	US ATLAS HL-LHC Upgrade BASIS of ESTIMATE (BoE)	**Date of Est:** **03/03/2020 in progress**
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		Docdb #: HL-LHC-doc-323

WBS number: 6.2.2	**WBS Title: Strips Tracker Readout Electronics**

WBS Dictionary Definition:
This WBS covers front end readout, and powering electronics.

The basic unit of the tracker is a sensor module (6.2.4). Each module is comprised of silicon strip sensor, either one or two readout hybrid circuits (6.2.3) and an integrated powering board (IPB) (6.2.2.2.6)

Each barrel hybrid contains 10 ABCStar chips and 1 HCCStar chip. The ABCStar (6.2.2.3.1 and 6.2.2.4.1) is the front-end readout chip while the HCCStar (6.2.2.3.2 and 6.2.2.4.2) is the local hybrid controller chip. Penn and UCSC will contribute to the ABCStar **design** and the US will pay for the 88,631 chips needed for the barrel tracker modules (6.2.4). The HCCStar design is a Penn **deliverable** with contributions from UCSC. We will produce and take responsibility for testing the 25,536 chips needed to supply the entire tracker needs.

The Integrated Power Board (IPB) implements all the LV, HV, monitoring, and power control functions in a single PCB. There is a single version for the barrel version and several versions for the endcap. The US will provide all 10,976 IPBs needed for the Barrel. LBNL evolved the V1 PCB design from Liverpool University into V2 and V3 prototypes. The first batch of the V3 prototype have been fabricated and distributed. The second batch of the V3 prototype, a pre-production version, and finally a production version will be produced. The boards will be fabricated, loaded, and assembled in industry. Final test and burn-in will occur at LBNL. A full test and burn-in system which can provide all boards in about 2 years will be developed in the US and used in the production run. The IPB contains several application specific components which are either dependencies or deliverables. Each barrel board contains one DC-DC converter bPOL12V ASIC, a linear regulator linPOL12V, one inductor (coil), one shield to cover them, one HV Mux circuit to enable the HV line, and one Autonomous Monitor (AMAC) chip for monitoring and control. The converter is the main voltage regulator on the board. CERN provides both bPOL12V and linPOL12V circuit design and the ASICs. Yale will design and provide the coils for the entire tracker, totaling 16,352 pieces (6.2.2.5.3). The shield which covers the DC-DC converter is a BNL design but is delivered by LBNL as a part of IPB fabrication. The HV Mux is a BNL design, prototyping, and production deliverable (6.2.2.1.4). BNL will produce all 17,888 pieces in the tracker. The AMAC chip is a Penn deliverable (6.2.2.3.5). The chip performs autonomous monitoring of up to 22 quantities and can supply a programmable LV and Sensor bias voltage

interlock function to turn off power regulators when a limit value is sensed. The US will produce and probe 100% of these chips, totaling 17,888 die.
Estimate Type (check all that apply – see BOE Report for estimate type by activity): _X_ Existing Purchase Order or Work Complete _X_ Engineering Build-up _X_ Extrapolation from Actuals _X_ Analogy _X_ Expert Opinion
Supporting Documents (including but not limited to): Attachments 1-17

Details of the Base Estimate (Explanation of the Work)

Prototyping Phase:
The prototyping phase of the readout electronics follows on from an earlier R&D phase which resulted already in versions of the front end and powering electronics. Already in hand are the ABC130 and HCC chips "non-star" versions, which support a daisy-chained readout, the AMAC V1 chip, the bPOL12V, coils, and HVmux test devices. V1 and V2 powerboards also exist. These devices have been used in the fabrication and test of prototype hybrids and modules and will also be used for the first 1% hybrids, modules, and stave pre-production.

The prototyping phase of the readout and powering electronics feeds components into the second preproduction phase of the hybrids and modules. This phase began in FY16 will end in FY19. New "star" versions of the readout chips were required to support higher trigger rates requested by ATLAS. The "star" version of the readout chips have a direct communication link from each ABCStar to the HCCStar, instead of the daisy-chain communication of several ABC130 to the HCC130 version. The ABCStar, HCCStar, and AMAC V2a chips have been fabricated and tested, they have been loaded onto hybrids as part of the second 1% pre-production phase of hybrid/module/stave building. Several key developments include:

- Design of prototype version of ABCStar, to which Penn and UCSC have contributed
- Design of prototype version of HCCStar by Penn and UCSC
- Design of AMAC V2 and V2a by Penn
- Fabrication of the ABCStar, HCCStar, and AMACV2a prototypes, submission in June 2018 and wafers returned in November 2018
- Testing of HCCStar and AMAC V2 and V2a by Penn, including ionizing radiation qualification
- Radiation hardness and reliability evaluation of GaN-FET based circuit for HV Mux by BNL
- Coil and shield tests by Yale
- Design, fabrication, and testing of V2 and V3 of the IPB by LBNL

In March 2019, ATLAS decided the HV Mux technology is mature enough to be included in the power board. However, the HV Mux may not be included if space is needed for shielding from noise. If not included, we will rely on existing segmentation of HV lines on the staves and petals.

More detailed descriptions of the prototyping and design activities for these electronics follow below.

6.2.2.3.1 and 6.2.2.4.1 ABCStar at Penn and UCSC

Our work on ABCStar is primarily involved with design and verification. Two chip specification reviews and a Preliminary Design Review (PDR) have been held. For the June 2018 chip submission, we developed the new chip blocks relative to the previous ABC130 design, such as new command decoder, faster clustering algorithm, data serialization and control protocol communication with HCC, as well as design verification. We will be available for post submission simulations to help answer any issues that arise when the chips are returned and to update designs for the production version of ABCStar. The architecture we have helped to design allows the ABCStar to be largely insulated from changes in DAQ requirements. We anticipate that our design work on ABCStar will be complete in Q4 FY20.

6.2.2.3.2 and 6.2.2.4.2 HCCStar design at Penn and UCSC

The new features of HCCStar design, compared to the previous HCC version, are much higher bandwidth and up to 11 input data streams. This required a rewrite of almost all the digital logiv. The design team has developed the specification and design blocks synergistically with those of ABCStar. This led to submission of the first HCCStar design required for prototyping with the ABCStar in June 2018. The prototype HCCStar works. The pre-production HCCStar is expected to be submitted in Q4 FY19. We expect that the design of the production ready HCCStar will need to continue until Q4 FY20 to allow incorporation of stave testing feedback into the design.

6.2.2.3.2 HCCStar testing at Penn

We have several working parametric single chip HCCStar testers at Penn and have measured the performance of the first prototype HCCStar chips. There is a program of irradiation tests for the prototype chips, with gamma irradiation at BNL from May-July 2019, 480 MeV protons at TRIUMF in May and June 2019, and heavy ions at Louvain in August 2019. We have developed wafer tests and tested the chips on the prototype wafers using a probe station at RAL in March 2019. For the pre-production and production wafer testing, a probe station to test these wafers at Penn was ordered in December 2018 and arrived at Penn in March 2019.

6.2.2.3.2 AMAC chip design at Penn

The monitor chip measures 22 module based parameters including temperatures on chip and in multiple places on the hybrid, voltages at the input and output of the DCDC converter, the AMAC regulated supply, bandgap and some internal references, current at the input and output of the DCDC converter and the ground reference potential of the power board and each of the readout hybrids attached to the sensor. The onboard programmable ring oscillator and dedicated bandgap reference will allow it to make measurements autonomously as long as it is powered and a private bond wire selected address will allow its unique identification along the stave or petal. AMAC will receive instructions, data and control information through a unidirectional single pair low level differential multi-drop bus on the stave or petal. These instructions will utilize a low bandwidth length-encoded protocol easily adaptable to the lpGBT eLink driver. Acknowledgement and readout data will be sent by AMAC over a dedicated single pair stave or petal bus utilizing a custom tristate differential driver with logic levels compatible with the lpGBT eLink inputs. AMAC enables the DCDC converter to provide raw power to all other ASICs on the sensor module. An interlock function makes it possible to automatically disable power to ASICs or Sensor bias in the event of a near limit operational condition. A first version of AMAC chip was produced in 2016 for prototyping purposes. A significant amount of work was required to extend the amount of monitoring and communication with other chips on the module, consistent with advances in module design and prototyping. The AMAC V2 prototype was submitted in November 2017 and the AMAC V2a prototype in June 2018. The AMAC V2 prototype arrived back from fab in July 2018 and has been tested at Penn and LBNL. There is a program of irradiation tests for the prototype chips as for HCCStar. The results of the testing and irradiation will lead to a pre-production chip that is expected to be submitted in Q4 FY19 on the same wafer as HCCStar. Wafer-level AMAC tests have been developed, and the prototype wafers are being tested at Penn in June 2019. The pre-production and production wafer testing will also take place with the probe station at Penn.

6.2.2.5.3 DCDC converter coils at Yale
The Yale group has pioneered the design and prototyping of low profile/low mass inductor/coils for use in the DCDC buck converter. The Yale coils were adopted as the baseline by the ATLAS silicon strip upgrade project. The Yale group will continue the engineering and oversee the production and QA of these coils for the entire strips tracker project.

6.2.2.1.3 HV Mux at BNL
The baseline plan is to have one HV Mux device on each sensor of the silicon strip tracker. The HV Mux consists of a rad-hard HV switch. Two technologies were considered, one based a GaN-FET and another based on a vertical silicon JFET technology. ATLAS review in April 2017 selected GaN-FET for continuing studies. The HV Mux is controlled by the AMAC chip from Penn. BNL has led the prototyping program in this area. Reliability studies and irradiations have been completed and a review in January 2019 decided to use the HV Mux as insurance against sensor failure, where one HV line powers several sensors. BNL will provide the final design of the HV Mux circuit, select, fabricate, and produce the final components which will be distributed to the collaboration.

6.2.2.2.6 Integrated Power Board at LBNL
The high density IPB has a size of 7.2 mm x 11 mm and contains a HV filter, the HV Mux, the DCDC converter, consisting of the bPOL12V and linPOL12V ASICs, the Yale coil, shield box, and AMAC chip. It connects to one or two hybrids on the module and to the bus tape. LBNL is responsible for the layout, fabrication, and test of these boards but is reliant on others to provide the aforementioned components. Most of the components are sourced from other US groups. The main exceptions are the bPOL12V and linPOL12V chips which are CERN deliverables. Originally, a V1 PCB was developed by Liverpool. It lacked the AMAC and HV Mux functions. In 2017 this board was tested across the ATLAS strip tracker community and at LBNL. In the middle of 2017, a V2 PCB was produced and tested at LBNL. It has been used by module groups in US and UK, and it performed well. The board included the first AMAC chip and it integrated the HV Mux prototype. This board has been used for QC, testing, burn-in, and reliability studies, as well as development of draft specifications. In 2018 prototyping continued to complete the final design, protocols, and specifications and production of the V3 PCBs is underway, with 30 produced in November 2018 and a larger batch of 800 under production. A significant design effort in 2018 established the mass testing and burn-in infrastructure for this component.

<u>Pre-production Phase</u>
As part of the international ATLAS tracker construction project, pre-production is used to demonstrate production quality for all components and to satisfy and document site qualification requirements. This requires all processes and quality assurance methods to be in place over the course of pre-production.

In 2018 and 2019 the performance test results of the prototype components will lead to their design modification. The next round of chip submissions and components orders will be placed at scaled-up quantities to verify the designs for production, fabrication scale, and to scale up testing throughput. The first pre-production ABCStar, HCCStar, and AMAC chips are expected to be available in January 2020.

During this phase we are working on several key developments:
- Pre-production ABCStar design revision to which Penn and UCSC are contributing
- Pre-production HCCStar design revision by Penn and UCSC; fabrication submission of at least 3 wafers, and testing of HCCStar by Penn
- Pre-production AMAC design revision, fabrication (with HCCStar), and testing by Penn
- Fabrication and testing of 22,000 production coil sets by Yale. In spite of this being still the pre-production phase we believe risk is reduced by ordering the coil early and the cost impact is small.
- Pre-production IPB design revision, fabrication of 1000 boards, and testing of the IPB by LBNL. Some of these boards (100) will be supplied to hybrid assembly sites for hybrid burn-in systems.

Production Phase

Verification of pre-production components performance and fabrication quality will lead to steady-state production of several deliverables.

During this phase we are producing the remainder of our deliverables, quantities and yields are given in a table in the cost estimate section:
- Financial contribution to ABCStar production
- Production HCCStar fabrication, testing, and distribution by Penn
- Production AMAC fabrication, testing, and distribution by Penn
- Production order for 24,000 GaN-FET devices, perform QC tests including irradiations by BNL
- Production IPB fabrication of 14,100 boards, and testing of the IPB, including burn-in, by LBNL. Some of these boards (400) will be sent to hybrid assembly sites for hybrid burn-in systems.

In this phase the ASIC delivery rate will be determined by wafer fab rate for a wafer batch and testing throughput.
- For ABCStar, the production is not a US deliverable. It will be done in five batches, with 144 wafers in the first four batches. The first chips from the first batch will be available in February 2021. The testing of the chips in the final batch will be completed in April 2023.
- For HCCStar and AMAC, which will be on the same wafer, the production and testing is a US deliverable and will be done in a single batch of 50 wafers. The first chips will be available in February 2021 and testing of all the chips will be completed in July 2021.
- The IPB fabrication will take place in 12 batches, from February 2021 to April 2023.

Yields for ASICs have been determined by several previous fabrication and wafer probing runs in the same 130 nm CMOS technology. Yields for the IPB (power board) are based on measured failure rates of similar scale PCB's and experience with the individual components during the R&D leading to this work.

Total Cost by Task Group from P6 output

The table below summarizes direct costs for deliverables, where labor hours includes uncosted labor. The WBS 6.02.02.01.07 contains payments for ASIC deliveries from CERN as a part of all other WBS items. Such costs are also shown in Attachments 1, 8, 9, 11, and 12.

Total Cost By Task Group

	Lbr Hours	Mat Direct	Trav Direct
6.02.02.01 Readout Electronics-BNL	**4,172**	**71,500**	
01 HV Supplies	64		
02 HV Mux Pre-Production	1,840	11,500	
03 HV Mux Production	2,268	60,000	
6.02.02.02 Readout Electronics-LBNL	**13,561**	**1,294,746**	**4,000**
Integrated Powerboard - LBNL	13,561	1,294,746	4,000
6.02.02.03 Readout Electronics-Penn	**28,398**	**630,978**	**24,100**
ABC Star Chip-Penn	1,147		
AMAC Chip-Penn	8,262	6,950	7,400
HCC Star Chip-Penn	18,989	624,028	16,700
6.02.02.04 Readout Electronics-UCSC	**1,960**	**71,532**	**10,000**
ABC Star Chip-UCSC	537	59,532	
HCC Star Chip-UCSC	1,423	12,000	10,000
6.02.02.05 Readout Electronics-Yale	**1,680**	**153,721**	
02 Pre-Production	828	54,183	
03 Production	852	99,538	
6.02.02.90 L3 Project Management	**2,816**		
Grand Total	52,587	2,222,477	38,100

	Mat Direct
6.02.07.01 US Contributions to CERN Procurements-BNL	**3,847,606**
US Contributions to CERN Procurements-BNL	3,847,606
EQUIP	3,847,606
Grand Total	3,847,606

Cost Estimate Description

There are significant engineering tasks covered in this WBS pertaining to the ABCStar, the HCCStar and AMAC, at Penn and UCSC, the coils at Yale, the HV Mux at BNL, and IPB at LBNL.

The custom ASICs production costs are based on CERN frame contract with Global Foundry (Attachment 10). The test plans and estimates for wafer probing time are based on the ASICs complexity and experience with wafer testing of FE ASICs for SCT, TRT, and the previous and current prototypes: ABCD3T, ASDBLR, DTMROC, ABC130, HCC130, ABCStar and HCCStar.

<u>Prototype and Pre-production Phase Costs</u>

All of the ASICs are evolutions or continuations from previous versions and ongoing designs also in 130 nm CMOS technology. The first star versions of ABCStar and HCCStar and AMAC V2a arrived back from fabrication in November 2018 and extensive single chips tests show the chips are operational. The second AMAC V2 prototype arrived back from fabrication in July 2018 and the chips are operational. All chips were designed by largely the same team. The estimates are based on experience of what was required already to complete the chip redesigns given the evolved specifications.

There are significant material costs for pre-production quantities of ASICs. These are based on the CERN frame contract (Attachment 10) and are shown in Attachments 9, 11, 12.

The coils, the rad-hard HV Mux switches, and the IPB, have been prototyped. The estimate for these engineering tasks is therefore based upon experience of designing these components, procuring them from vendors in prototyping quantities and using them in functional circuits, as well as the time already encountered.

We have purchased the wafer probe station in December 2018 and it arrived at Penn in March 2019 (Attachment 17).
We have ordered custom probe cards for testing of HCCStar and AMAC die. In 2019 we have begun programming the wafer probe station and implementation of a data base for test entries. The development effort is based upon the experience with probing the earlier versions of the HCC and AMAC chips. For these die we already developed and ran a complete die testing system. The cost of a wafer probe station and appropriate accessories is included in the M&S for prototyping and pre-production and is of order $150K.

Production M&S Costs
The ASIC fabrication costs for the tasks covered by this WBS were derived as part of the ATLAS wide strips costing exercise. They are based upon vendor quotes or estimates and experience exists in all cases from the prototyping work which is ongoing. US members of the collaboration with direct experience and knowledge of these items and tasks were directly involved the costing process. This process yielded a cost model and calculating framework which then took parts costs and parts counts as input.

The summary of parts counts is shown in Table 1. The number of parts to produce is larger than the number to install due to a cascade of losses at the level of chip probing, dicing, PCB mounting, module assembly and stave assembly. While each loss factor is small (and therefore the Yield Factor is close to 1), the aggregate system yield factor needs to be accounted for in the planning. The yield model we are using is consistent with ATLAS assumptions. Further description of the yield assumptions is shown in the paragraphs below for ASICs and in the corresponding BOEs for hybrids and modules.

Table 1. The number of electronics components to be delivered. The System Yield Factor takes into account losses in downstream system assembly. The Component Yield Factor accounts for yield losses when fabricating individual items. The Yield Factors are shown with several digits for the purpose of checking the calculations. This is not a reflection of the estimate precision.

Deliverable	Number to install	System yield factor	Component yield factor	Production number to fabricate	Production QA/QC	Pre-production number (circa 5%)	Total with pre-production
ABCStar (37.9%)	88,631	1.1890	1.1340	**119,504**	-	5,975	125,479
HCCStar	25,536	1.1890	1.1340	**34,431**	-	1,722	36,152
AMAC	17,888	1.1890	1.1340	**24,119**	305	1,206	25,630
HV Mux	17,888	1.1890	1.0730	**22,821**	685+305	-	23,811
Coils	16,352	1.1890	1.0500	**20,415**	305	1,021	21,741
IPBs (barrel)	10,976	1.1530	1.0740	**13,592**	508	1,000	15,100

The number of ABCStar, HCCStar and AMAC chips required for the final barrel and end-cap strip detector is described below. The yield estimates are as follows:

- System yield factor of 1.1890 includes the down-stream efficiency of the ATLAS assembly process. This includes failure of installation of components on hybrid is 97% (rounded to 1.031), failure of module assembly of 91% (rounded to 1.095), and failure of stave substructures of 95% (rounded to 1.053). This gives a system yield factor of 1.1890 for all components except the IPBs, which have a system yield factor of 1.1530 since the factor for installation of components on hybrids does not apply. These downstream production yields are described in other BOEs.
- Component yield factor of 1.1340 for ABCStar, HCCStar, and AMAC. The estimated production yield is based on the probing of the ABC130 and HCC prototype ASICs produced in the same GF CMOS8RF process and which has a similar size and complexity. This includes a yield of 90% after probing, and a subsequent 98% after dicing/handling based on experience from handling prototypes. The total yield for the ABCStar/HCCStar chip ready to be assembled is estimated at 88.2%. The recent prototype run had a yield above 90% for ABCStar and a yield above 95% for HCCStar. The dicing/handling efficiency was 100%.
- Component yield factor estimate is 1.073 for HV Mux.
- Component yield factor estimate is 1.050 for Coils.
- Component yield factor estimate is 1.074 for IPB.
- The QA/QC column requires 685 more HV Mux, primarily for radiation testing, and 305 more HV Mux, AMAC, and Coils to load the 60% of the 508 QA/QC powerboards that will be loaded.

6.2.2.3.1 ABCStar Masks

One mask set is required for the ABCStar chip. Two iterations, for a pre-production mask set and a production mask set, are assumed in the calculation of the cost. The mask costs were provided by CERN Foundry Services within the CERN Global Foundries (GF) frame contract for the options used in the ABCStar production. This cost estimate is consistent with the procurement of the masks for the prototypes. The cost estimate for the ABCStar mask is $325,280 (Attachment 10). The USA pays a 33.7% fraction for the masks, which is $109,619 per mask set.

6.2.2.3.1: ABCStar chip

Each ABCStar chip processes signals from 256 silicon strips. The number of ABCStar chips per module, therefore, varies depending on the number of strips within it.

- Each short barrel module requires 20 ABCStar chips, 3808 modules are installed resulting in 76,160 chips.
- Each long barrel module requires 10 ABCStar chips, 7168 modules are installed resulting in 71,680 ABCStar chips.
- There are 112 ABCStar chips required on each side of the endcap petal (224 for each side of the petal). There are 384 petals (32 petals per disk and 12 endcap disks), so the total number of ABCStar chips required is 86,016.
    - 17 ABCStars and 2 HCCStars on two hybrids on R0 sensor
        - 8 ABCStars and 1 HCCStar on the lower hybrid
        - 9 ABCStars and 1 HCCStar on the upper hybrid
    - 21 ABCStars and 2 HCCStars on two hybrids on R1 sensor
        - 10 ABCStars and 1 HCCStar on lower hybrid
        - 11 ABCStars and 1 HCCStar on upper hybrid
    - 12 ABCStars and 2 HCCStars on one hybrid on R2 sensor
    - 28 ABCStars and 4 HCCStars on two hybrids on two R3 sensors connected side-by-side
        - 14 ABCStars and 2 HCCStars on each hybrid
    - 16 ABCStars and 2 HCCStars on one hybrid on two R4 sensors connected side-by-side
    - 18 ABCStars and 2 HCCStars on one hybrid on two R5 sensors connected side-by-side

The total installed number of ABCStar chips in the tracker is therefore 233,856. Given the component and system yield factors, the total production number is 315,300 chips. For the expected ASIC size, the estimate is that 470 ABCStar chips are expected to fit in a wafer; hence, the total number of ABCStar-wafers required for production is 670 wafers. The ABCStar wafer cost of $2852 each have also been provided by CERN Foundry Services within the CERN GF frame contract used in the ABCStar production, including wafer dicing costs at a second firm.

All of the 670 production ABCStar wafers cost $1,910,840. The USA pays for 37.9% of the production fabrication. This corresponds to $724,208. This amount represents 60% of the chips needed for the barrel section of the tracker.

The US portion for a production mask set ($109,619) and production chips ($724,208) is then $833,800 (Attachment 9). The estimated fabrication cost per production ABCStar chips is $7.09.

The dominant uncertainty is the number of the ABCStar ASICs which can be placed per wafer; this will depend of the final dimensions of the ABCStar, which are fairly well understood and unlikely to increase as the current size is set by bond-ability arguments and not by the amount of circuitry. The international schedule currently assumes a larger number of 500 chips per wafer, with pre-production order of 35 wafers and production order in 4 batches of 144 wafers and a final batch of 72 wafers, for a total of 648 production wafers.

ABCStar probing is not a USA deliverable.

6.2.2.3.2 and 6.2.2.3.5: HCCStar/AMAC Masks

One mask set is required for the combined submission of HCCStar/AMAC chips. Two iterations, a preproduction mask set and a production mask set, are assumed in the calculation of the cost to allow for a second iteration in order to be conservative. The cost estimate for the HCCStar/AMAC mask is identical to the ABCStar as it is also within the GF frame contract with identical options used. The cost estimate for the HCCStar mask is $325,200 (Attachment 10). The USA pays 100% of the submission cost.

6.2.2.3.2 and 6.2.2.3.5: HCCStar/AMAC chip

Each HCCStar chip processes signals from 10 ABCStar front-end chips in the barrel region. The number of HCCStar chips required for the barrel is therefore 14,784. In the endcap an HCCStar chip processes signals from 6-11 ABCStars, depending on the hybrid. One side of a petal needs 14 HCCStar chips (28 on both sides) and there are 384 petals. Hence the endcap requires 10,752 chips. The total number of HCCStar chips in the installed detector is 25,536. Given the component and system yield factors, the total number of HCCStar chips to be fabricated is 34,431. The USA pays 100%.

There is one AMAC chip associated with each barrel module to provide monitoring and control for all the ASICs and the sensor on that module. Thus, 10,976 AMAC chips are required for the barrel strip detector. For the endcap, each side of a petal needs 9 AMAC chips (18 on both sides). The inner three rings of the endcap have one sensor per module and require 1 AMAC chip per module. The outer three rings of the endcap have two sensors per module and require 2 AMAC chips per module to monitor the sensor current. Hence the endcap requires 6,912 AMAC chips. The total number of AMAC chips in the installed detector is 17,888. Given the component and system yield factors, and the need for 305 chips for QA/QC for the IPB, the number of production AMAC chips to be fabricated is 24,424. The USA pays 100%.

The 34,431 HCCStar and 24,424 AMAC chips are combined in a single reticle to be produced on the same wafer. The relative number of each will be weighted by amount needed in the detector (roughly 1.4:1 HCCStar to AMAC). For the current expected size (3.56 mm x 5.36 mm) of the HCCStar and AMAC chips, at least 48 wafers will be needed for production, with approximately 720 HCCStar and 500 AMAC per wafer. The cost estimate per wafer of $2852 is the same as the ABCStar (Attachment 10). The cost of the HCCStar and AMAC production chips is then 48 wafers at $2852 for a cost of $136,896.

Including the cost of the mask set brings the total cost for production of HCCStar and AMAC to $462,096. Assuming equal value for each chip, the production fabrication cost per chip is $7.85. The USA pays 100%. The calculation for the fabrication costs of the chips is shown in Attachment 11.

6.2.2.3.2 and 6.2.2.3.5: HCCStar/AMAC Probing

The HCCStar/AMAC chips that will be required for the strips upgrade will be manufactured on 8” wafers. To facilitate handling, it will be important to perform wafer-level chip testing prior to dicing. Chips will be selected for detector construction based on these results. Parametric data may be used to determine selection criteria by geographic location on the detector. The baseline approach is a purchase of an automated wafer probe station and development of custom readout for testing both HCCStar and AMAC chips on these wafers.

The HCCStar/AMAC probing infrastructure estimate is based on the ABCStar estimate. The cost of a wafer probe station (Attachment 17) and appropriate accessories is included in the M&S for prototyping and pre-production and is of order $150K. The cost for additional required infrastructure ($10k) is based on estimates for the similar setups during SCT and TRT chip probing. This is a USA deliverable.

6.2.2.1.4 HV Mux

HV-Mux for production and pre-production, the minimum number is 23,963, rounded up to 24,000. Recall that we provide HV Mux and AMAC chips for the entire tracker. The three outer endcap modules cover two sensors and this require two HV Mux chips and two AMAC chips. This is the reason that the order numbers for HV Mux and AMAC are larger than the number of coils. This is obtained by multiplying the 17,888 needed (one per sensor as for AMAC) to be installed by a system yield factor (assumed to be 1.1890 based on hybrid, module and stave factors) and a component yield factor for HV-Mux (assumed to be 1.073). A further 990 chips are needed for QA/QC for HV Mux (685 chips) and for IPB (305 chips). There is a long lead-time for HV Mux and there are sufficient parts from the prototype run for pre-production of barrel and endcap.

The HV Mux estimates (Attachments 1 and 2) are based on vendor quotes, expected cost evolution, as well as engineering judgement and experience for the testing process. Attachment 2 shows a cost of $40.00 each for an order of 2,447 pieces. The estimate of the direct cost was based on an order of 20,000 chips at $40.00 each on this quote, resulting in $800k of the $801k direct cost of RE140400M. The expected production order is larger at 24,000 chips and it is assumed that the larger order will have a lower price per chip of about $25-30.

6.2.2.5.3 Coils

For Coils for production and pre-production, the minimum number is 21,741. This is obtained by multiplying the 16,352 needed to be installed (10,976 in the barrel and 5,376 in the endcap at 7 coils per petal side since the R3 module requires 2 coils) by a system yield factor (assumed to be 1.1890 based on hybrid, module and stave factors) and a component yield factor for Coils (assumed to be 1.05). Then we also need an extra 5% for pre-production and an extra 305 for QA/QC of the IPB. Rounding up, these 24,000 coils for pre-production and production components will be ordered together here to ensure parts are on hand for assembling powerboards.

The DC-DC coils cost (Attachment 13) is based on the vendor quote for the selected solution, as well as engineering judgement and experience for the evaluation process. The estimate of the direct cost is based on an order of 22,000 coils, resulting in $105,600.

6.2.2.2.6: Power board

The integrated power board IPB is built up of numerous components on a standard substrate material and therefore corresponds to a more typical printed circuit board design and fabrication project. A similar circuit was prototyped in FY16 and FY17 as part of a generic R&D exercise aimed at high throughput fabrication of electrical and mechanical components for future large-scale physics instrumentation. That exercise allowed us to determine directly the cost of this high-reliability manufacturing and assembly of high density hybrid IC electronics. Most notably, there are great similarities with numerous high reliability hybrid circuits produced for IceCube, ATLAS, and CDF experiments.

The cost model for IPB (Attachments 3-8, 14-15) has several parts. The IPB estimate is described in Attachment 3 and supported by Attachments 4-8. Additional significant costs are for a burn-in test system (Attachment 14) as well as passive test carriers and active boards (Attachment 15), based partially on quotes and partially on experience with evaluation and testing process on similar projects.

- The **passive components** cost about $3.80 per board. The total cost is $54k for parts for 14,100 boards. These costs are well known from catalogs and supported by Attachment 4.
- The fabrication of specialized **shield boxes** costs $6.70 each, and $0.50 for engraving. The total cost is $101,520 for 14,100 boxes, supported by Attachment 5.
- The fabrication of the **flex**ible circuit of the IPB costs $4.42 per board, and the total cost is $62,764 for 14,200 circuits, supported by Attachment 6.
- The loading of **comp**onents onto the IPB costs $50.00 per board, and the direct cost is $705,000 for 14,100 boards, supported by Attachment 7.
- The DC-DC converter bPOL12V and linPOL12V chips are supplied by CERN. Attachment 8 shows estimates of the cost of $188,222 for bPOL12V and $31,932 for linPOL12V. The linPOL12V chips were ordered to reduce the risk of delay to IPB.
- The HV Mux is a separate WBS item 6.2.2.1.4 designed and tested by BNL. The cost is described earlier in this estimate and supported by a quote in Attachment 2.
- The AMAC chip is a separate WBS item 6.2.2.3.5 designed and tested by Penn. The cost is described earlier in this basis of estimate and supported by Attachment 10.
- The coil is a separate WBS item 6.2.2.5.3 supplied by Yale. The cost is described earlier in this basis of estimate and is supported by Attachment 13.
- Attachment 14 is a bill of materials for a burn-in system for the IPB. This cost is significant at $150k.
- Attachment 15 is a bill of materials for 1410 passive test carriers and 100 active test boards for the IPB. Note that 10 IPBs will be loaded onto each passive carrier and will stay there until they are used for module production. The cost is $67k.

Production Labor Costs

HCCStar Production- Once the pre-production prototype is accepted through a FDR review, we will submit a production ready HCCStar design. Tests will be performed on the first two wafers from this run in the wafer probe station and if acceptable, chips from those wafers will be mounted on test boards or hybrids with sensors. When those tests are complete the masks will be approved for production. The EE effort is similar to prototype testing.

Production Testing of HCCStar using the Wafer probe station- Will begin in 2020 and finish in 2021. For the 34,000 production chips, the full production testing of HCCStar will take ~900 hrs at 1.5 min per chip. The labor is split between the tasks of setting up the test equipment, commissioning, data interpretation, probing, diced die inspection, and shipment. There is about equal split between engineers and technicians, since the relatively small size of the batches does not allow to convert the probing into a routine operation. In addition, there will be a significant involvement from uncosted physicists, postdocs, and students.

Production Testing of the AMAC Chip - the Wafer Probe station described above will need to be adapted with a different probe card for AMAC production testing but this should be a far easier test in that the LVDS interface will have very limited timing requirements and relatively simple communications protocols. We estimate the time for production testing of a monitor chip at an average test time of 1.5 minute each. For the 24,000 production chips, the time for production testing would take around 600 hrs. The required labor amount is very similar to the one for the HCC testing.

Production Testing of the HV Mux

This task covers the production, testing, and distribution of the HV Mux components to IPB construction sites. The barrel portion of the components will be sent to LBNL.

The HV Mux will be produced in one batch of wafers and delivered in February 2020. At that time, the wafers will need to undergo QC testing, and be prepared and sent for irradiation. Upon return, additional QC and testing must occur. Based upon experience with prototyping, these tasks require a full-time technician under supervision under supervision of a staff physicist for several months duration leading to the labor costs in the schedule.

Production of the Power Board

The fabrication and assembly of the power board is largely done as a procurement. An engineer and an uncosted physicist will oversee this effort. Based upon previous oversight of prior high reliability fabrication projects, including the prototyping of the IPB, the effort levels are given in the table. Power boards will be delivered in panels and then re-tested and burned in. This will also consume the efforts of a dedicated technician for the periods July 2020-September 2022 and the support of uncosted student and physicist labor. An LBNL mechanical technician will be responsible for packaging and shipment of all the IPBs to international module assembly sites.

Un-costed Labor

A portion of the labor in the project is contributed by faculty, scientists, and postdocs funded through base grants and other means. These are very important contributions which do not cost the project directly. The table 2 below gives an FTE estimate of such labor categories.

Table 2. The labor estimates for off-project resources at different institutions contributing to Strip Electronics projects, WBS 6.2.2 .

Institute	WBS	Labor Type	FY18	FY19	FY20	FY21	FY22
BNL	6.2.2.1.4 : HV Mux	Staff Scientist	0.11	0.16	0.14	0.04	0.00
LBNL	6.2.2.2.6 : IPB	Scientist	0.41	0.61	0.66	0.53	0.68
		Postdoc	0.27	0.58	0.15	0.25	0.52
U. Penn	6.2.2.3.1, 6.2.2.3.2, 6.2.2.3.5 : ABCStar, HCCStar, AMAC	Professor	0.36	0.52	0.32	0.30	0.00
		Postdoc	0.40	0.52	0.32	0.30	0.00
		Graduate Student(s)	0.59	1.86	0.55	0.44	0.00

UCSC	6.2.2.4.1, 6.2.2.4.2: ABCStar, HCCStar	No off-project labor	0	0	0	0	0
Yale	6.2.2.5.3 : Coils	No off-project labor	0	0	0	0	0

Travel Costs

Travel costs supported by Attachment 16 are included to allow interaction of project supported staff with international ATLAS colleagues and with staff at other U.S. sites. The cost for an international trip is assumed to be $2400 and a domestic trip is assumed to be $1000. The travel budget is most significant in FY19-20 as design completes and production begins. Most of the travel is for engineers at Penn.

Total travel is $7K in FY18, $20 in FY19, $24K in FY20, and $12K in FY21.

Penn budgets 3 international trips in FY18-21 and 1 domestic trip in FY19

LBNL budgets 1 domestic trip in FY19

UCSC budgets 1 international trip per year in FY19-20

Assumptions:

We assume that the ASIC fabrication costs will remain stable in the next several years. In principle, they may depend on the market conditions for the 130 nm process node. A lack of commercial interest may lead to higher prices.

The chip area sizes for HCCStar and AMAC are based on the current floorplans of these chips. They may change if a significant redesign is required.

Schedule:

A detailed schedule has been entered into P6. The durations for the prototyping, pre-production and production phases for each deliverable are shown in the table below.

Deliverable	Prototype Phase		Pre-Production		Production	
	Start	End	Start	End	Start	End
HV Mux	2015	2017-10-12	2017-10-13	2019-04-17	2019-04-18	2020-12-24
IPB	2016-10-03	2019-04-08	2019-04-09	2020-03-02	2020-02-26	2023-04-05
ABCStar	2016-10-03	2019-03-11	2019-03-12	2020-01-23	2020-01-24	2020-06-18
HCCStar	2016-10-03	2019-03-11	2019-03-12	2020-01-23	2020-01-24	2021-05-18
AMAC	2015	2019-03-11	2018-03-12	2020-01-23	2020-01-24	2021-08-03
DC-DC power	2015	2017-01-09	2017-01-10	2018-12-06	2018-12-07	2019-11-18

Risk Analysis: in risk registry

Comments:

Attachments:

- Attachment 1: Bill of Material for HV Mux
- Attachment 2: HV mux chip quote
- Attachment 3: Bill of Material for IPB
- Attachment 4: Bill of Materials for IPB Assembly with Surface-mountable components
- Attachment 5: Fabrication cost for Shield box to be used in IPB
- Attachment 6: Quote for IPB flexible circuit fabrication
- Attachment 7: Quote for IPB component loading and assembly
- Attachment 8: Estimate of CERN components cost for IPB
- Attachment 9: Bill of Material for ABCStar
- Attachment 10: ASIC fabrication estimate
- Attachment 11: Bill of Material for HCCStar
- Attachment 12: Bill of Material for AMAC
- Attachment 13: Coil fabrication quote
- Attachment 14: Bill of Material for burn-in system for IPB.
- Attachment 15: Bill of Material for IPB Active test boards and Passive test carriers.
- Attachment 16: Cost of an average foreign and domestic trip
- Attachment 17: Quote for wafer probe station at Penn

Attachment 1: Bill of Material for HV Mux

Information from David Lynn (BNL)

			FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024		Total
6.2.2.1	HV Mux									$ -	
		prototype	$ 85,000							$ 85,000	
		QC	$ 4,500							$ 4,500	
		supplies	$ 3,000							$ 3,000	
		irradiation	$ 3,000							$ 3,000	
		post irr test		$ 1,000						$ 1,000	
		production 1			$ 801,000					$ 801,000	
		testing			$ 50,000					$ 50,000	
		QC			$ 4,000					$ 4,000	
		irradiation			$ 4,000					$ 4,000	
		post irr test			$ 2,000					$ 2,000	$ 957,500

Attachment 2: HV Mux chip quote (Dec 2018)

Per item cost is $40.00 from a prototype order of 2,400 chips.
Estimate assumes order of 20,000 chips for $800,000.
This is RE140400M.
Comment: Expect cost per chip to be lower at $25-$30 per chip for large production order, but also need to order more than 20,000 chips. Explanation of number of HV Mux chips for production order:

- 17,888 to install on detector.
- 22,821 after including yield factors (1.189 for system, 1.0730 for components).
- QA/QC for HV Mux requires another 685 chips.
- QA/QC for powerboard needs to stuff 60% of 500 powerboards, another 300 chips.
- Total production order is then 22,821+685+300 = 23,806 chips.
- Round up to 24,000.

Panasonic

Proforma invoice

Panasonic Industry Europe GmbH
Robert-Koch-Straße 100, 85521 Ottobrunn

Ust-Id/Vat-Id-No: DE813890706
Serien-Nr./Serial No:

No.: 94078093
Date: 12.04.2018
Customer: 60984228

Administrator Yevgeniya Degtyareva
Telephone +49 (0)89 46159 0
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Postfach 54 08 49 22508 Hamburg

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CB3 0HE
UNITED KINGDOM

Ship to
University of Cambridge
Department of Physics
Cavendish Laboratory
JJ Thomson Avenue
CAMBRIDGESHIRE CAMBRIDGE
CB3 0HE
UNITED KINGDOM

Your Order	KG-2740958	**Incoterms**	DDP CAMBRIDGE
Ordering Person	Mr Steven Day		Duty Paid in EC
Ordering Date	29.03.2018		
Your VAT Number	GB 823 8476 09		

Your Material / Material / **Description** / **Your Order**		**Goods Issue/Service date** / **Country of Origin** / **Commodity No**	**Serial No.**	**Price**	**Per**	**Qty**	**(USD) Value**
600 V GAN	SAMPLE	12.04.2018					
600 V GaN transistors		Japan					
KG-2740958 / 1							
3144846 / 10				40.00 USD	1 PC	2,447 PC	97,880.00

Contract No UCAM 073/17 Equipment: 600 V GaN transistors in bare die form (as per specification - Section 3)

			USD
Taxable basis			**97,880.00**
VAT amount	**0.000**		**0.00**
Total amount incl. VAT			**97,880.00**
Value for customs purposes only			97,880.00

Payment Details, Payment Currency in USD
Cash In Advance
EU-internal delivery turnover tax free as per paragraph 6a TTL

Attachment 3: IPB estimate (May 2019) Estimated by Carl Haber and Timon Heim. These costs are supported by quotes in the attachments.

Attachment in this basis of estimate	Part		**Vendor**	**# of parts**	**Cost per part**	**Total cost**
6	Flex		EPEC	2,500	4.42$	11,050.00$
6				4,600	4.42$	20,332.00$
6				4,600	4.42$	20,332.00$
6				2,500	4.42$	11,050.00$
4	SMDs		Digikey	14,100	3.80$	53,580.00$
5	Shield		TechEtch	14,100	6.70$	94,470.00$
5	Shield engraving		Laser Mark	14,100	0.50$	7,050.00$
8	bPOL12V		CERN	14,659	12.84$	188,221.56$
8	LinPOL12V		CERN	14,100	0.00$	0.00$
13	Coil		Wurth via Yale	14,100	0.00$	0.00$
2	GaNFET		Panasonic via BNL	14,100	0.00$	0.00$
7	Assembly	SMD Loading	Amtec	14,100	5.00$	70,500.00$
7		Wirebonding	Amtec	14,100	40.00$	564,000.00$
7		Testing	Amtec	14,100	5.00$	70,500.00$

Attachment 4: Bill of Materials for IPB components

Estimate from catalogs. Recently checked and updated to $3.80 per powerboard.

Bill Of Materials for AtlasU_PowerBoard_v2r12.sch on Thu Jan 26 10:01:15 2017								Minimal-cost suppliuer out of 4		
									Newark	
Item	Qty	Part Number	Manufacturer	Description	Value	Reference	PCB DECAL		Price/Unit	Price/Board
								Total:	$2.88	$3.88
1	1	AMAC13	PENN	ASIC, DIE, HV CONTROLLER	AMAC_ASIC	U1	AMAC_COB-1			
2	1	HV MUX SWITCH	BNL	ASIC, DIE, HV MUX SWITCH	HV_MUX_ASIC	Q1	HV_MUX-COB			
3	16			BOND PADS - DO NOT LOAD COMPONENT		J1-16	BONDPAD-4X8			
4	1			BOND PADS - DO NOT LOAD COMPONENT	Bond Wire	F1	SMD0201			
5	2			BOND PADS - DO NOT LOAD COMPONENT	BONDPAD	R4-5	SMD0201			
6	2	C1005X7R1A104K050BB	TDK	CAPACITOR, MLCC, 0402, 100nF, 10V, X7R, 10%	100nF	C13-14	0402		$0.00800	$0.02
7	2	GRM1555C1H101JA01D	Murata	CAPACITOR, MLCC, 0402, 100pF, 50V, C0G/NP0, 5%	100pF	C25-26	0402		$0.00500	$0.01
8	1	C0402C103K8RACTU	Kemet	CAPACITOR, MLCC, 0402, 10nF, 10V, X7R, 10%	10nF	C22	0402		$0.00500	$0.01
9	1	500R07S100JV4T	Johanson	CAPACITOR, MLCC, 0402, 10pF, 50V, C0G/NP0, 5%	10pF	C23	0402		$0.03700	$0.04
10	3	C1005X5R1A105K050BB	TDK	CAPACITOR, MLCC, 0402, 1uF, 10V, X5R, 10%	1uF	C18 C20-21	0402		$0.00900	$0.03
11	2	C1005X7R1A224K050BB	TDK	CAPACITOR, MLCC, 0402, 220nF, 10V, X7R, 10%	220nF	C4-5	0402		$0.01700	$0.03
12	1	GRM155R71H472JA01D	Murata	CAPACITOR, MLCC, 0402, 4.7nF, 10V, X7R	4.7nF	C24	0402		N/A	
13	3	C1608X7R1E105K080AB	TDK	CAPACITOR, MLCC, 0603, 1uF, 25V, X7R, 10%	1uF	C9 C11 C27	0603		$0.01000	$0.03
14	2	C1608X5R1E475K080AC	TDK	CAPACITOR, MLCC, 0603, 4.7uF, 25V, X5R, 10%	4.7uF	C10 C12	0603		$0.08100	$0.16
15	4	C2012X5R1E106K125AB	TDK	CAPACITOR, MLCC, 0805, 10uF, 25V, X5R, 10%	10uF	C2-3 C6-7	0805		$0.10500	$0.42
16	2	C2012X5R1E226M125AC	TDK	CAPACITOR, MLCC, 0805, 22uF, 25V, X5R, 20%	22uF	C1 C8	0805		$0.26600	$0.53
17	2	C1210C223KFRACTU	Kemet	CAPACITOR, MLCC, 1210, 22nF, 1.5kV, X7R,10%	22nF/1.5kV	C15-16	1210		$0.18200	$0.36
18	2	C1210W473KDRACTU	Kemet	CAPACITOR, MLCC, 1210, 47nF, 1kV, X7R, 10%	47nF/1kV	C17 C19	1210		N/A	
19	1	HSMS-282R-TR1G	Broadcom Ltd/Avago	DIODE, SCHOTTKY, DUAL RING, 15V, 1A, SOT-363	HSMS-282R-TR1G	D1	SOT-363		N/A	
20	1	FEAST	CERN	IC, DC-DC CONVERTER, 10W, Step Down, Rad Tol	FEAST2	U2	QFN32-5X5-0_5			
21	1	CUSTOM-AIRCOIL-250nH	Wurth	INDUCTOR, CUSTOM WOUND, AIR COIL, 250nH	250nH	L2	L0806A			
22	2	0806SQ-12NJLB	Coilcraft	INDUCTOR, RF, AIR COR, 0806, 12.3nH	12.3nH	L1 L3	L0806			
23	1	TPS70915DBV	Texas Instruments	LDO VOLTAGE REG, FIXED, 1.5V, 150mA, SOT23-5	TPS70915DBV	U3	DBV0005A		$0.56200	$0.56
24	1	TPS70925DBV	Texas Instruments	LDO VOLTAGE REG, FIXED, 2.5V, 150mA, SOT23-5	TPS70925DBV	U4	DBV0005A		$0.51100	$0.51
25	1	OPA369AIDCK	Texas Instruments	OP AMP, Zero-Crossover, SC-70-5, 12KHZ, 0.005V/us	OPA369AIDCK	U5	DCK5		$0.81500	$0.82
26	2	CRCW0201100KFKED	Vishay/Dale	RESISTOR, SMT, 0201, 100k OHM, 30V, 1%, 50mW	100k	R23-24	SMD0201		$0.02700	$0.05
27	3	CRCW020110K0FKED	Vishay/Dale	RESISTOR, SMT, 0201, 10k OHM, 30V, 1%, 50mW	10k	R8-9 R19	SMD0201		$0.00600	$0.02
28	1	CRCW0201130KFNED	Vishay/Dale	RESISTOR, SMT, 0201, 130k OHM, 30V, 1%, 50mW	130k	R1	SMD0201		$0.01600	$0.02
29	1	CRCW02011M00FKED	Vishay/Dale	RESISTOR, SMT, 0201, 1M OHM, 30V, 1%, 50mW	1M	R2	SMD0201		$0.03900	$0.04
30	2	CRCW0201200KFKED	Vishay/Dale	RESISTOR, SMT, 0201, 200k OHM, 30V, 1%, 50mW	200k	R21-22	SMD0201		$0.02800	$0.06
31	2	CRCW0201499KFNED	Vishay/Dale	RESISTOR, SMT, 0201, 499k OHM, 30V, 1%, 50mW	499k	R25-26	SMD0201		$0.01600	$0.03
32	1	CRCW0201634KFNED	Vishay/Dale	RESISTOR, SMT, 0201, 634k OHM, 30V, 1%, 50mW	634k	R3	SMD0201		$0.01600	$0.02
33	1	CRCW020190K9FNED	Vishay/Dale	RESISTOR, SMT, 0201, 90.9k OHM, 30V, 1%, 50mW	90.9k	R20	SMD0201		$0.01600	$0.02
34	1	CRCW04020000Z0ED	Vishay/Dale	RESISTOR, SMT, 0402, 0 OHM, 50V, 0.063W	0	R15	0402		$0.00300	$0.00
35	2	CRCW04021K00FKED	Vishay/Dale	RESISTOR, SMT, 0402, 1k OHM, 50V, 1%, 63mW	1k	R10 R14	0402		$0.00300	$0.01
36	1	ERT-J0ET102J	Panasonic	RESISTOR, SMT, 0402, 1k OHM, NTC	1k	NTC1	0402		$0.07800	$0.08
37	1	CRCW040220K0FKED	Vishay/Dale	RESISTOR, SMT, 0402, 20k OHM, 50V, 1%, 63mW	20k	R16	0402		$0.00400	$0.00
38	1	CRCW040249R9FKED	Vishay/Dale	RESISTOR, SMT, 0402, 49.9 OHM 1% 63mW	50	R13	0402		$0.00300	$0.00
39	2	CRCW06031K00FKEA	Vishay/Dale	RESISTOR, SMT, 0603, 1k OHM 1% 1/10W	1k	R11-12	0603		$0.00300	$0.01
40	2	CRCW06032M00FKEA	Vishay/Dale	RESISTOR, SMT, 0603, 2M OHM 1% 1/10W	2M	R17-18	0603		$0.00600	$0.01

Attachment 5: Fabrication cost for Shield box for IPB

This is based on a per item estimate of \$6.70+\$0.50 for engraving.
Total cost \$7.20 for 14,100 pieces = \$101,520.
This is RE261370M.

We have two previous quotes for gold and tin boxes.
We make a conservative estimate 0.75 scaling for larger batches of gold-plate, giving our estimate of \$6.70 per box. For engraving, source is LaserMark.

Gold-plate box \$8.96 for small batch of 500. Estimate 0.75 scaling for batch over 10,000. Supports estimate of \$6.70 per box.	Tin-plate box \$3.41 for 10,000 and up. See 0.63 scaling for batch of 500 to 10,000.

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Attn: JOHN JOSEPH
LAWRENCE BERKELEY LABS
1 CYCLOTRON ROAD
BERKELEY, CA 94720 USA

Phone #: (510) 486-4382 Ext: Fax #:
E-Mail: JMJOSEPH@LBL.GOV

Date: 4/26/2018
Product Code: J
Quotation No: 146975
Reference: RFQ DATED 4/19
Territory: SS

#	QUANTITY	DESCRIPTION	UNIT PRICE	UNITS	LEAD TIME
1		P/N: SHILED BOX-V3		EA	START SHIPPING 15 TO 16 WEEKS
	25	MAX/MIN	\$34.00		
	50		\$20.00		
	100		\$13.44		
	250		\$10.75		
	500		\$8.96		
		N/R TOOLING	\$600.00		

GENERAL NOTES
1) MATERIAL TO BE .004" THICK ALUMINUM.
2) FINISH TO BE 10 MICRO INCHES MINIMUM GOLD PLATE.
3) CORNER SEAMS TO BE SOLDERED CLOSED.
4) TECH-ETCH TO CREATE DETAILED MANUFACTURING DRAWINGS FOR CUSTOMER APPROVAL APPROXIMATELY 3 DAYS AFTER RECEIPT OF PURCHASE ORDER. LEAD TIME BEGINS ONCE DRAWINGS ARE APPROVED.

Sales Contact:
Ross Marketing Associates
Santa Clara, CA 95054
408-844-8259
408-844-8334
Tools will be retained by us for your exclusive use. Listed exceptions shall apply to all future orders for the part specified unless otherwise specified at a later date. Lead time is based upon capacity and material availability at the time of quotation and is subject to change. Lead time is determined from receipt of order and complete information.
4.3.F1, Rev. B

For Technical Assistance:
William Borghesani x3119
Product Engineer - Precision Parts
wborghesani@tech-etch.com

For Customer Service or Order Placement:
Barbara Ford x3128
bford@tech-etch.com

ITAR: Customer must inform Tech-Etch, Inc. if parts are specifically designed for a military, missile, satellite, or other controlled use listed on the United States Munitions List (USML), US Code of Federal Regulations Title 22, subchapter M, part 121.

Unless Otherwise Specified
Quotation expires in 60 days
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Attn: JOHN JOSEPH
LAWRENCE BERKELEY LABS
1 CYCLOTRON ROAD
BERKELEY, CA 94720 USA

Phone #: (510) 486-4382 Ext: Fax #:
E-Mail: JMJOSEPH@LBL.GOV

Date: 6/22/2017
Product Code: J
Quotation No: 137722
Reference: RFQ DATED 6/20
Territory: SS

#	QUANTITY	DESCRIPTION	UNIT PRICE	UNITS	LEAD TIME
1		P/N: POWERBOARD-SHIELD-V1		EA	START SHIPPING 4 TO 5 WEEKS
	25	MAX/MIN	\$22.00		
	50		\$13.00		
	100		\$9.00		
	250		\$6.80		
	500		\$5.44		
	1,000		\$4.53		
	2,500		\$3.94		
	5,000		\$3.58		
	10,000	& UP	\$3.41		
		N/R TOOLING	\$200.00		

GENERAL NOTES
1) MATERIAL TO BE .004" THICK ALUMINUM.
2) FINISH TO BE 200-500 MICRO INCHES BRIGHT TIN PLATE PER ASTM-B545.
3) ALL SEAMS TO BE SOLDERED CLOSED.

Sales Contact:
Ross Marketing Associates
Santa Clara, CA 95054
408-844-8259
408-844-8334
Tools will be retained by us for your exclusive use. Listed exceptions shall apply to all future orders for the part specified unless otherwise specified at a later date. Lead time is based upon capacity and material availability at the time of quotation and is subject to change. Lead time is determined from receipt of order and complete information.
4.3.F1, Rev. B

For Technical Assistance:
William Borghesani x3119
Product Engineer - Precision Parts
wborghesani@tech-etch.com

For Customer Service or Order Placement:
Barbara Ford x3128
bford@tech-etch.com

ITAR: Customer must inform Tech-Etch, Inc. if parts are specifically designed for a military, missile, satellite, or other controlled use listed on the United States Munitions List (USML), US Code of Federal Regulations Title 22, subchapter M, part 121.

UNLESS OTHERWISE SPECIFIED
QUOTATION EXPIRES IN 60 DAYS
TERMS - NET 30 DAYS
F.O.B.: PLYMOUTH, MA USA

Page: 1 of 1

Attachment 6: Quote for IPB flexible circuit fabrication (April 2019)
Per item cost is \$4.42. Will order 4 batches of 2500, 4600, 4600, 2500.
Total cost is \$4.42 times 14,200 boards = \$62,764. Note QC uses 100 unstuffed.
This corresponds to RE261330M, RE261332M, RE261373M, RE261374M.

epec
Engineered Technologies

Quote #285601

Date	4/30/2019	**Customer Ref #**	
Expires	5/30/2019	**Terms**	Credit Card

Customer	Part Number/Rev	Customer Part Number	Unit of Measure
LAWRENCE BERKELEY NATIONAL LAB 1 CYCLOTRON RD MS71W Berkeley CA 94720 United States	LBL POWERBOARD V3 REV B		PCS

	Standard Delivery Unit Pricing			Quick-Turn Unit Pricing				
QTY	32 Days	30 Days	25 Days	20 Days	5 Days	3 Days	2 Days	1 Day
100				23.88				
2500		4.42						
5000	3.88							
15000*	2.95							

Part Attributes

Boards in Array?	Yes	Coverlay Color	
Number Up in Array	10	Silkscreen	Top Only
Array X x Y (inches)	6.926 x 3.565	Silkscreen Color	White
Board X x Y (inches)	2.913 x .433	Outer Layer Copper	1 oz
Board Spec	IPC 6012 Class II	Inner Layer Copper	1 oz
Material	Polyimide	Tab Route	No
Plating Method		Scoring	No
Number of Layers	4	Blind Vias	Yes
Flex Thickness		Buried Vias	No
Finish Thickness	.015	Stiffeners	
Finish	ENEPIG	Epoxy Strain Reliefs	No
Min Spacing	.005"	Controlled Impedance	No
Smallest Hole		X-Outs Allowed, Qty	
Hole Tolerance	+/- .003	ITAR	No
Coverlay Type		RoHS Compliant	No

Add an SMT Stencil to Your Order

\$ 99.00 - Prototype Stencil
\$240.00 - Laser Cut Stencil - 20"x20" Frame
\$260.00 - Laser Cut Stencil - 29"x29" Frame
\$150.00 - Laser Cut Stencil - Frameless

Misc Charges

NRE Tooling \$110.00

NRE Test \$130.00

Comments

- Drill files to be supplied. Not included in data set
- 15K qty based on split deliveries, TBD

Please be aware that effective March 1st, 2019 this product will be subject to a U.S. tariff under US Section 301. If you have any questions regarding this tariff, please contact your Sales Representative.

Toll Free: (888) 995-5171 61 John Vertente Blvd. New Bedford, MA 02745 United States www.epectec.com

Attachment 7: IPB component loading and assembly (January 2019)
Per board cost is $50.00. Plan to stuff 14,100 boards.
This is $705,000.
This corresponds to RE261420M.

AmTECH MICROELECTRONICS, INC.

BUDGETARY CONSIGNMENT QUOTE

Date: 1/18/2019

To: Carl Haber
LBNL
One Cyclotron Road
Berkeley, CA 94720

Quote No: 8517

CONFIDENTIAL

We are pleased to quote the following SMT/COB assembly:

Assy No: Power Board Assembly V0.0 (2x5=10up)
PCB-Flex: 72mm x 11mm x 0.3mm

PO Qty:	250	750	15000
Lot Size: (250-300 units per week)	250	750	1250
Power Board SMT Assembly (WS Sn63Pb37)			
Power Board COB Assembly			
Test, Thermal Cycling & Burn-In			
TOTAL (EA)	$70.00	$60.00	$50.00

TOOLING and NRE:

S/No	Description	Qty	Unit Cost	Amount
1	SMT Program	1	250.00	250.00
2	SMT NanoSlic Gold Stencil	1	500.00	500.00
3	Wire Bond Program	1	1000.00	1000.00
4	Wire Bond Tooling (Workholder)	1	750.00	750.00
5	Die Attach (Manual)	0	0.00	0.00
6	Encapsulation (Not Required)	0	0.00	0.00
				$2,500.00

THIS QUOTE IS BASED ON THE FOLLOWING INFORMATION:

1) SMT Pick & Place: (58) Components. (28 Caps + 23 Res + 3 Ind + 2 Diodes + 2 IC)
2) SMT Hand Solder: (2) Components. (Coil and Shield Box)
3) Die Attach: (2) Die. (U3 = AMAC V2 IC, Q1 = HV MUX Transistor)
4) Wire Bond, (293) 1.0 mil Al Wedge Wire Bonds. (U3 = 120, Q1 = 18, Perimeter Bonds = 155)
5) Glob Top Encapsulation: None.
6) Visual Inpection at 60X

TERMS & CONDITIONS:

1) Customer to provide all **DICE** in 2" Waffle Packs, all **SMD** components on Tape and Reel.
2) Customer to provide Assembly drawing, Wire Bond Diagram, BOM and Gerber Files.
3) Customer to provide all tooling & equipment for Test, Thermal Cycling & Burn-In.
4) Workmanship: IPC-A-610 Class 2 and MIL-STD-883 Method 2011 for DPT.
5) All tooling for SMT and COB is CA taxable.
6) Payment: N-30, FOB AmTECH

Walter Chavez
AmTECH

AmTECH Microelectronics, Inc.
485 Cochrane Circle, Morgan Hill, CA 95037

Attachment 8: Estimate of CERN components cost for IPB

Notes from a discussion of power regulators with ATLAS strips upgrade Nov 16, 2017
Revised December 4, 2017
F. Faccio, S. Michelis
Carl Haber, Tony Affolder, Timon Heim, Ashley Greenall, Peter Phillips, Dennis Sperlich

1) The linear regulator will be 2 circuits per die. We refer to it as LinPol12V. It is pin-to-pin compatible with a commercial part.
2) The linear regulator submission is ready and will be by IMEC/OnSemi
3) We had the choice of an MPW on Dec 4, 2017 getting us 200 parts for $9K or an Engineering Run now getting us 45,000 parts for $26K – **We choose the Engineering run**
4) The run will take 5 months
5) We will also pay for packaging: $3K NRE + ~$0.2/package of the parts we use, **but CERN will package all of them**

…

On 2018-01-30 1:55 AM, Federico Faccio wrote:

Dear XXX,

….

The improved version should also come in QFN32 package (the addition of the other chip-on-package is transparent for the user) but at a somewhat larger cost. We are waiting for quotes from the companies involved in this side development, but we expect the cost of the improved version to be around 10-12 CHF per part.

…

o RE260745M Material payment for linear regulator from CERN $33,417
Estimate: $26k (Eng Run) + $3k (NRE) + $0.2/package*14,659 (pre-pro + pro for barrel) = $31,932

o RE261405M Material payment for production bPOL12V from CERN $210,413
Estimate: 12 CHF x 14,659 (pre-pro + pro for barrel) = 12 CHF * 1.07 $/CHF * 14,659 = $188,222

(Note: minimum order for production is to stuff 14,100 powerboards and 305 for QA/QC.)

Attachment 9: Bill of Material for ABCStar

			FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024		Total
6.2.2.3.1	ABCstar									$ -	
		prototype submission	$ 50,367							$ 50,367	
		testing	$ 26,000							$ 26,000	
		pre-production submission		$ 162,186						$ 162,186	
		production submission		$ 833,800						$ 833,800	$ 1,072,353

The production cost corresponds to RE310390M.

Production cost estimate for ABCStar		
Quantity	**Number**	**Comment**
Number of chips in the system	233,856	
System Yield Factor	1.189	
ABCStar Yield Factor	1.134	
Total number of chips to fabricate	315,300	= 233,856 * 1.189 * 1.134
Chips per Wafer	470	
Production Number of wafers	670	= 315,300 / 470
Mask cost	$325,200	Attachment 10
US portion of Mask Cost	33.7%	
Per-wafer cost	$2,852	Attachment 10
US portion of Chip Fabrication	37.9%	
Total cost	$833,800	=33.7%*$325,200 + 37.9%*670*$2,852

Attachment 10: ASIC fabrication estimate

On Tue, 24 Feb 2015, Kostas Kloukinas wrote:

Dear XXX,

…. engineering run NRE cost (2 wafers included): 308,160 USD

For your information:
additional wafer cost from the engineering run (up to 12): 3,320 USD / wafer
production wafer cost (24 wafers): 2,420 USD / wafer
production wafer cost (240 wafers): 2,200 USD / wafer
production wafer cost (480 wafers): 2,080 USD / wafer

Let me know if you need any further information or
clarification.

Best Regards,
Kostas

==
Dr. Kostas KLOUKINAS
PH/ESE-ME dept.   Room: 14-6-015
CERN
CH-1211, Geneve 23
SWITZERLAND
tel: +41 22 767 9734   fax: +41 22 767 3394
==

Note: For the estimate purpose we use the fabrication cost of $2,852/wafer, which includes the wafer dicing component. We use the mask costs of $325,200. Given the CERN Frame Contract with the foundry, we do not use the cost escalation in our estimates.

Attachment 11: Bill of Material for HCCStar

			FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024		
6.2.2.3,4	HCCstar									$ -	
		prototype fabrication	$ 161,787							$ 161,787	
		supplies	$ 7,000							$ 7,000	
		supplies		$ 6,000						$ 6,000	
		prober purchase		$ 130,000						$ 130,000	
		prepro fabrication		$ 325,200						$ 325,200	
		computer support and licenses		$ 6,000						$ 6,000	
		Since chip test board		$ 3,000						$ 3,000	
		probe card fabrication			$ 6,000					$ 6,000	
		wafer sawing, chip shipments			$ 2,000					$ 2,000	
		production fabrication			$ 462,176					$ 462,176	
		computer support and licenses			$ 6,000					$ 6,000	
		wafer sawing, insp., shipment			$ 2,500					$ 2,500	
		wafer sawing, insp., shipment				$ 5,000				$ 5,000	$ 1,122,663

The production cost corresponds to RE321030M.

Production cost estimate for HCCStar+AMAC		
Quantity	**Number**	**Comment**
Number of chips in the system	25,536	
System Yield Factor	1.189	
HCCStar Yield Factor	1.134	
Total number of chips to fabricate	34,400	= 25,536 * 1.189 * 1.134
Reticles per Wafer	720	
Number of wafers	48	= 34,400 / 720 in 2 batches of 24 wafers
Mask cost	$325,200	Attachment 10
US portion of Mask Cost	100%	
Per-wafer cost	$2,852	Attachment 10
US portion of Chip Fabrication	100%	
Total cost	$462,100	=100%*$325,200 + 100%*48*$2,852

Attachment 12: Bill of Material for AMAC

Recall HCCStar and AMAC are on the same wafer, so wafer costs are in Attachment 11 for HCCStar.

			FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024		Total
6.2.2.3.5	AMAC									$ -	
		prototype	$ 131,000							$ 131,000	
		test PCB board	$ 1,450							$ 1,450	
		test supplies		$ 800						$ 800	
		shipment supplies		$ 700						$ 700	
		test supplies			$ 950					$ 950	
		sawing and shipping			$ 2,500					$ 2,500	
		sawing and shipping				$ 5,000				$ 5,000	$ 142,400

Attachment 13: Coil fabrication quote (April 2019)

The cost is $4,800 for 1,000 parts.

Need 16,352 coils for the entire tracker. System yield is 1.1890 and component yield is 1.05. For Production need 20,415 parts. Also need 305 for powerboard QA/QC and 1091 for pre-production. This gives a total of 21,810, which is rounded to 22,000 parts. Total cost is $105,600.

This is RE530450M.

more than you expect

Wurth Electronics Midcom Inc.
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57201-6330, USA
Tel: +1 (605) 886 4385 • Toll Free: +1 (800) 643 2661
www.we-online.com

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WÜRTH ELEKTRONIK

Yale University
Mr. Satish Dhawan
Sr. Research Scientist
260 Whitney Ave / 522JWG
06511 New Haven,CT
UNITED STATES OF AMERICA

quotation date:	quotation no.:	customer no.:
4/11/2019	**A19US011803**	**003005291**

your sales agent:
Michael Rego michael.rego@we-online.com
phone: 475-202-9277 fax: 201-939-1606 mobile: 475-202-9277

your partner in the office:
Isabel Cruz isabel.cruz@we-online.com
phone: (201)-939-1720 fax: (201)939-1606

your VAT no. :
supplier no. :
your inquiry :

Quotation

CONFIDENTIAL

Dear Mr. Satish Dhawan,

Thank you very much for your inquiry. All supplies and services are made exclusively on the basis of the General Conditions of Trade of Wurth Electronics Midcom Inc. (www.we-online.com/midcom-tc).

pos.	part number / your part number description	quantity	price USD / per	SPQ Carton	current lead-time	price USD
001	**S15 100 075** WE-WPCC Wireless Power Charging Coil type of packaging: Tray RoHS - conform, MSL: 1, eiSos® Approval: Halogenfree - IEC 61249-2-21	22,000PC	4,800.00 /1000	80 2400	9/7/2018	105,600.00

Confirm terms of delivery based on applicable INCOTERMS 2010 unless specified otherwise.

net value	total amount
105,600.00	**105,600.00**

payment conditions : 30 days net
delivery conditions : ex works,

Wurth Electronics Midcom Inc.
Bank Accounts : Bank of America, NA, 100 West 33rd St,; New York, NY 10001
Beneficiary : Wurth Electronics Midcom Inc. ; Account no: 1233050584 – ABA: 026009593 – Swift BOFAUS3N

Attachment 14: Cost of Burn-in system for IPB (LBNL)

List of items, total is $158,272. This is RE261430M. Estimates without attached quotes are from experience or online calculations.

Type	Item	Purpose	Source	Qty	Price	Total
Assembly jigs	Vacuum chuck		machining	10	300.00$	3,000.00$
Reception test jigs	Cooling chuck		machining	30	100.00$	3,000.00$
QC/QA/Burn-in system	Cooling crate		machining	4	5,000.00$	20,000.00$
	Passive metal carrier		machining	40	100.00$	4,000.00$
	Chiller		SP Scientific	2	20,160.00$	40,320.00$
	Interlock/Monitoring	Flow control		4	1,000.00$	4,000.00$
		Temp monitoring		8	1,000.00$	8,000.00$
		Humidity monitoring		8	1,000.00$	8,000.00$
	LV Power Supply		Wiener	4	6,500.00$	26,000.00$
	Picoscope 5000		Picoscope	12	2,275.00$	27,300.00$
	Computer		DELL	2	1,500.00$	3,000.00$
Coupon tester	Pogo-pin jig			10	100.00$	1,000.00$
	Ohmmeter			2	5,326.00$	10,652.00$
Total						158,272.00$

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935 Mearns Road Warminster, PA 18974 215.672.7800 Toll Free: 800.523.2327 Fax: 215.672.7807 www.SPScientific.com

Quote For:

Zachary Galloway

University of California Santa Cruz

1156 High Street
Natural Sciences Room 377
Santa Cruz, Cali 95064
USA

Phone: 8315020254

Email: zacharygalloway90@gmail.com

Payment Terms:

Net 30 Days

Please Note: Freight is not included in this quote

Prepared By: James Shiever

Date	Quote #	Expires	Est. Ship ARO*	Ship Via	Incoterms (2010)
2/13/2019	RESQ-012687-0	4/13/2019	Approx 24 wks Dependent on plant loading at time of order	Best Way	FCA Warminster, PA

Qty	Part #	Description	Unit Price	Ext. Price
1	RC211C0	ULT RECIRCULATING COOLER Temp Range: -80 C to +75C Heat Removal: 880W @ -60C, 1150W @ -40C Pump: 2 to 3 GPM @ 22 PSI; dependent on temp and fluid Reservoir: 5 Liter Control: Deluxe Digital, PID RS-232 interface 0.1 indication Low fluid alarm Low flow alarm Overtemperature alarm with contact closure Remote RTD sensor Heater: 1126W (1500 W nominal 240V) Connections: 1/2" NPT, Male Dimn: 21"W x 29"D x 48"H Weight: 400 lbs Elect: 208V/60Hz/1PH	$20,160.00	$20,160.00
1	WarrantyD	Covers all parts and associated labor, freight and/or travel and expenses in the first twelve months, with the exclusion of those resulting from equipment misuse e.g. operating in high ambient temperatures.	$0.00	$0.00

WARNING: Cancer and Reproductive Harm -

www.p65warnings.ca.gov

Subtotal	$20,160.00
Total	**$20,160.00**

A Phoenix Mecano Company

WIENER Plein & Baus, Corp

Timon Heim
Lawrence Berkeley National LAB
1 Cyclotron Road
Berkeley, CA

Phone: (510) 944-9508
Fax:
Email: t h e i m @ l b l . g o v

OFFER #:

WU16_0313AR2

Date: 3/13/2016

Qty	Item	Description	Price	Total
1	PBN512 3U RATO	PBN512 3U RATO :PL512 bin; for 3U power box;3U;bottom air entry	$737.00	$737.00
1	PBX512	PBX512_10 : PL512 power box; 3U; 10 channels 7V .... 24V/12A (5 x MDL 7...24V/12A);; up to 3kW;Ethernet;USB;Easy Lever extraction	$6,218.00	$6,218.00
1	PBX512	PBX512_12 : PL512 power box; 3U; 12 channels 7V .... 24V/12A (6 x MDL 7...24V/12A);; up to 3kW;Ethernet;USB;Easy Lever extraction	$7,009.00	$7,009.00
1	PBX512-EX	PBX512-EX_10 : PL512 power box; 3U; 10 channels 7V .... 24V/12A (5 x MDL 7...24V/12A); up to 3kW;Ethernet;USB;Display;Easy Lever extraction	$6,490.00	$6,490.00
1	PBX512-EX	PBX512-EX_12 : PL512 power box; 3U; 12 channels 7V .... 24V/12A (6 x MDL 7...24V/12A); up to 3kW;Ethernet;USB;Display;Easy Lever extraction	$7,281.00	$7,281.00
		Sub Total		$27,735.00
		Shipping & Handling		
		Taxes	0.000%	$.00
			TOTAL	**$27,735.00**

Terms:

Delivery time:	about 8 … 10 weeks a.r.o.	Andreas Ruben
Delivery:	f.o.b. Springfield-OH, add shipping	Office Use Only:
Payment:	MC/VISA (add 2.5% for orders of $5,000 or more) or net 30 after credit approval,	
Warranty:	3 years parts and labor	
Validity of this offer:	1 month.	

Thank you for your business.

Attachment 15: Cost of passive and active test boards for IPB (LBNL)

These costs are in RE261380M for parts ($68,483.20) and RE261425M for loading ($7984.90). Estimates without attached quotes are from experience or online estimators.

Board	Item	Activity	Quote	Amount	Price per item	Total
Passive Test Carrier	PCB		Bittel	1,410	16.59$	23,391.90$
	SMDs		DigiKey	1,410	8.93$	12,591.30$
	Assembly	SMD Loading	Bittel	1,410	3.89$	5,484.90$
Active Tester	PCB			100	25.00$	2,500.00$
	SMDs			100	150.00$	15,000.00$
	Assembly	SMD Loading		100	25.00$	2,500.00$
	FPGA boards (MicroZed)		Avnet	50	200.00$	10,000.00$
Total Parts	RE261380M					63,483.20$
Total assembly	RE261425M					7,984.90$

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- Functional Testing

PCB Fabrication Quote

This instant PCB online quote only applies on prototype, small and mid-volume orders. To get your circuit board price, all fields are required. If you need a quote for PCB assembly, please **click here**.

Board Quantity	1500
Board Size	6 X 9.7 inch
Thickness	0.062 inch
Layers	4
Copper Weight	2.0 oz
Solder Mask Color	Green
Routing	Individual
Impedance Control	None
Ship to	United States (West)
Boards arrive in	9 days

Re-Calculate

Boards arrive in (Business Days)	Price (US$)	Freight (US$) *
9	21,926.45	1,468.53

Notes: The price above is for the minimum trace/space = 4 mil, the minimum hole size = 8 mil, 2 Sides Silkscreen, 2 Sides Solder Mask, ENIG(RoHS), 100%

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Product Category: Kits & Tools, Evaluation & Development Kits
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Secondary Manufacturer Part #: ADXAES-Z7MB-7Z010-G

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Lead Time From Supplier: 21 Weeks

On Order:
Arrives by 6/18/2019 290

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Price For: Each
USD$: **$199.00**

Quantity:
Min: 1 Mult: 1

- 1 +

Subtotal: **$199.00**

ADD TO BOM | ADD TO

FLAT RATE SHIPPING
$8 Ground Shipping | $15 for 2 Day Air
SEE DETAILS

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MicroZed is a low-cost development board based on the Xilinx Zynq-7000 All Programmable SoC. Its unique design allows it to be used as both a stand-alone evaluation board for basic SoC experimentation, or combined with a carrier card as an embeddable system-on-module (SOM). MicroZed contains two I/O headers that provide connection to two I/O banks on the programmable logic (PL) side of the Zynq-7000 AP SoC device. In stand-alone mode, these 100 PL I/O are inactive. When plugged into a carrier card, the I/O are accessible in a manner defined by the carrier card design. Thus designers can start with MicroZed in stand-alone mode as a learning platform and then easily expand its functionality as a SOM through the addition of an off-the-shelf or custom designed carrier card. This combined stand-alone/SOM approach can quickly move a design idea from concept to production, making MicroZed the ideal platform for SoC based applications.

Attachment 16: Cost of an average foreign trip (e.g. CERN) and domestic trip (e.g. to BNL)

These estimates are based on UC Santa Cruz trip records between May 2016 and May 2017. An average foreign trip lasts 7.1 days, and costs $2,392. An average domestic trip lasts 2.9 days and costs $1,012.

Foreign Travel 2016-2017				
Departure	Return	Destination	Total Cos	delta-T
2016-05-28	2016-06-05	Poland	$1,916.00	8
2016-06-14	2016-06-19	Oxford, UK	$2,808.00	5
2016-09-08	2016-09-18	Valencia, Spain	$2,522.00	10
2016-09-10	2016-09-17	Valencia, Spain	$2,836.00	7
2016-09-10	2016-09-18	Valencia, Spain	$2,699.00	8
2016-09-10	2016-09-18	Valencia, Spain	$3,136.00	8
2016-11-12	2016-11-19	CERN/Geneva	$2,344.00	7
2016-11-12	2016-11-19	CERN/Geneva	$2,219.00	7
2016-11-12	2016-11-19	CERN/Geneva	$2,152.00	7
2016-11-12	2016-11-23	CERN/Geneva	$2,693.00	11
2017-02-03	2017-02-09	CERN/Geneva	$2,226.00	6
2017-03-24	2017-03-31	CERN/Geneva	$2,247.00	7
2017-03-24	2017-03-31	CERN/Geneva	$2,685.00	7
2017-03-24	2017-03-31	CERN/Geneva	$2,312.00	7
2017-03-24	2017-03-31	CERN/Geneva	$2,278.00	7
2017-03-25	2017-04-01	CERN/Geneva	$1,993.00	7
2017-03-26	2017-04-02	CERN/Geneva	$2,430.00	7
2017-05-05	2017-05-10	CERN/Geneva	$1,559.00	5
Average			$2,391.94	7.28
Std.dev.			$379.65	1.45

Foreign and Domestic Travel 2016-2017				
Departure	Return	Destinatio	Total Cos	delta-T
2016-05-10	2016-05-13	Penn Univ	$1,383.00	3
2016-10-07	2016-10-11	CPAD	$1,161.00	4
2016-10-08	2016-10-10	Pasadena,	$700.00	2
2016-10-08	2016-10-10	Caltech	$1,060.00	2
2016-10-08	2016-10-10	Pasadena	$732.00	2
2017-01-29	2017-02-01	Philadelphi	$939.00	3
2017-01-29	2017-02-02	Penn Univ	$1,111.00	4
Average			$1,012.29	2.86
Std.dev.			$242.56	0.90

Attachment 17: Cost of wafer probe station (Dec 2018)
Cost of probe station is $101,184.50.

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QUOTATION

UNIVERSITY OF PENNSYLVANIA 209 SOUTH 33RD STREET PHILADELPHIA, PA 19104-6323 USA		Quote: Revision: Quote Date: Expiration Date:	172944 5 12/12/2018 2/10/2019
Attention Phone Email	ADRIAN NIKOLICA 215 898 5000 nikolica@hep.upenn.edu	Location of End Use: UNIVERSITY OF PENNSYLVANIA USA	

Ln	Description	Quantity	Unit Price	Ext. Price
1	SUMMIT 12000B-S **STATION,200mm,SEMI-AUTOSTANDARD** Cascade Microtech Summit "B" Series Semi-Automatic Station Platform. (Standard) INCLUDES: - Integrated safety enclosure (Wafer protection & door access) - Roll-out wafer stage (for safe/easy wafer loading) - High stability platen with linear lift - 4-axis precision motorized stage - User Guides, Tools, and accessories - Universal Power cord Kit	1 EA	46,815.00	46,815.00
2	OPT PWRUSA **POWER KIT,COUNTRY,N.AMERICA** Station power cords for USA, Japan and ROW power Kit includes: - 2 ea country specific AC power cords. - 1 ea. IEC 6 outlet power strip (UL-SA-CE) - 4 ea. IEC 2 meter AC power cords - 2 ea. IEC 3 meter AC power cords * NOTE: PRICE FOR THIS ITEM IS INCLUDED IN THE STATION SELLING PRICE WHEN SOLD WITH A STATION.	1 EA	0.00	0.00
3	TC-002-101 **[C]CHUCK,200MM,COAX,NI,NON-THERMAL,HI-ISO** Cascade Microtech modular chuck, Hi-ISO Coaxial, for Summit 11000/12000 Station Platforms INCLUDES: - RF/Microwave chuck, 200mm, Nickel - Hi-Isolation coaxial layers - Auxiliary Chucks (2) for holding separate calibration substrates - Integrated service loop for high accuracy station XY stepping - Coaxial cable and connection panel . NOTE: For use with Summit 11/12000 M-S platforms ONLY	1 EA	9,536.25	9,536.25

QUOTATION

Ln	Description	Quantity	Unit Price	Ext. Price
4	162-160 **ASSY,BRIDGE,2X2 MANUAL,PNEU Z,SUMMIT** High Stability Microscope Bridge Mount for Tesla, Summit 11000/12000 series Probe Stations. INCLUDES: - High stability bridge with air-assisted optics lift - Precision 2x2" X-Y microscope transport - Ideal for probing fine structures - Includes scope mounting plate - Also compatible with laser setups	1 EA	7,421.25	7,421.25
5	157-459 **SLIMVUE MICROSCOPE CPL. W/O OBJECTIVE LENS** - 3.2x manual zoom - 10x eyepieces - Trinocular photo tube with c-mount - Coaxial LED illumination - Focus block included - Quick lens exchange mechanism (2 objective adapters included) - Supports Mitutoyo MPlan Apo objective lenses (not included)	1 EA	10,020.00	10,020.00
6	102-517 **LENS,10X,MITU FINESCOPE**	1 EA	937.50	937.50
7	158-270 **ASSY, CONTROLLER,VELOX,SUMMIT** 158-270 High Performance Probe Station Controller for Cascade Microtech Summit 12000B, S300 and REL-6100 Semi-Automatic Probe Stations. INCLUDES: - Velox Probe Station Control Software including Toolbar, Control Center, SPECTRUM Vision System, Wafer Map and GPIB, RS232, TCPIP Interfaces - Industrial grade cabinet (19" rack mountable) - Intel Core i7 (Quad Core), 8GB RAM, 1TB HDD, DVD-RW, 2xDVI, 2xLAN, 2xRS232, 8xUSB 2.0, 4xUSB 3.0, 2xPCI, 1xPCIx16, 1xPCIx1 - Single and Dual monitor output - NI488.2 USB GPIB adapter - Windows 7 64bit Operating System and Acronis True Image NOTE: *** All technical specifications are subject to change without notice.	1 EA	3,795.00	3,795.00

QUOTATION

Ln	Description	Quantity	Unit Price	Ext. Price
8	153-144 **KIT,24" LCD FLAT MONITOR W/ SPEAKERS** Computer 24" LCD Multi-Media Monitor INCLUDES: - TFT Active Matrix, 23.6" Diagonal viewing area - Integrated Stereo Speakers - Thin Bezel design with Anti-glare screen - Max Resolution: 1920x1080 - Fast response time: 5ms - VESA mount and stand - Analog and digital video input (HDMI) - 100-240VAC 50/60Hz, UL/TUV/CE/RoHS	1 EA	592.50	592.50
9	114-338 **PROBE CARD HOLDER,NON-MICROCHAMBER,S11/12&300M**	1 EA	3,933.75	3,933.75
10	142-032 **TABLE,STND,VIBRATIONISO,V2** Vibration isolation table for 200mm probe stations V2 (STANDARD package) FEATURES: - Heavy duty frame and steel tabletop (40"W x 40"D X 32"H) - Integrated leveling feet and rolling casters - Seismic restraint kit - Storage shelf below tabletop - Ergonomic front support bar NOTE: - Optional side instrument shelves and accessories available	1 EA	6,480.00	6,480.00
12	169-080 **VELOX DIGITAL CAMERA KIT** Velox digital camera package for Cascade Microtech probe stations using C-Mount microscopes. This camera is supported with SPECTRUM Vision System. INCLUDES: - Digital Video Camera, 780x582 pixel, 1/2 inch CCD sensor, IEEE1394A connector - IEEE1394A (Firewire) interface board and cable - White light LED fitting into microscope illumination port NOTE: Requires Velox Probe Station Control Software	1 EA	2,298.75	2,298.75

QUOTATION

Ln	Description	Quantity	Unit Price	Ext. Price
30	SRV-INSTALL-SYS **SYSTEM INSTALLATION CASCADE CERTIFIED FSE** On-site system installation of Cascade Microtech Probe Station by a Certified Service Engineer. INCLUDES: - Probe station assembly and CMI accessory setup - Probe station system verification and - Thermal Calibration (if applicable) - Assist with station placement - Basic Software/Prober Training-(Load, Align, Contact, Video) - Travel, lodging, per-diem to/from customer site (one trip). REQUIREMENTS: - Customer Facility Connections based on current Station Facility Guide. - Customer equipment and/or personnel to lift/move Station EXCLUSIONS: - Measurement Training (WinCal & RF or DC) - please order SRV-APPS-TRAIN	1 EA	6,904.50	6,904.50
31	SELECT-US-DE-200 **SERVICE,LOGISTICS,200MM,GERMANY TO US** Included: Cascade Microtech will provide flat rate price for ground/economy transportation services. No inside delivery, dock delivery only. This will include door-to-door transport service, import duty, taxes, customs clearance, and any other fees, but does not include insurance. Cascade Microtech will act as Importer of Record on your behalf. We will monitor the tracking and manage any delays that may occur during transit. Please let us know if you have any special delivery requirements at the time of order. (e.g., lift gate or pallet jack). ** CPT DESTINATION FREIGHT TERMS, BEST INT'L ECONOMY ** TITLE AND RISK OF LOSS PASSES AT THE FIRST CARRIER ** IF CHOOSING SELECTSHIP OPTION, INCLUDE THIS AMOUNT ON YOUR PO *** SHIPMENT ORIGIN: SACKA, GERMANY COLLECT: Customer chooses to use their preferred freight forwarder or carrier. Customer is responsible for all transportation, customs clearance, import duty, taxes and any other fees. Customer is responsible for all tracking and management of any transit delays. If this is a small parcel shipment you must provide a valid FedEx or UPS account number at the time of order. If this is a large freight shipment, you must provide all relevant contact details of your preferred forwarder in Europe at the time order. Details regarding shipment size/weight are not available until time of shipment. **IF CHOOSING COLLECT OPTION, DO NOT INCLUDE THIS AMOUNT ON YOUR PO **IF CHOOSING COLLECT, MUST INCLUDE SHIPPING INSTRUCTIONS ON YOUR PO **FREIGHT TERMS FOR COLLECT SHIPMENTS: FCA FACTORY/ORIGIN OR EXWORKS * **PRICING REFLECTS A 25% DISCOUNT** ****DOES NOT APPLY TO FREIGHT** **	1 EA	2,450.00	2,450.00

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Ln	Description	Quantity	Unit Price	Ext. Price

On your purchase order all service items are required to be listed separately from products. Failure to do so may cause a delay in processing	Product Total:	91,830.00
(LN: 30)	Service Total:	6,904.50
	SUB Total:	98,734.50
	Select Shipping:	2,450.00
	Quote Total: USD	101,184.50