to meet the requirements."

43) Benoit: Page 27: Etalon effect. The end of section 1.3.9 seems to explain that we need a good finess asymmetry only for the power recycling configuration. Do it means that we need the etalon effect (with the large cost overhead), "only" for the PR configuration? Anyway, the justification of the need for the etalon effect seems a little too short given the implications.
Section 1.3.10 have been enlarged:
As explained in the previous section, in the power recycled case it is necessary to maintain the finesse asymmetry below 1\% in order to meet the requirement on frequency noise coupling to the detector sensitivity. During Virgo commissioning the ability to minimize the coupling of common noises at low frequency has been extensively used and proved crucial to reach good detector sensitivity. The noise sources that coupled proportionally to the finesse asymmetry were only partially identified (frequency noise, limited by the sensor shot noise, and input beam jitter). There remained several noises which source was not identified, since it was possible to largely reducing their coupling to the detector

sensitivity by fine tuning the finesse of the two arms.

For these reason it is proposed to implement input mirrors with parallel faces, in order to be able to fine tune the finesse asymmetry in a continuous way during the interferometer operations. The plan for Advanced Virgo would be to stabilize the input mirror temperature with slow servo systems. They will use heaters attached to the vacuum towers which will then act as a thermal bath for the input mirrors. This technique has already being tested successfully in Virgo. The needed range of finesse change is under study and will be decided as soon as more detailed simulations will be available.

44) Benoit: Section 1.3.8: Replace "technical noises" by power and frequency noise in several places, especially in the figure.
Done.

45) Benoit: Page 28: Is the finesse 445 or 450?
The nominal value is 443. Changed everywhere I could find it.

48) Jerome: Still 1.4.2, could you add one sentence to say what is the technique use to lock MICH at half fringe using the DC power ? (a kind of dithering ?)

Added to the chapter:

"the ratio of the power transmitted to the dark port over the power impinging on the arm cavities (read with the PR pick-off beam) gives an estimation of the Michelson fringe value."

49) Jerome: Table 1.8, Could you add that the arm cavities are locked in the table (if it true) and does it take into account the change in input power from the start of the lock to the science mode or is it normalised to 25W ?

All states described in the table have the arm-cavities locked. As noted in the caption of the table, all values are calculated for 1 W in input power. The label "fringe offset" in the table has been changed to "MICH offset" to be more clear.

51) Benoit: The section 1.4.2 is very detailed and could probably be trimmed down
As agreed, some small titles are added to make the flow of operations more clear to the reader in haste.

52) Fulvio: It is matter of fact that the strategy for controlling the interferometer in the final configuration (125 W +SR) is not studied yet. This is explicitly mentioned but no plan and timeline for the study is included.
Added:
"The lock acquisition strategy for the dual recycled interferometer is at this stage not a high priority task, since it is expected that during the first commissioning phases the Advanced Virgo detector will run in power recycled configuration. Nevertheless the study of the lock acquisition in dual recycled configuration will start in the next months and first results are expected at the beginning of the next year."

53) Benoit: The section 1.4.3 and the introduction of 1.5 are not very consistent. It is a little bit unclear of the strategy. Are we just making the ITF compatible with the possible installation of the auxiliary laser, waiting for further lock acquisition studies, or is it the baseline?
54) Fulvio: It is not clear in the present form what is the importance of the auxiliary laser strategy. Did we study it to reduce the project risk? Is it useful in the context of future study for the controlling the SR interferometer?

Added in the introduction to aux lasers:

With the current finesse for Advanced Virgo (443), it has been shown that even if we reduce the actuator maximum forces by a factor 5 (with respect to Virgo+ during the lock acquisition) we can still lock the long arm cavities with the main laser \cite{cavalier} using a Virgo-like technique. Therefore, as explained in sec.~\ref{sec:pr-lock}, the lock acquisition strategy in the power recycled configuration will be very similar to the Virgo one and there will be no need of auxiliary lasers.

However we will still face the problem to lock the interferometer with the presence of the signal recycling mirror, which will increase the complexity to acquire the lock. As explained in the previous section, the lock acquisition will be eased if we can have the long cavities frozen but off-resonance from the main laser. Such action could be performed with an auxiliary laser as long as we can control the long cavities without getting the main laser resonating in the arms during the five minutes planned for the lock acquisition of the central interferometer.

therefore the design and integration of the auxiliary laser system in Advanced Virgo can be break down in two steps. The interferometer must be designed in order to be compatible with the system as explained in the next sections, but choosing the correct mirror coating and foreseeing the room of optical benches. If needed and useful, the actual installation could take place only in a second time, when Advanced Virgo will move from power recycled to dual recycled operations.

55) Fulvio: Moreover, if we need to apply this technique for the first two steps of Advanced VIRGO how far we are to have at least the conceptual design for the integration of the system with the main VIRGO optics?

Rewritten 4th paragraph of 1.5.2:

“We think we can use two lasers with the same wavelength for the two arms and select a different polarization for each of them. Then a polarizer will be needed for all photo-diodes used in the system. The design of the optical table is currently under study. The system will be a standard one with laser and optics to select the polarization, a pick–off towards the reference cavity, an \ac{EOM}, a telescope to match the beam to the end arm detection table and some motorized optics for alignment. We will use a set of photo-diodes to control the lasers (power and frequency) and the long cavity by using the reflected beam. We will also control the position and alignment of the beam with some quadrants photo-diodes. The loops to control the laser will be done locally. The control of the cavity will be performed directly in the locking algorithm of the global control system.“

And added another paragraph in the same section:

“The auxiliary lasers will not be needed before the installation of the \ac{SRM} and so their installation can be delayed up to that time. The different interactions with the MIR, DAQ and DET subsystems have been defined and taken into account in their designs. The installation could be done in two steps. We could start to construct the in-air optical table independently and characterize the beam and the different optical elements. This phase may be done in LAL before bringing the elements on site. Otherwise we could start the installation in the end-arm station. Finally we will need to have access to the long cavities to align the beam correctly for at least one month per arm.”

56) Benoit: Last line of figure 1.12 caption: Is there a price on the sensitivity (due to coating thermal noise) required by the use of auxiliary laser?
Changed caption to:
The new coating have been studied to reduce at maximum the number of layers: between the two designs the width of the coating will be changed by 300 nm (on a total of 7 μm). The impact on thermal noise is expected to be negligible.

57) Jerome: Regarding the angular control, I keep wondering how is degenerated the control for PRM/BS and SRM. A sensing matrix would be welcome to appreciate the difficulty. Is there a way to understand why the angular control for PRM is from demodulated f1 while for BS is from demodulated f2, could be also the otherway around.

Added:

The \ac{PRM} is controlled by using the first demodulation frequency while the BS using the second one. The \ac{BS} and \ac{PRM} error signals can be exchanged if needed by retuning the Gouy and demodulation phases. It was chosen to use the best signal, in terms of SNR, for the \ac{PRM} since it is strongly coupled with the Differential(+), especially in the final configuration~\cite{darm}. This sensing scheme should then assure the lowest PRM control noise re-introduction in the Differential(+) mode.

Plus a table

58) Luciano: Section 1.7.5, pag.43 – Could you specify starting from which frequency the QPD sensors on the end benches should be shot noise limited?

Added:

"In other words all quadrant photo-diode signals are assumed to be shot-noise limited everywhere above 10~Hz."

59) Benoit: Table 1.11: Give the frequency used for these requirements.
Added to th table caption:
Spectral requirements are valid above 10~Hz.

61) Benoit: Implicitly some of the quadrant will use galvo to center the beam. It would useful to explicitly state which ones.
Added:
All quadrants will be equipped with fast galvo centering system. The quadrants on the end benches will also need translation stages that might be used during the pre-alignment steps.

62) Benoit: Section 1.7.5 is long and would benefit of some internal structure; Removing some of the details of the history (like the end of the section) could also help.
The section has been divide with sub-titles.

63) Benoit: It is often complain that we don't have a good simulation, but the goal of developing it is not given, while we expect that as an ISC task (for longitudinal and alignment).
Added a sentence in the conclusion:
"Plans for the development of such a tool are being considered, compatibly with the available manpower."

64) Benoit: Section 1.7.6: I'm not sure to understand the second paragraph.
Re-written:
The residual angular displacements and the AA control noise, evaluated with the Optickle simulation, are in agreement with the accuracy and the sensitivity requirements, for all the three configurations. The most critical degrees of freedom in terms of control noise are the (-)-modes, for all the three commissioning configurations.

66) Benoit: P. 38: Could you give the value of the (-) mode frequency?
Done

67) Benoit: Last lines of figure caption 1.15 and 1.16 could be dropped.
Done.

68) Benoit: Most of section 1.8.1 could probably be dropped.
The section has been re-written with less details.