低温レーザー干渉計CLIO(25) Digital 制御

2009/9/10(木) 日本物理学会2009年秋期大会
於　甲南大学岡本キャンパス
宮川　治、和泉　究、新井宏二、辰巳大輔
CLIO collaboration

本研究の目的

RSEという複雑な制御を必要とするLCGTでは
デジタル制御は必須である

- LCGTと同じような制御帯域幅であるCLIOにデジタル制御システムを導入し、実際の干渉計で稼働することにより、デジタル固有の技術を蓄積する
- デジタルシステムのLIGOグループとの共同開発により、国際協力体制を築く
- LCGT建設時にスムーズにデジタル制御を導入できるようにする

現状

- Caltech LIGOと東大宇宙線研とのMOUを締結
- 実際の共同作業はResearch Agreementにより推進

- LIGOからの技術提供
- 宮川、和泉がCaltechにて基本システムを組み上げ
- 必要なAnalog回路（AA/AI, whitening/dewhitening filter等）は、国立天文台辰巳が担当で、日本において制作

- Wind River社Real time linux kernelのライセンスの米国輸出制限問題で時間がかかっている
  - 日本に代理店があるので、次機からはライセンスは日本で取得した方が無難

MOU and RESEARCH AGREEMENT

AGREEMENT ON ACADEMIC EXCHANGE
BETWEEN
THE INSTITUTE FOR COSMIC RAY RESEARCH
(THE UNIVERSITY OF TOKYO)
AND
THE LIGO LABORATORY
(CALIFORNIA INSTITUTE OF TECHNOLOGY)

The Institute for Cosmic Ray Research (ICRR) in the University of Tokyo (Japan) and the LIGO Laboratory in the California Institute of Technology (U.S.A) (hereinafter referred to as the "parties"), in the firm conviction that academic exchange between the parties will promote scientific advances in the field of gravitational wave science, hereby establish the following Agreement.

Article 1. The parties agree to implement exchanges and other activities in areas of academic research of mutual interest through the following.

(1) Short-term and longer-term visits in both direction, by faculty and administrative staff and researchers.
(2) Short-term and longer-term visits in both direction, by students.
(3) Conducting collaborative research.
(4) Holding joint lectures and symposia.
(5) Exchange of academic information and materials.

Article 2. Actual projects to be implemented for the realization of specific exchange activities as defined in the preceding article shall be decided through discussion between the parties.

Article 3. In the case that research results impacting upon matters of intellectual property rights are expected to arise in the course of collaborative projects carried out under the terms of Article 1 above, the parties shall discuss in good faith and agree in a separate document the conditions regarding the treatment of intellectual property rights so arising, prior to the start of the collaborative project in question and in accordance with the policies of each party.

Article 4. This Agreement is valid for five years effective from the date of the final signature affixed below by the parties hereto (hereinafter referred to as the "term"). The term of the Agreement may be extended upon agreement by the parties. Either party may terminate the Agreement during its term by giving six months advance written notice to the other party.

Article 5. This Agreement is created in duplicate in Japanese and in English, each of which shall be deemed originals.

The parties hereby establish this Agreement by duly signing it, as of the respective dates below.

Institute for Cosmic Ray Research (The University of Tokyo)	LIGO Laboratory (California Institute of Technology)
T. Kajita	Jay Marx
Director, Takaaki Kajita	Executive Director, Jay Marx
Date Aug. 10, 2009	Date Aug 17, 2009

RESEARCH AGREEMENT
Caltech Agreement #ICRR-2009-1

RESEARCH AGREEMENT between the **CALIFORNIA INSTITUTE OF TECHNOLOGY**, of Pasadena, California, U.S.A., ("Institute") and the **INSTITUTE FOR COSMIC RAY RESEARCH, UNIVERSITY OF TOKYO** of Kashiwa, Chiba, Japan ("Sponsor").

WHEREAS, the research program relating to "Fabrication of Digital Control System for the (CLIO) Detector Operated by ICRR, University of Tokyo," ("Project") as contemplated by this Agreement, is of mutual interest and benefit to the Institute and the Sponsor, and will further the instructional and research objectives of the Institute in a manner consistent with its status as a nonprofit, tax-exempt, educational institution.

NOW, THEREFORE, the parties hereto agree as follows:

1. STATEMENT OF WORK. The Institute will collaborate on the research defined in the Statement of Work attached as Exhibit I.

2. PRINCIPAL INVESTIGATOR. The research will be supervised by **Alan J. Weinstein** The PI will supervise the work performed under the funding described in Section 4, below.

3. PERIOD OF PERFORMANCE. The research shall be conducted during the period **February 1, 2009 through January 31, 2010**. This Agreement and the period of performance may be extended by mutual written agreement of the parties.

4. REIMBURSEMENT OF COSTS. In consideration of the foregoing, the Sponsor shall reimburse the Institute for all costs incurred to complete the project. The total cost shall not exceed **$40,000** without written authorization from the Sponsor.

5. INVOICING AND PAYMENT. Payment shall be made in advance based on an invoice submitted by Institute. All payments to the Institute shall be net, and free and clear of all taxes, duties and other levies. Payment shall be remitted based on banking information provided by the Institute:

6. ACCOUNTS AND RECORDS. The Institute agrees to maintain books, records, documents, and other evidence pertaining to all costs and expenses to the extent and in such detail as will properly reflect all net costs incurred in the performance of this research.

7. TRAVEL. Travel costs are not funded under this Project.

8. EQUIPMENT. Title to all equipment purchased under this Agreement shall vest in the Sponsor.

9. TECHNICAL DATA.

a. Ownership of, and the right to register copyright to documents related to computer hardware and software and associated documentation (hereinafter "Documents") shall remain in the Institute. The Sponsor shall be granted a nonexclusive, nontransferable, royalty-free license to use Documents, but only for Sponsor's own internal purposes. The Sponsor further agrees not to provide or otherwise make available Documents, or any copy or modification thereof in any form to any third party, except as may be permitted in writing by the Institute. As used herein "modification" shall mean any source tapes, listings or other documentation in any identifiable or separately usable form included in any program developed by Sponsor in machine readable or printed form, where such source tapes, listings, or other documentation remains essentially the same in both form and function as when originally provided by the Institute to the Sponsor.

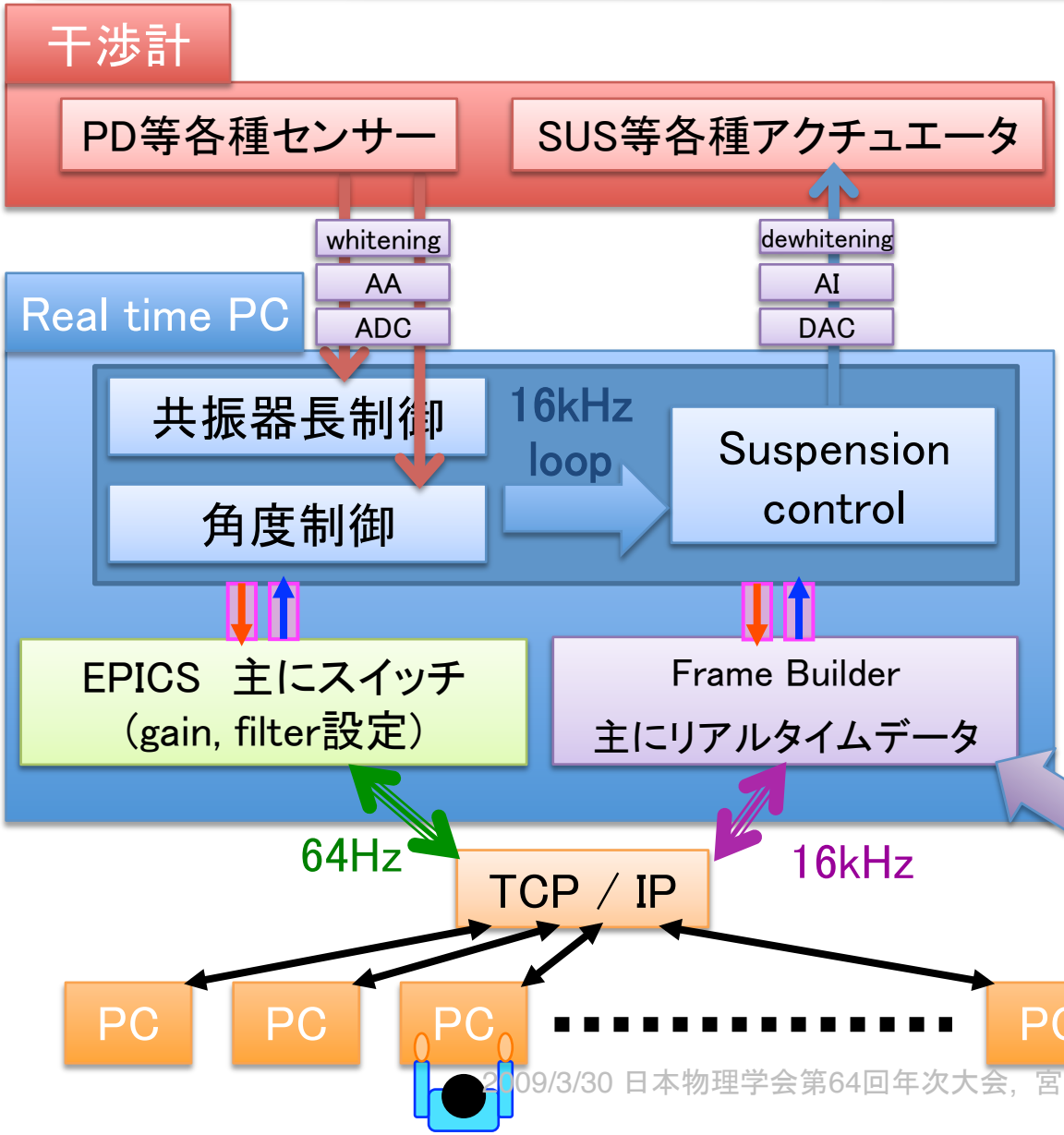
b. All technical data other than Documents resulting from the research program under this Agreement shall be the property of the Institute; however, a copy of all such technical data shall be provided to the Sponsor upon request, and, subject to Article 12 hereof, Sponsor shall have the right to use and disclose all such technical data as it sees fit.

デジタルシステムの利点と欠点

- ひと言で言うと、「干渉計へのアクセスのしやすさを提供する」
  - フィルターの設計制作が簡単
  - ゲイン、信号等の切り替えの自動化
  - 全パラメータの記憶
  - 開発された技術を簡単にコピーできる
- 干渉計全体を把握出来る人を増やす
  - 初心者でもほんの少しの訓練で干渉計が触れる
  - 誰がやっても最適化のレベルが毎回同じで、その状態が長く続く
  - 長期観測時等のためのオペレーター制度の採用の可能性
- 感度向上のための時間の短縮につながる

- デジタル固有の問題がある(ゼロ割、ゼロゲインによる遅延など)
- 一ヶ所動かないとすべてのループがとまることがよくある
- 遅い(16kHzサンプリングでUGF=300~400Hz)
  - LCGT、CLIOなら大丈夫
- ADC、DACのノイズが大きい、alias, imageがある
  - whitening, dewhitening, anti alias, anti imaging filterが必要

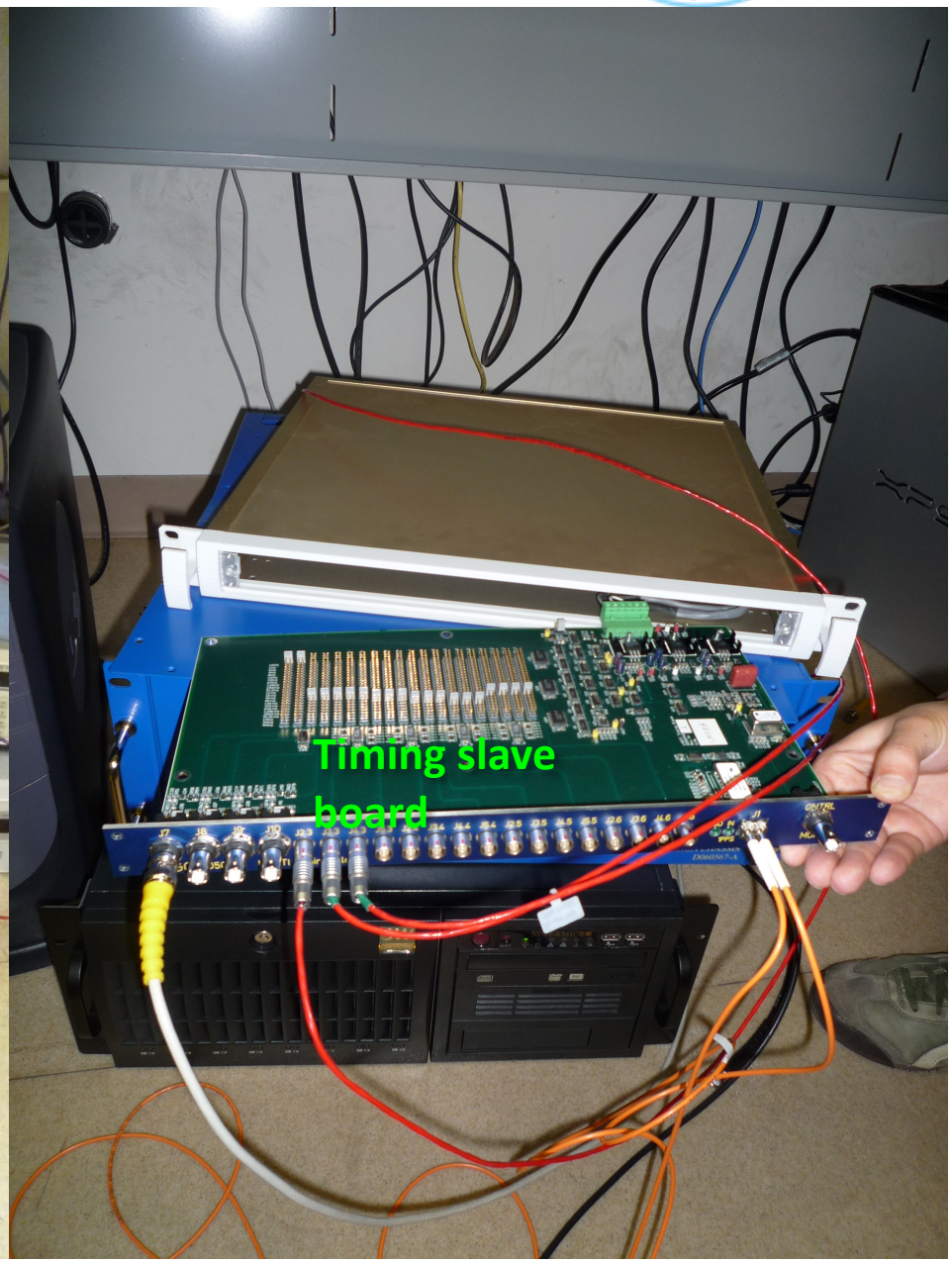
デジタル制御の概念図

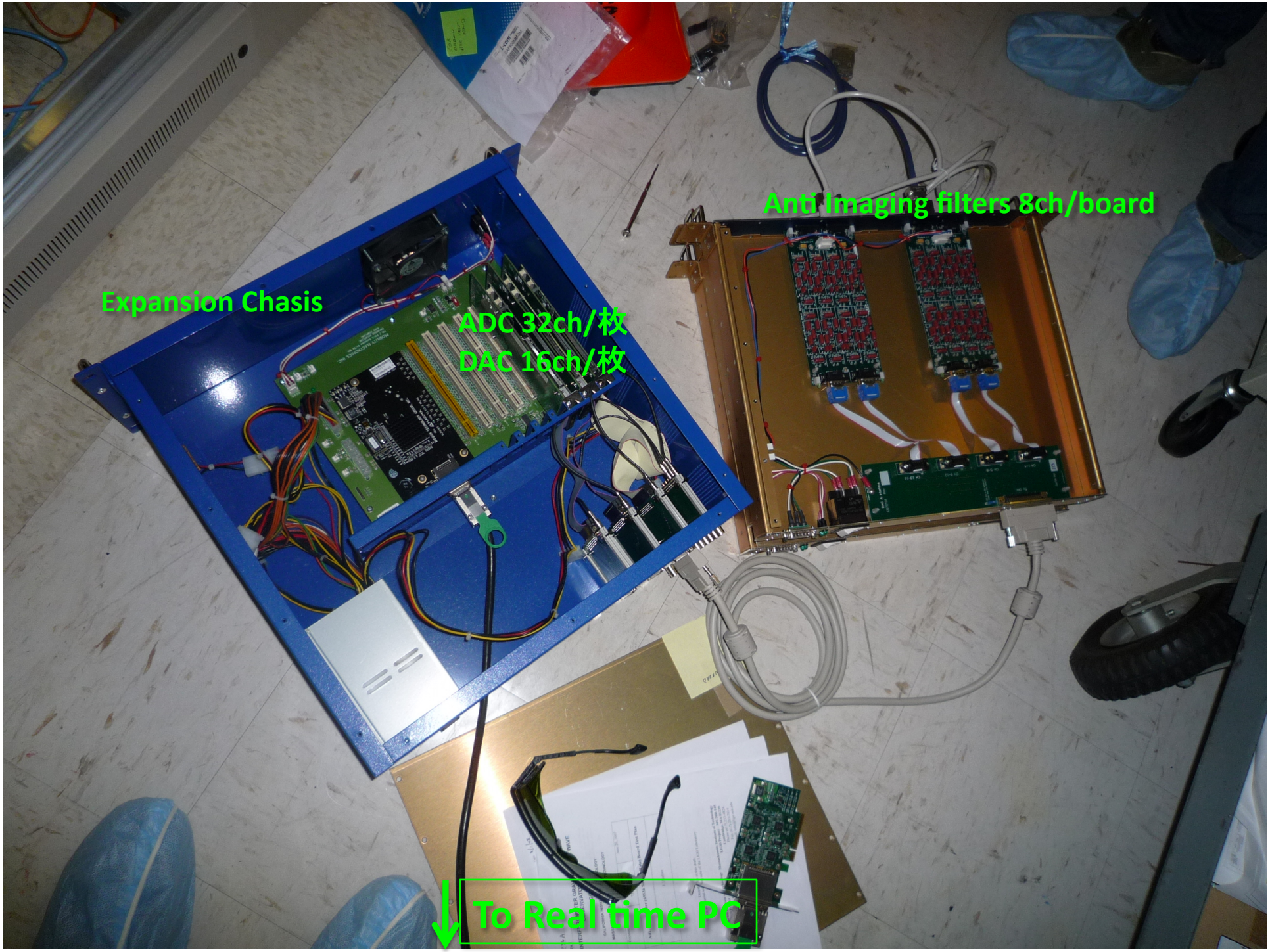


- Real time PC内に16kHzで回る速いループがある
- そこにアクセスする方法はEPICSを使う遅いアクセスと、Frame Builderを使う速いアクセスがある
- 別に用意した任意のPCからネットワークを通してデータ、制御にアクセス可能

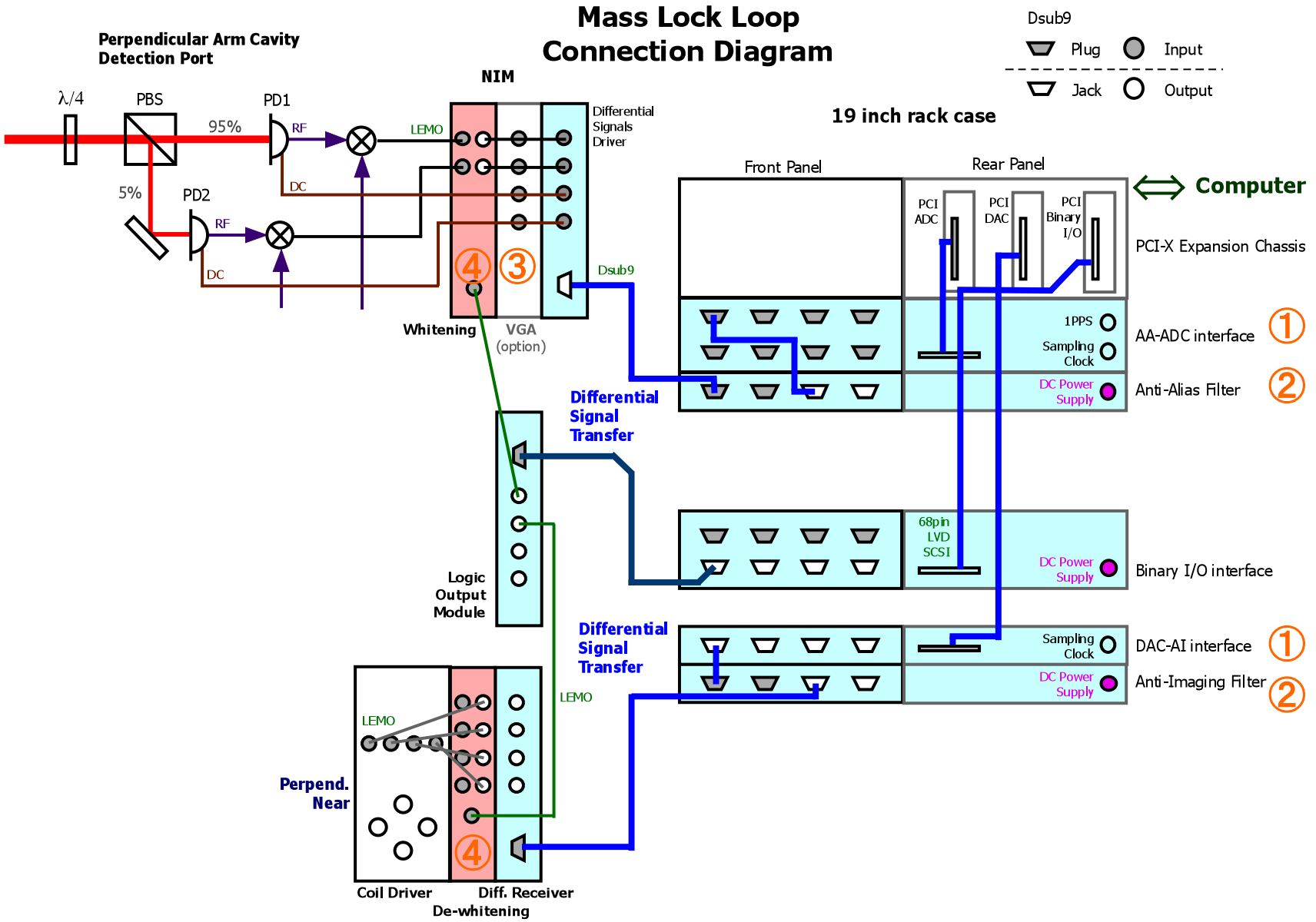
Pictures


Anti Imaging filters
Anti Alias filters
timing
Real time PC
ADC/DAC
In Expansion Chasis
8core, PCIe based PC with CentOS 5.2
ADC:32ch/枚、$4K
DAC:16ch/枚、$3.5K
Binary Output:32ch/枚、$250


Timing slave
board


Expansion Chasis
ADC 32ch/枚
DAC 16ch/枚
Anti Imaging filters 8ch/board
To Real time PC

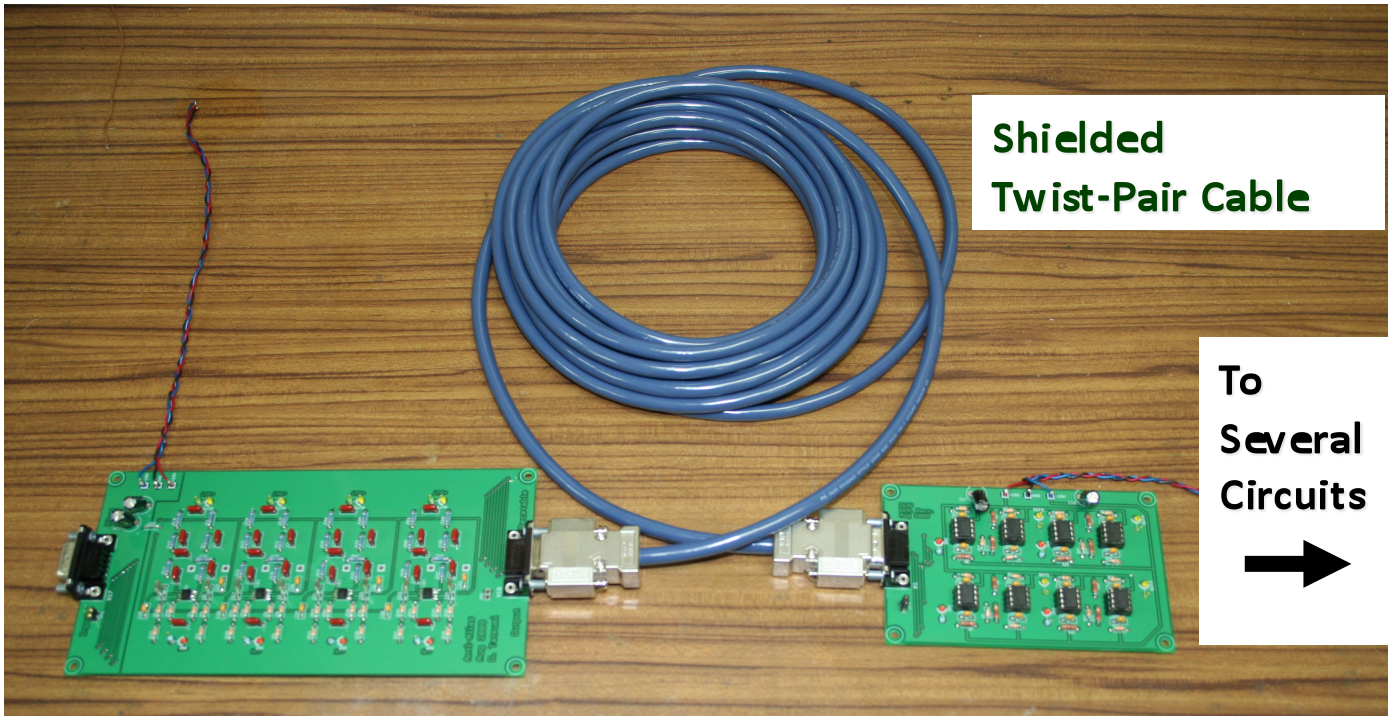
CLIO Digital Front-End



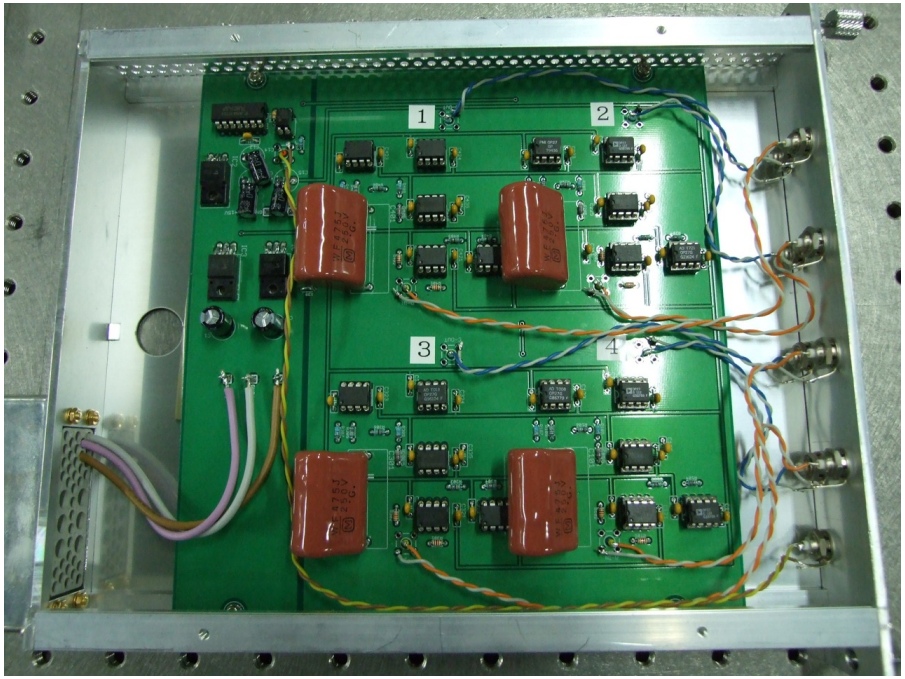
1. **ADC / DAC to AA/AI interface**: 基盤完成、システム到着後 pin配置check
2. **AA/AI filter**: 試作機完成
3. **Variable Gain Amp.**: 試作機完成
   - デジタルコントロール部分を切り離した試作機を作る: 試作機完成
   - 後に、デジタルからコントロールできるものを作る: 未制作
4. **Whitening / De-whitening filter**: 完了
   - 3.5nV/rtHz @ 20Hz / Whitening filter input
   - 5.0nV/rtHz @ 20Hz / De-Whitening filter output

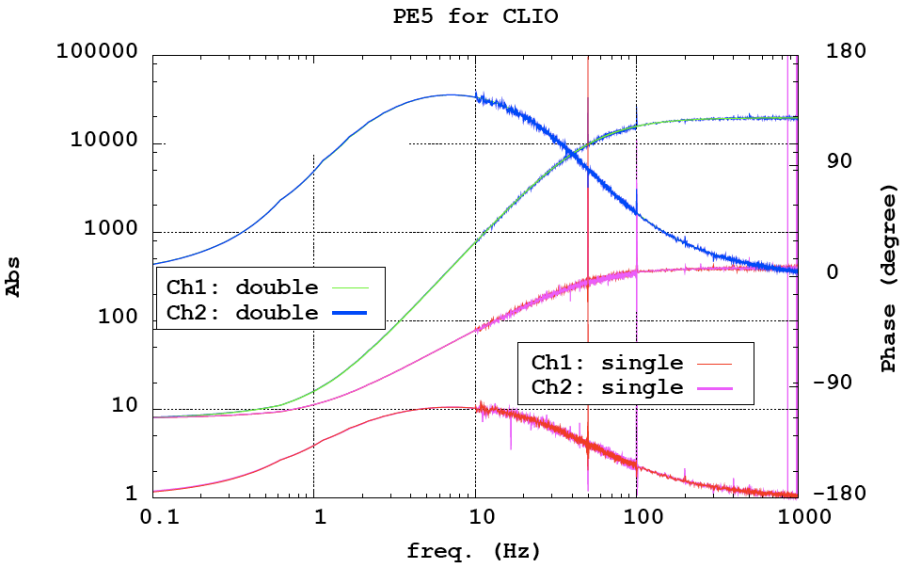
Differential Signal Transfer with AA/AI

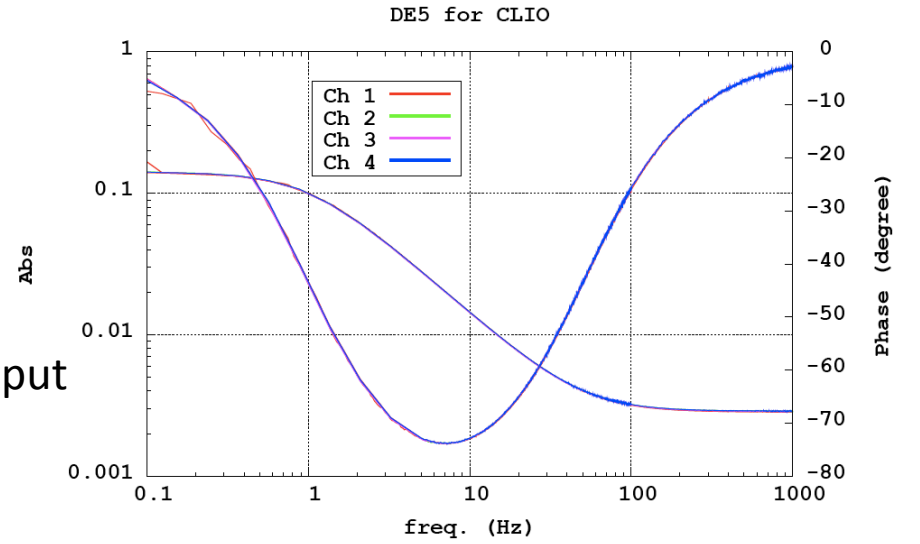
To realize good sensitivity below 100 Hz region,
Ham noises should be reduced.
Therefore, differential signal transfer is necessary for CLIO.



Whitening/dewhitening filter







- 3.5nV/rtHz @ 20Hz / Whitening filter input
- 5.0nV/rtHz @ 20Hz / De-Whitening filter output

CLIOへの実機の導入計画

1st stage, 2nd stageに分ける

1st stageの目標

- Per armの制御（Massに返すのみ）をデジタル化する
- アナログと同じ感度をデジタル上で出す
- 長期モニターチャンネルの設置
  - レーザーパワー、温度、地面振動等を記録する

2nd stageの目標

- In-lineからMC endへ返す信号のデジタル化
- MC feedaround、MC servoのGain、Boostのスイッチング
- アラインメント信号のデジタル化（エンドまでの拡張）
- 長期モニタの多チャンネル化

LIGO digital systemの広がり

- 世界ではMIT, 40m, Caltech labo, GEO, ANU等で使われている
- 日本でもCLIOの他に東大坪野研でも同様のデジタルシステムの導入計画がある

- 導入による利点
  - 多自由度のテーブルトップ、プロトタイプ実験のスムーズな開発
  - 大型干渉計への技術の蓄積
  - 干渉計シミュレータの開発
  - 提供元のLIGOグループへの技術フィードバックによる国際貢献

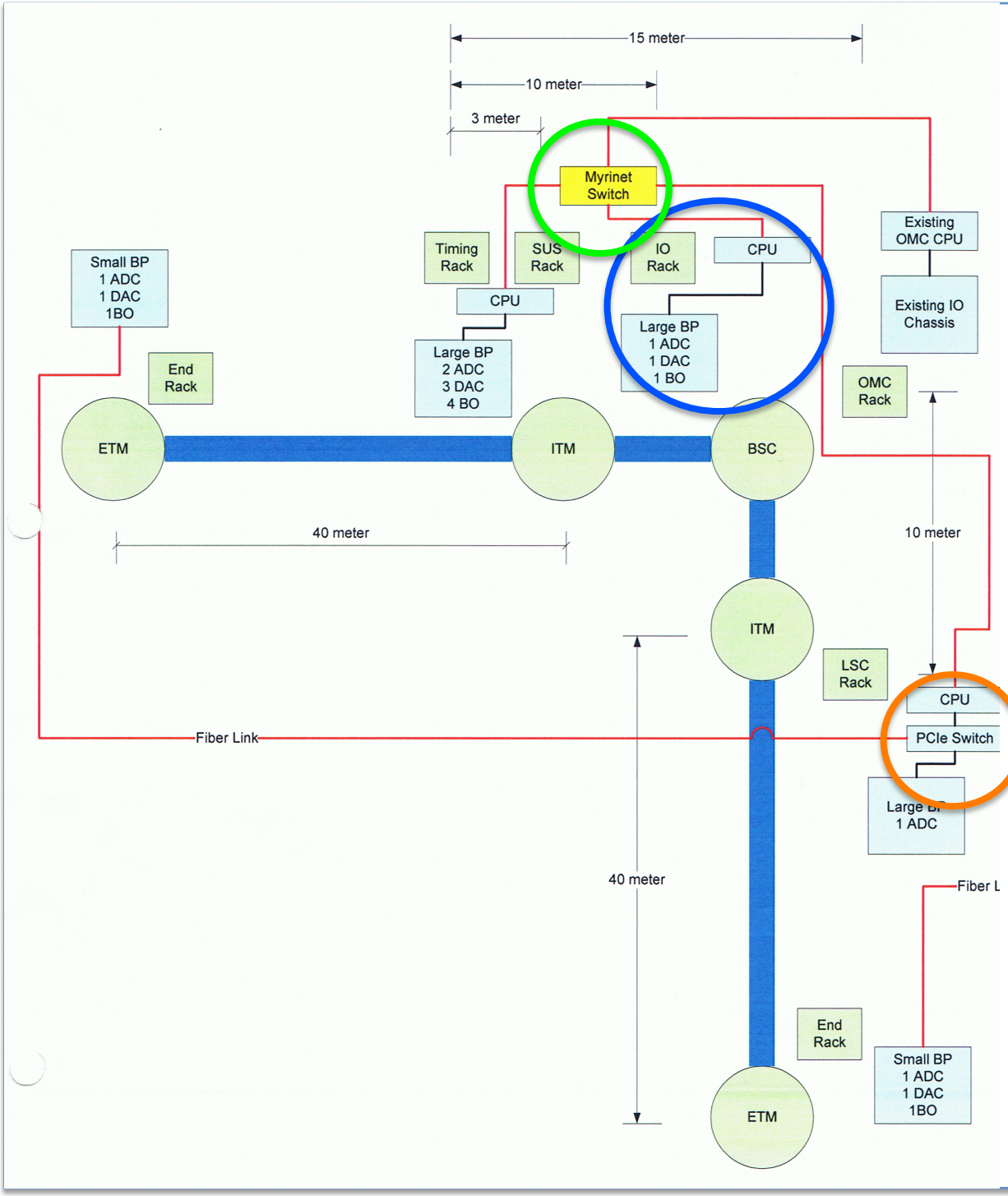
cost

項目	値段(千円)	コメント
Multi core PCIe based PC	550/一台	
拡張ボックス	600/一台	
ADC	400/枚	32ch/枚
DAC	350/枚	16ch/枚
Binary Output	25/枚	32ch/枚
Matlab/Simulink	120	
Real Time core	1100	日本で買うと価格up

項目	値段(千円)	コメント
Analog回路	150/4ch	Inputからoutputまでを1chとする
Oscillator	300	
Timing master	200?	
Timing slave	100?/1station	
Fiber adapter, cable	200 for 100m	100mは拡張可能だが、kmはまだ未検証
Switching hub	600	

Example

1. Table top実験での例(ADC,DAC,BO各1枚の場合): 約400万円
   - PCIeを3枚させるPCを見つけて、フリーのReal time coreを使い、回路を自作し、発信器を既存のものにすれば150万円程度できるかもしれないが、まだ未検証
2. CLIOクラスでエンドルームに拡張boxをしない場合(センターからエンドまで普通のケーブルで持っていく、ADC,DAC,BO各3枚): 約550万円
3. CLIOクラスでエンドルームに拡張boxを設置(ファイバーケーブル、ADC,DAC,BO各4枚):約800万円



LCGTに向けて

大型化にともない、いくつか開発しなければならない技術がある（LIGOでも未解決）

- 今回のCLIO1st の規模
- Endまで届けるのに必要
  - PCIe switch
  - Optical adapter
  - Optical cable
  - Timing master/slave
- 複数台の計算機をつなぐのに必要
  - Myrinet switch

大容量データストレージ

Summary

- Clatech LIGOグループとCLIOデジタル開発についてのMOU及びReserch Agreementを締結した
- LIGOとの共同開発でCLIOにデジタル制御を導入するためのシステムを開発した
- ソフトウェアのライセンス問題により輸入に時間がかかっている
- アナログ回路の開発は順調に進んでいる
- システムが到着し次第すぐにテストできる体制が整いつつある

- 今後の予定
  - システム到着後、天文台で2週間程度の稼働テスト
  - CLIOに移動して、Massロックを試し、アナログで出ているノイズを汚さないか確認
  - アラインメント等に拡張