ATLAS PIXEL DETECTOR FLEX HYBRIDS

The University of Oklahoma
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8 November, 2001

U.S. ATLAS

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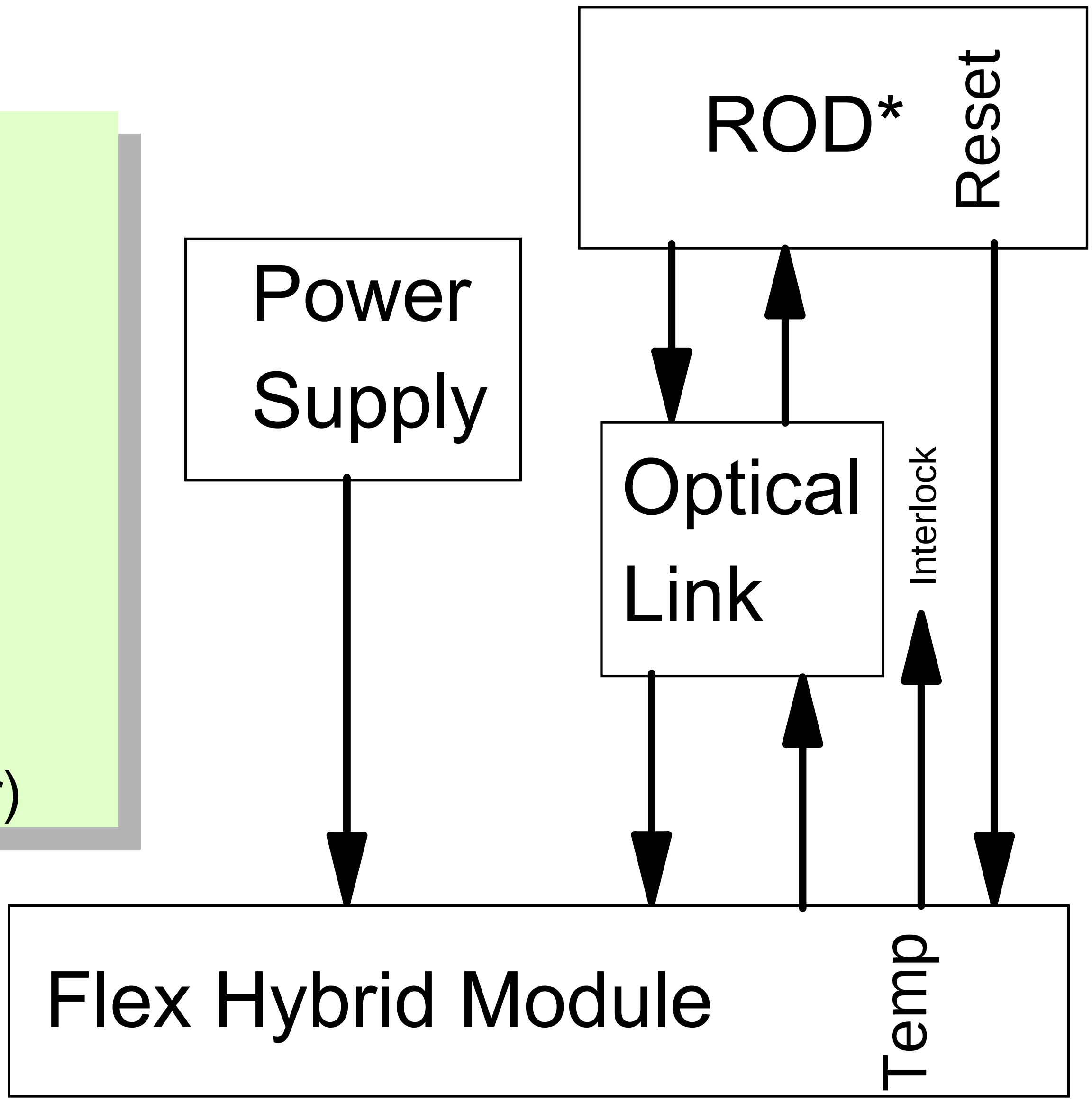
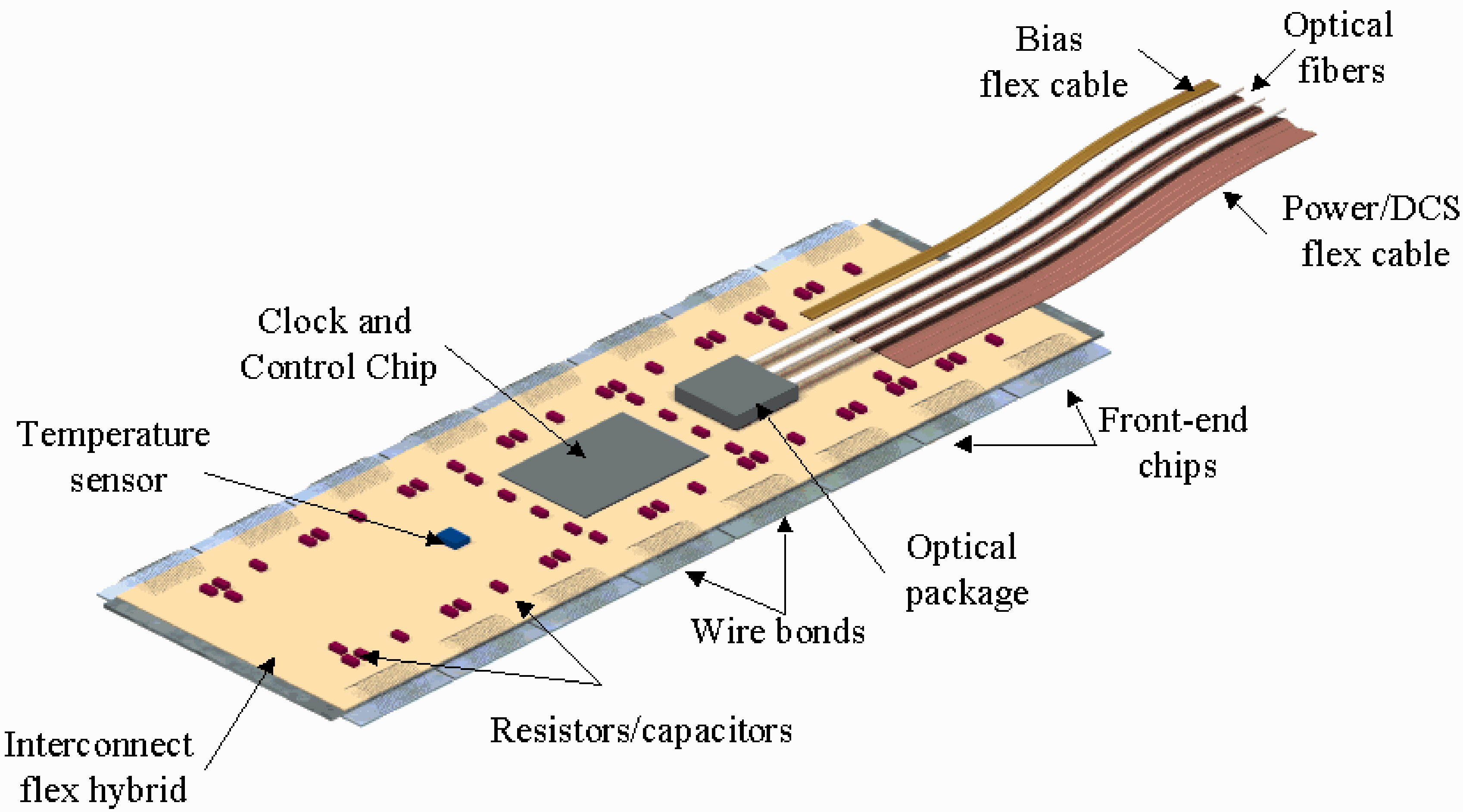
Function

- Provide connection for:
  - Power
  - Clock
  - Data In
  - Data Out
- Between module and:
  - Power supply
  - Optical link
  - Interlock (temp. sensor)



* Read Out Driver

Function (*continued*)

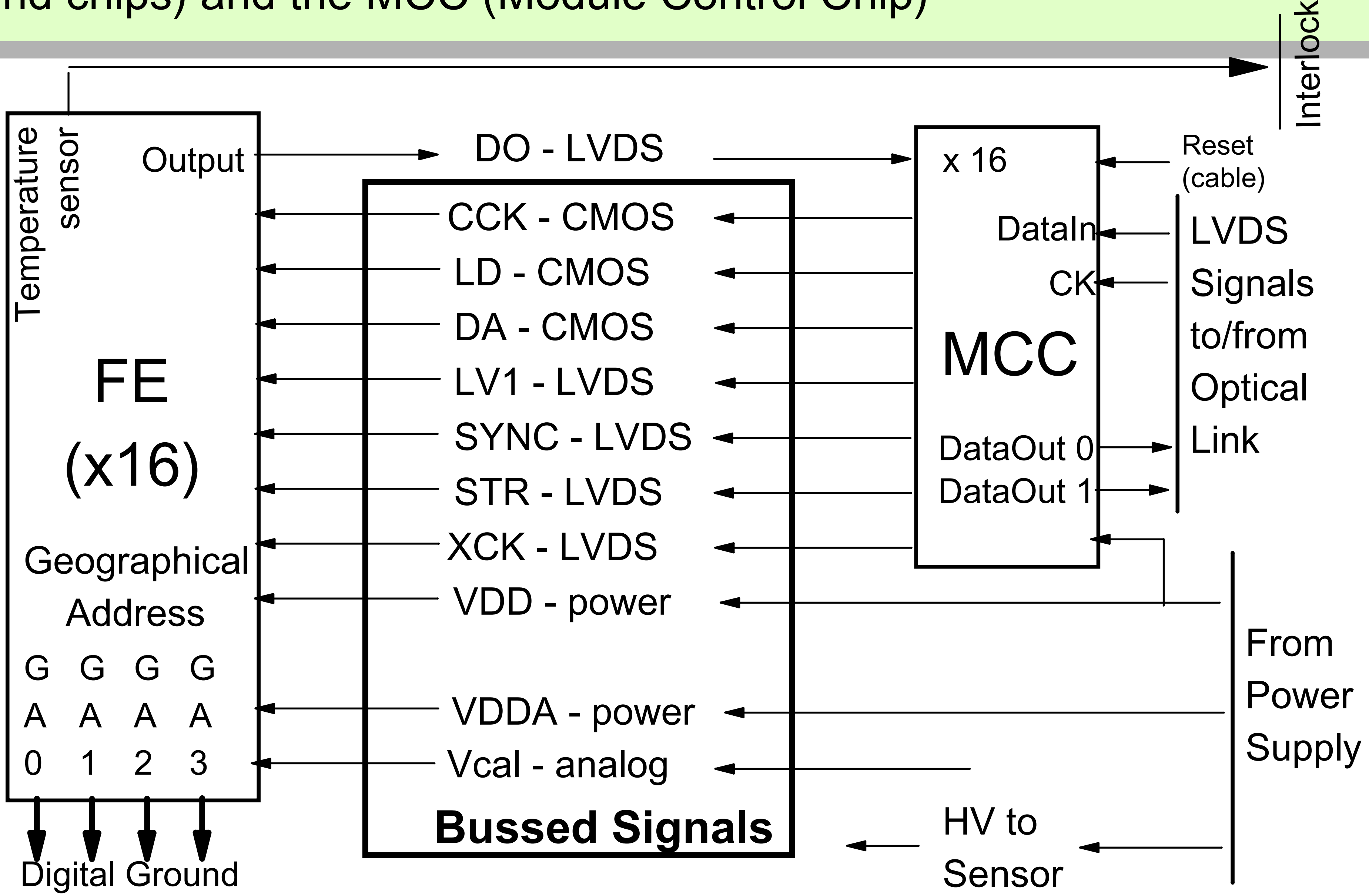


Early Flex Hybrid module concept

Optical link no longer included on module

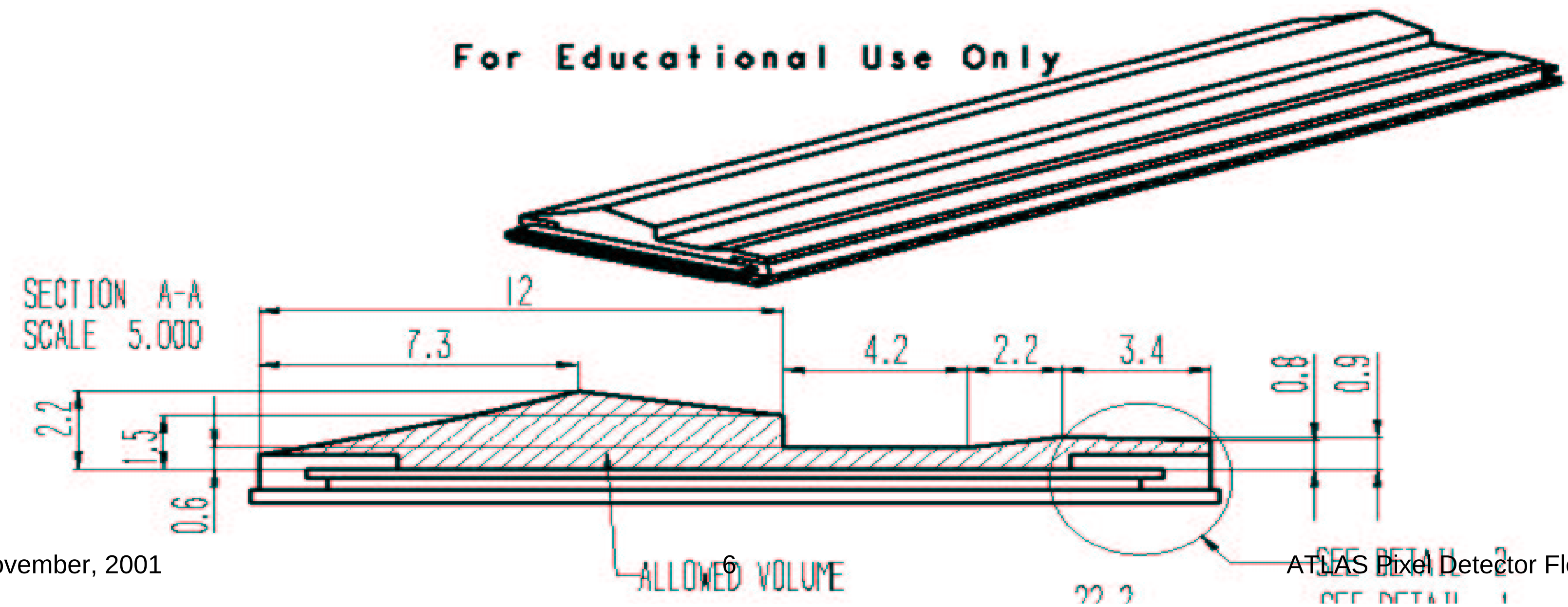
Function (*continued*)

- The Flex Hybrid provides interconnection between the 16 FE's (Front End chips) and the MCC (Module Control Chip)



Specifications

- Pixel detector specifications:
  - Power: Current spec calls for no greater than 50 mV drop round trip fo any power + return trace on Flex Hybrid
  - 150 μm pitch on FE/MCC wire bond pads -> 75 μm traces/spaces and only 50 μm between bond pads
  - Design must accommodate 700 V sensor bias
  - Barrel module envelope constrains component heights in some areas of flex to no greater than 0.6 mm
  - 0402 0.1 μF capacitors are spec.'d at 0.5 mm ± 0.1 mm



Specifications (*continued*)

- Flex fabrication specifications
  - ► Delivered size 86.6 mm x 19.6 mm
  - ► Substrate of 25.4 μm polyimide (Kapton or Upilex)
  - ► Two metal layers connected by through-hole vias with no break out of via cover pads
  - ► Sputtered seed metal (Cr or Ti) on polyimide
  - ► 16 μm (min.) Cu, 1 μm - 2 μm Ni, 0.1 μm - 0.2 μm Au compatible with Al ultrasonic wire bonding
  - ► Patterned cover layers top and bottom of 25.4 μm Pyralux with placement accuracy of ± 125 μm (trying other substrates/cover layers in v3 & v4)

Prototypes

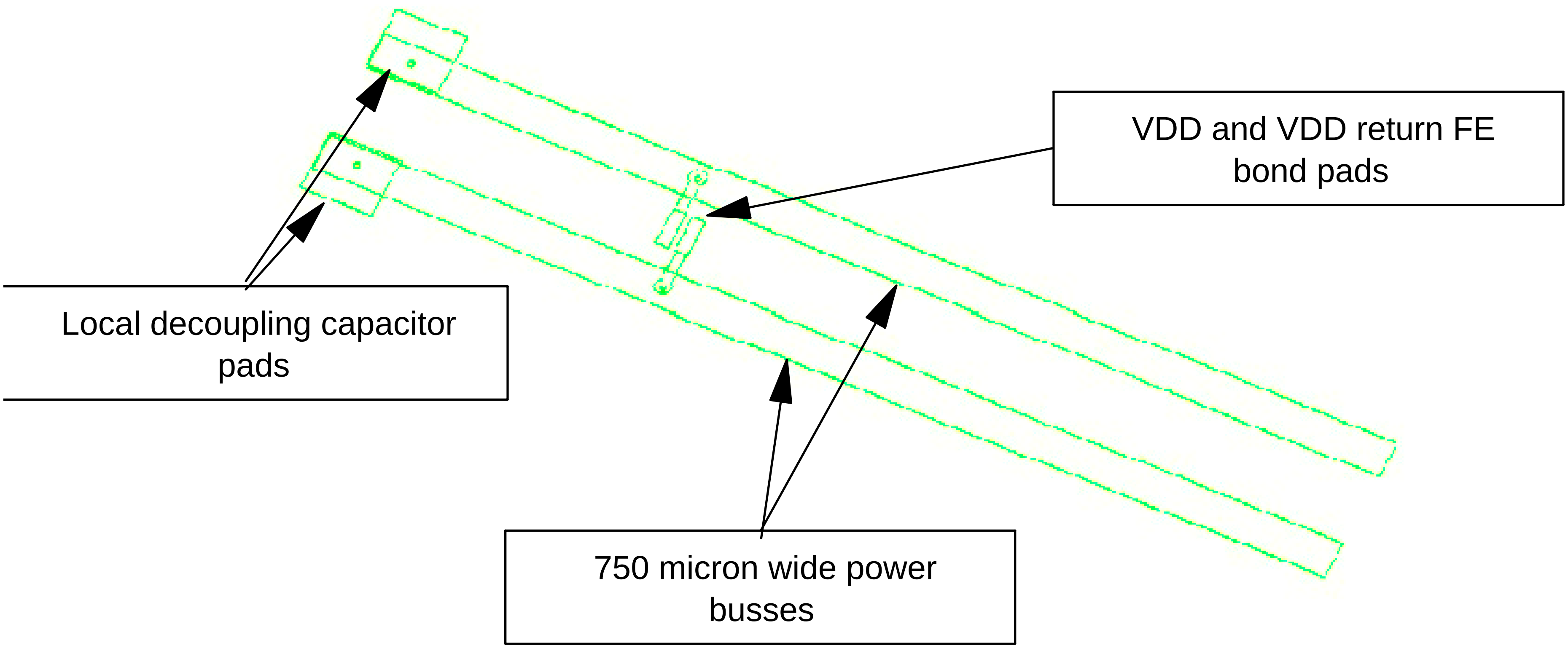
- v1.0 Flex Hybrids: Work - two "working" modules built (bumping issues)
- v1.x: 4 Flex Hybrid modules constructed show that v1.x works
- v2.x: CERN delivered 100, Compunetics delivered 41
  - Test coupons good on electrically good flex
    - Indicates via resistance of ~10 mΩ
    - Tests of trace resistances consistent with calculated and simulated values for actual thickness of Cu
    - Compunetics Cu thickness was low ~ 8μm
  - Some variability of wire bonding results on v2.1 (Compunetics)
    - Bond pad lift off on electrically bad flex (show evidence of over etching)
    - Results good on good flex when cleaned first
    - Learned that wire bonding is more reliable when there is no adhesive under bond pads, then:
    - Seeing average 9 gf pull strength at OU and LBL
- Both vendors have been slow to produce prototype
- Several modules have shown that v2.x works

Prototypes (continued)

- V3 should ship - *in test, ship by Monday, latest*
  - ► Compunetics only - 50 good circuits, about 100 bad from first failed batch
  - ► Delayed by issues with plating - as with v2.1, Au plating shorted many wire bond pads, flying probe tester broken (again)
  - ► Still don't have 16 μm Cu - too much being etched away by plating process
  - ► Supports AMS MCC and FE-I
    - In case MCC-I is not available
    - Still violates envelope (too many components and large MCC)
    - Barrel and disk pigtails use same bond pads on flex, got rid of tab and connector of v2.x
    - Now use frame PCB as carrier and interconnect for tests of flex hybrid
- V4 is 95% same as v3
  - ► Supports FE-I and MCC-I
  - ► Delete resistors needed to interface AMS MCC with FE-I
  - ► Delete extra 3.5 Vdc power and extra capacitors required by AMS MCC
  - ► Uses same frame PCB, pigtails as v3

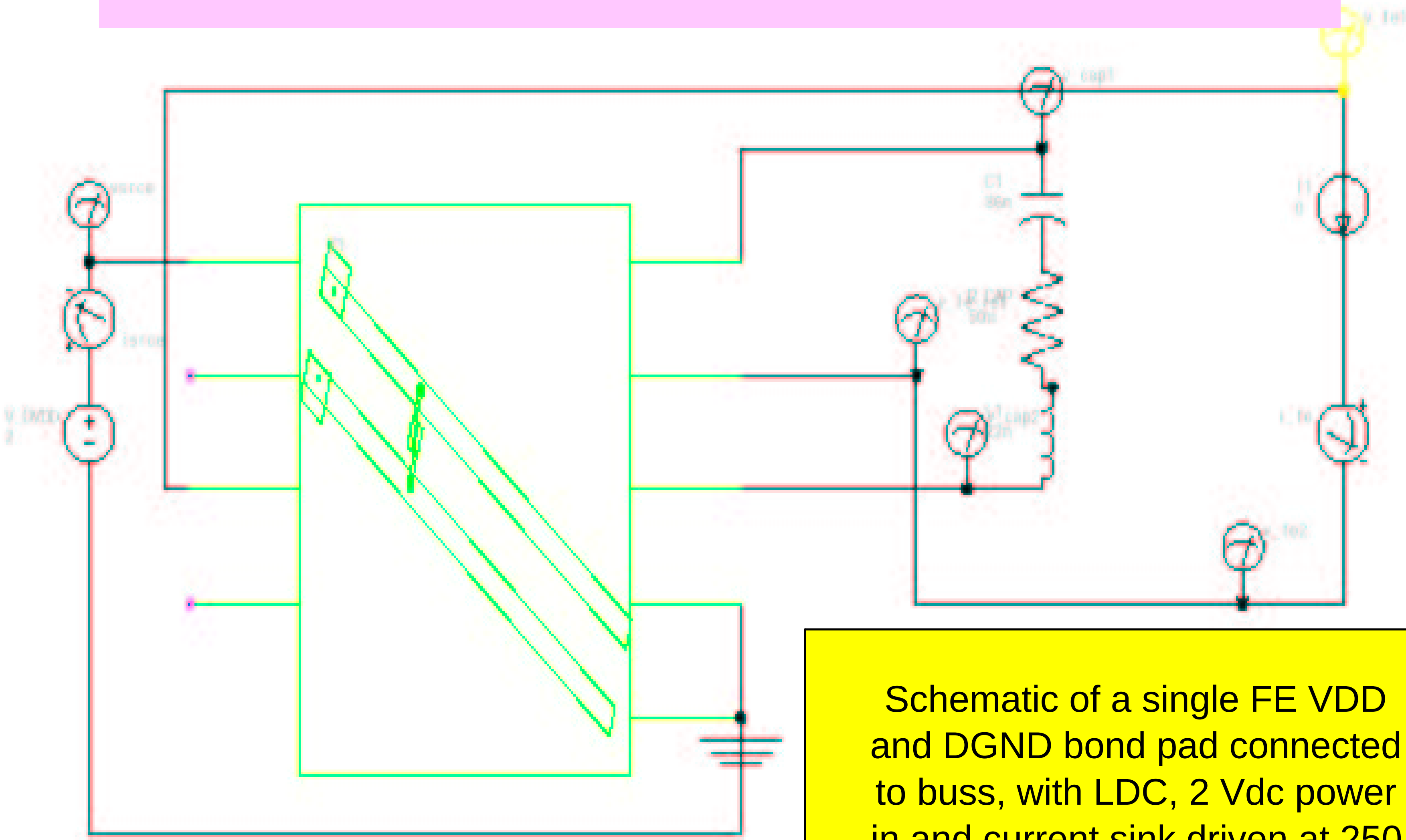
Flex Hybrid Simulations

- We've been using Maxwell Spicelink to model and simulate various aspects of the flex hybrid since we began our involvement with ATLAS
- We have developed a lot of confidence in the program
- Simulations of DSM electronics with the present bussed layout have caused concern



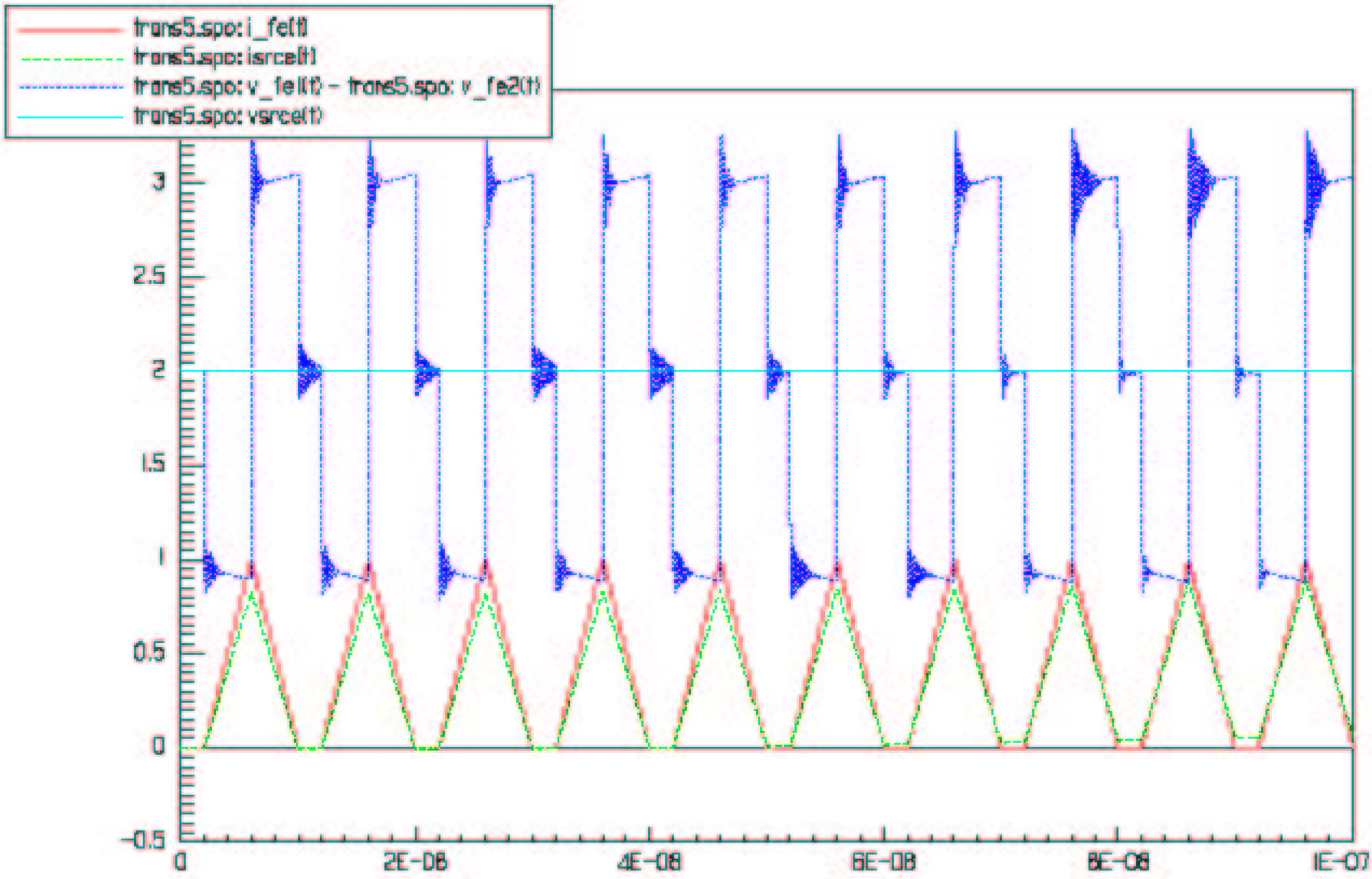
Flex Hybrid Simulations (*continued*)

The weakness here is that we don't know what the input current slew rate for DSM really is, but it could be as high as 1 A/ns



Schematic of a single FE VDD and DGND bond pad connected to buss, with LDC, 2 Vdc power in and current sink driven at 250 mA/ns to simulate FE-I

Flex Hybrid Simulations (*continued*)



Plot of simulated model and 250 mA/ns slew rate input current to FE. Blue is the voltage across the FE, without including the wire bond.

Flex Hybrid Simulations (*continued*)

- The solution is VDD power & ground planes
  - Reduces resistance linearly
  - Reduces inductance in proportion to $\ln(4l/2(t + w))$ - with a power plane, $w >> l$ between local decoupling capacitor and bond pads, so inductance "disappears"
- Plan to test this (important as backup, too!) with v4
  - Holes will be laser cut through some v4 flex where connections (bond pads, LDC's) are made to VDD/VDD_ret
  - No electrical connection between v4 and power plane flex (inexpensive)
  - ~~Toughest part is aligning two flex and gluing them together with < 2 mi error over flex hybrid~~
  - LDC's are mounted on power plane flex and thus do not violate envelope
  - Believe VDDA (analog) LDC's are not required - FE PSRR high
- Trying to simulate power planes - extraction takes several days

Assembly

- Assembly of v1.0 and most of v1.x & v2.x done in labs
- About 20 flex of v1.x & v2.x have been assembled at AMA (CA), Flex One (CA) and Surface Mount Depot (OKC)
  - ► All efforts involved at least some degree of manual assembly
  - ► None used automated pick and place
  - ► Demonstrated need for improvements in layout and cover layer applicatio to prevent solder leaching onto wire bond pads
- 15 v2.2 assembled at Mipot (Italy)
  - ► Automated pic and place
  - ► MCC attached and wire bonded
  - ► 7 passed electrical tests, various problems, not all assembly related
- On v3 there are:
  - ► 35 0402 capacitors
  - ► 4 1206 capacitors (1 HV)
  - ► 13 0402 resistors
  - ► 1 0603 NTC temperature sensor
  - ► 1 MCC

Assembly (continued)

- V4.x will have:
  - 35 0402 capacitors (17 for power plane trials)
  - 3 1206 capacitors (1 HV)
  - 10 0402 resistors
  - 1 0603 NTC temperature sensor
  - 1 MCC
- Use of frame PCB will enable easier auto pick and place assembly
  - Flex is stabilized
  - Can easily design carrier to process more than 1 flex at a time
- SMD in OKC is working on proposal to attach flex to frame PCB and do assembly for v3 and v4
  - *Compunetics is looking at doing this for v4 - say it will help them out durin test*
- Since they are local, we can be present during first assembly runs to assist and supervise

Components

- NTC
  - ► Selected, irradiated, qualified by Wuppertal
  - ► 4000 ordered and on hand (Wuppertal)
- Irradiation
  - ► Irradiation at CERN June, 2000, to full fluence 1.9 x 10^{15} p/cm^2 (24 Gev) of resistors, ceramic capacitors and flex, ^{60}Co to 60 Mrad and capacitors again at 3.5 Vdc in October, 2000
    - Capacitors show no catastrophic failure (large value changes, shorts)
    - Observe < 20% reduction of pre-irradiation value, no change in leakage
    - Have not observed any change in resistors or flex (other than color)
  - ► HV caps irradiated with 700 V to full fluence in May, 2001
    - Observe < 20% reduction of pre-irradiation value, no change in leakage
    - Increase of leakage from less than 1 nA to about 3 nA
    - Continuing to monitor irradiated devices and controls

Production

- Deliverables
  - ►Layout of prototype and final designs
  - ►Simulations of flex hybrid power traces and decoupling
  - ►Flex Hybrid test design
  - ►100% Flex Hybrids
  - ►Attachment & wire bonding of (50% of?) MCC's
  - ►Testing of (50% of?) Flex Hybrids in UOK & Albany

Production (*continued*)

- Flex fabrication
  - Compunetics - 200 flex/week after "ramp up"
    - Typical of other commercial vendors
  - CERN - 200 flex/mo. - if they can still do it and fix problems
- Assembly of components onto Flex Hybrids
  - Entire production can be done in less than one week with automated pick & place (including part tolerance verification)
  - Attachment and wire bonding of MCC (UOK) - estimate 16/day = complete production of 3 hit system in 1 year
- Flex testing, same rate, should be able to complete in one year
- Should be much more certain of this by this time next year

Flex Vendors

- CERN PCB facility
  - Charge for materials only, but:
    - Two tests required (outside vendor):
      - Before defect repair
      - After Ni/Au plating
    - More expensive/risky shipping (to US)
    - Cutting (singulation) not provided
  - In house electroless Ni and Au plating
  - Has fabricated v1.0, v1.1, v1.1, v1.4 and v2.2 flex
  - Although functional, have never produced flex to specs (mainly material thicknesses)
  - Not willing to fab more flex until 2002 - turnover in personnel
  - Second batch of v2.2 of very poor quality
    - Nearly all have defects in cover layer
    - Many defects in metal
  - Quoted ~$85/flex (adding test and singulation) in 2000 - must check if they are still able/willing to fab for Pixel production

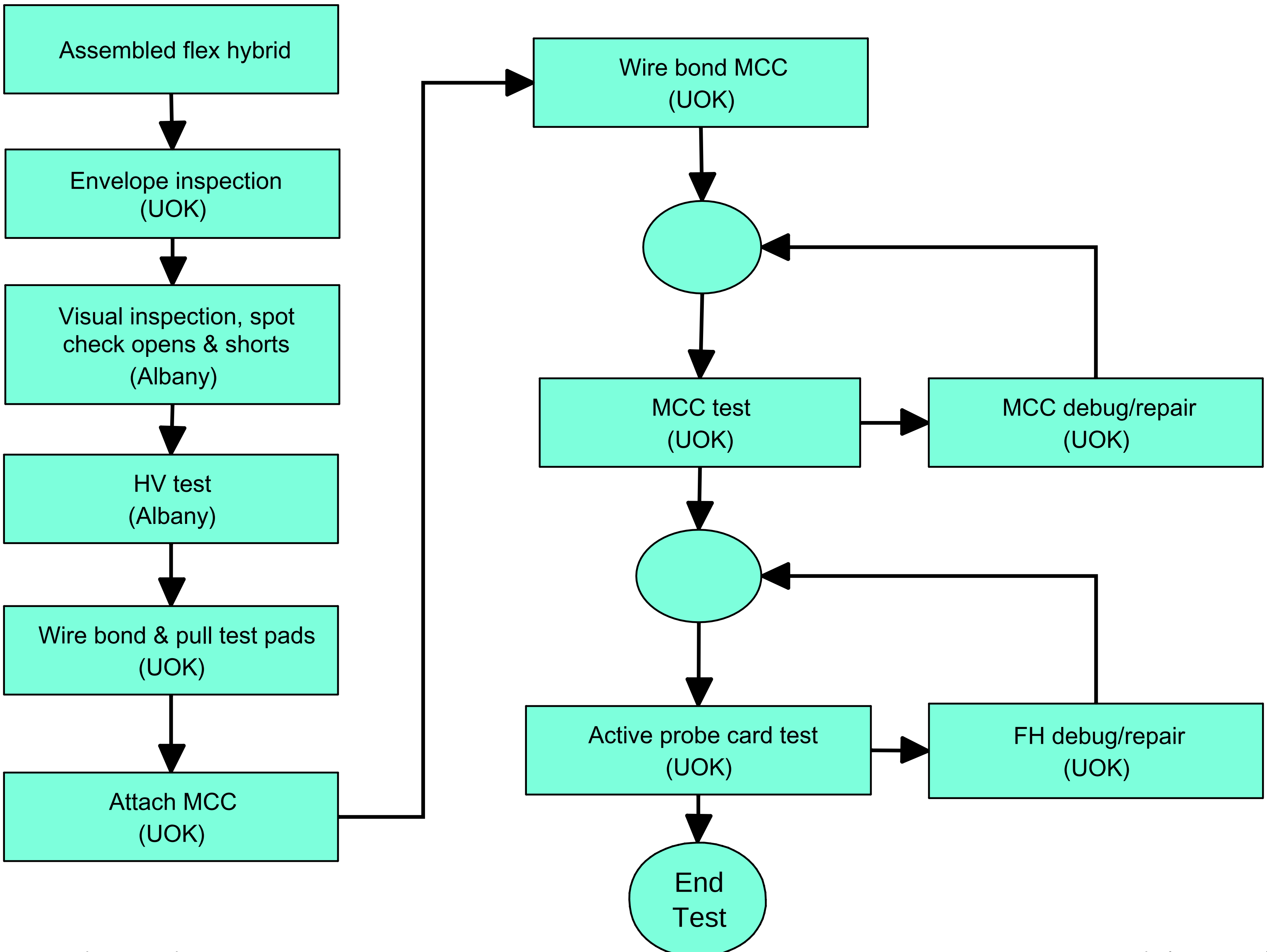
Flex Vendors (continued)

- Compunetics (Monroeville, PA)
  - Quotes $85/flex for production
  - In house testing (two tests, also)
  - In house laser cutting
  - Has produced v1.1, v2.1 and (producing) v3 flex
  - Out-sourced Ni and Au plating (has been source of some problems)
    - First batches of v2.1 & v3 ruined by plater
    - Continues to have problems meeting Cu thickness spec of 16 microns because of plater
  - Has produced flex for D0
- Many other potential vendors have been contacted, those that have technology tend to not be interested in small orders (< 100k units), most that will do small orders don't have technology

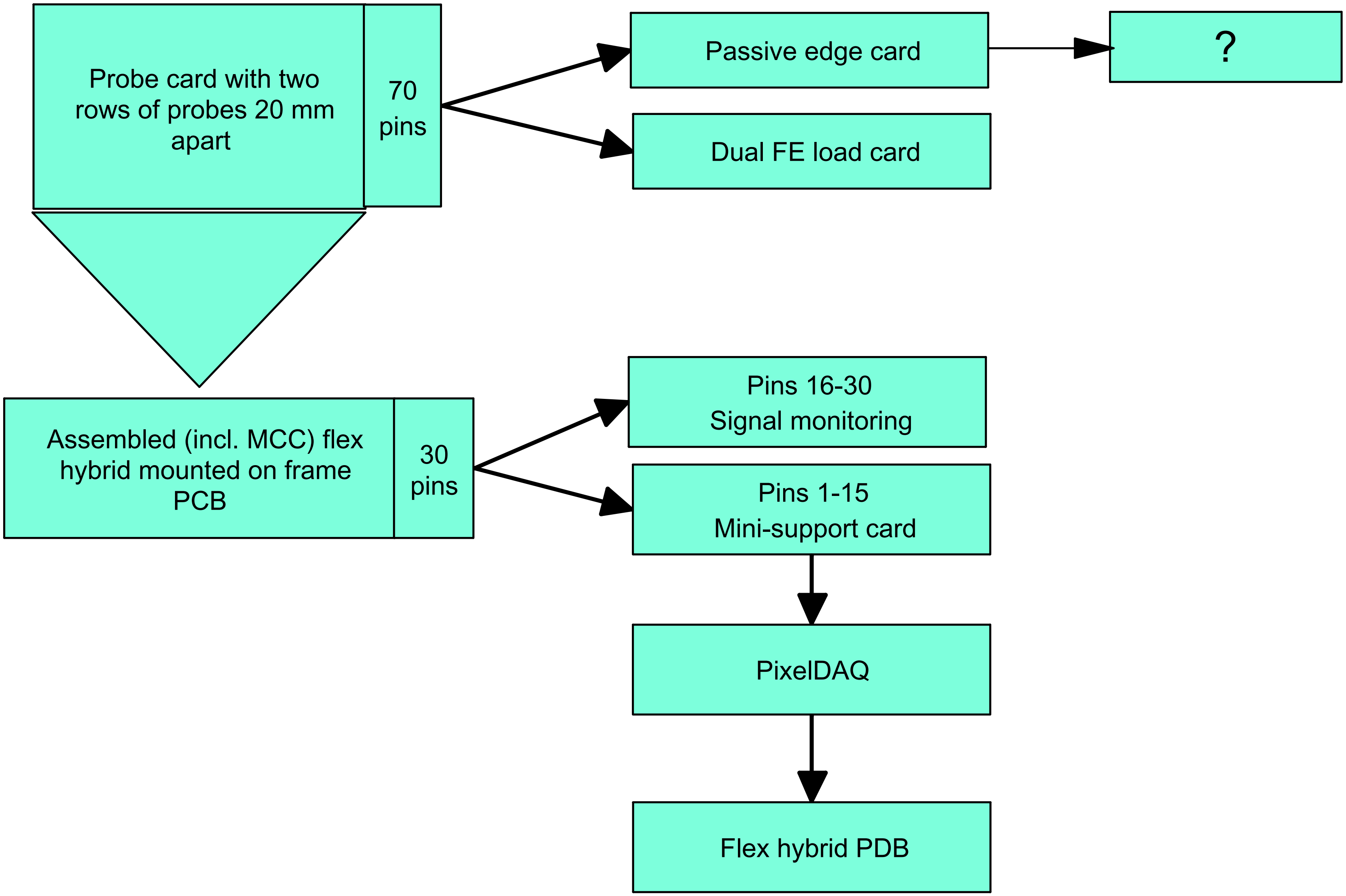
Flex Vendors (*continued*)

- Dyconex (Switzerland)
  - ~$10k for 50 - 100 (??) v4
  - Quote $16/flex for 4000 flex (have had similar quotes from other vendors that did not hold up)
  - New materials, but have been used in HEP experiments
  - Partnership with Nextek (assembly firm) - deliver assembled flex
  - Great reputation, but has had limited technology in past
- Speedy Circuits (Huntington Beach, CA)
  - Quotes $85/flex for 100 pieces
  - Has built flex for FNAL experiments
  - No in house test
- Microconnex (Snoqualmie, WA)
  - Quotes $123/flex for 100 pieces
  - No in house test

Flex Hybrid Test Flow Chart v1.4



Flex Hybrid Test Block Diagram v1.3



Genoa has a test system, but not practical to replicate most of it, nor necessary

FY'02 Activities at UOK

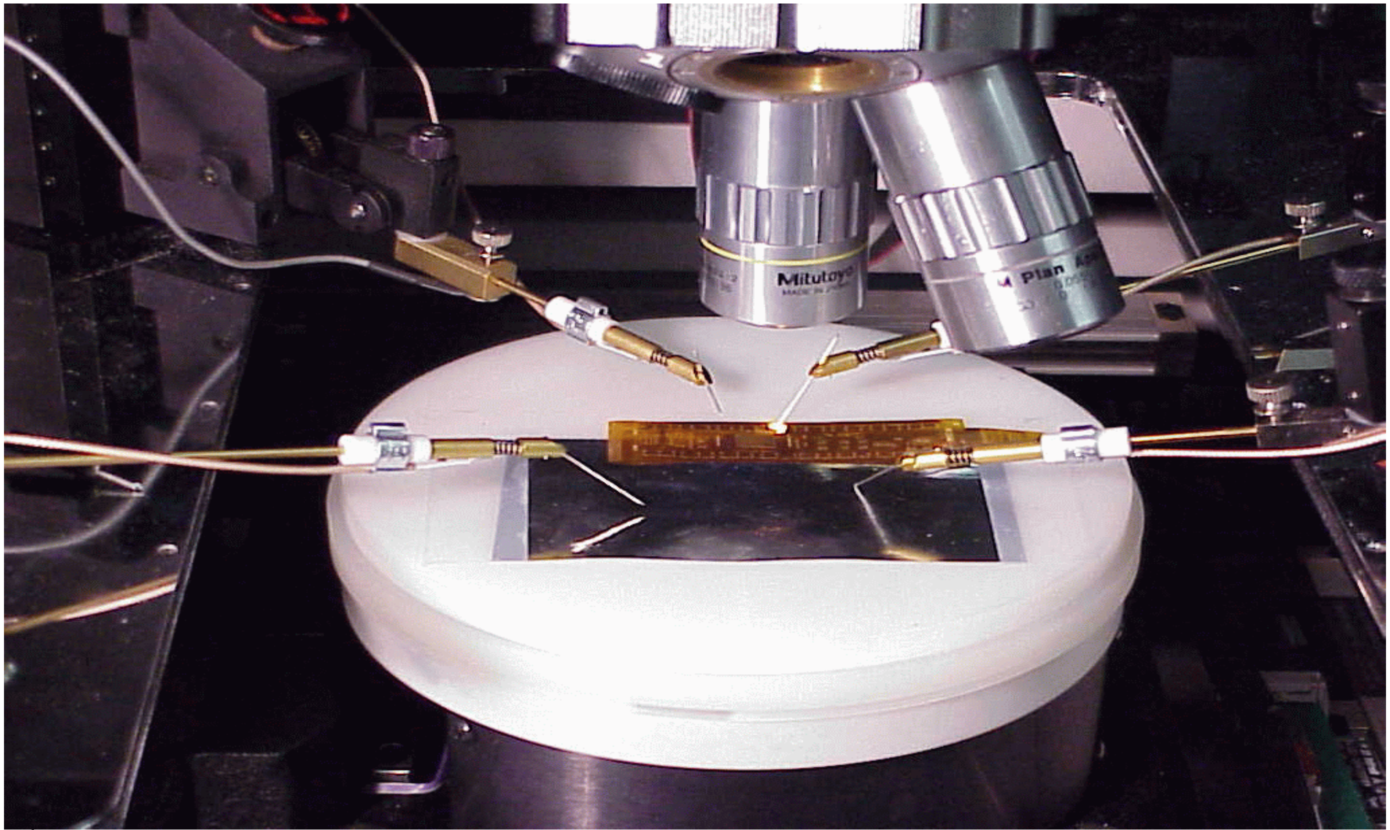
- Intermediate design review completed in 2001
  - ► Flex Hybrid Task Force created partly as a result
    - Addresses interface, coordination issues relating to flex hybrid modules
    - Consists of R. Boyd, M. Garcia-Siveres, G. Darbo (Genoa)
    - Meet biweekly by various means
- Prepare for PRR in June (??) - basically all the following + documentation
- Complete design and fabrication of v4 (in progress)
- Complete final flex hybrid design (after FE-I module results are known - in serious jeopardy because of electronics delay)
- Specify Flex Hybrid Production Database (needs to be ready for v3 and v4)
- Graduate student doing flex modeling and sims leaves end of Dec.
- Expand clean room (searching for funding)

FY'02 Activities at UOK *(continued)*

- Integrate new equipment into production, test (MRI grant, waiting for the check)
  - Westbond 2400 wire bonder (could take 8 weeks ARO)
    - Fully automated
    - Optical pattern recognition (tested with dummy module)
  - Plamsa cleaner
  - Optical comparator for checking envelope compliance of assembled flex hybrids
  - Environmental chamber for module burn-in
  - Logic analyzer for module debug
- Complete development of test systems
  - Design and fabricate probe card(s) (just need to get PO done)
  - Design and fabricate FE-B and FE-I load cards (after v4 design)
  - Design and fabricate new mini-support cards for AMS MCC and MCC-I (after v4 design)
- Test a lot of flex with the above (using a single 2.1 flex for now)

FY'02 Activities at Albany

- Continue HV test system development
  - Only a few v2.2 flex left to test
  - Integrate HV test with new frame PCB paradigm
- Replicate UOK probe card-PixelDAQ assembled flex test system
  - F. Wappler and R. Bula coming to UOK for PixelDAQ training 11-19



Production Schedule

Hard to imagine keeping this production schedule with delay in FE-I module production - need three months after module evaluation is complete to complete final design

Not likely to have a final design by then

No longer makes sense

196	1.1.1.4.1	Flex Hybrid FDR	15-Dec-00
199		Release Flex Bids	24-Apr-02
200		Flex Bid Evaluation Complete	5-Jun-02
201		Flex Hybrid PRR	3-Jul-02
202		ATLAS PM Approval of Flex Proc	17-Jul-02
203		Release initial MC for flex hybrid and assembly	17-Jul-02
204		Award Flex Contracts	31-Jul-02
218	1.1.1.4.2	Initial Flex 3.x tests complete	13-Dec-01
226	1.1.1.4.3	Start initial production buy of components	13-Dec-01
228		First outer flex delivered	20-Nov-02
230		First outer flex available for module assembly	12-Feb-03
231		Need date for first outer flex	20-Nov-03
232		Outer flex testing complete	5-Nov-03
234		First B-Layer flex delivered	5-Nov-03
235		First B-Layer flex available for modules	28-Jan-04
236		Need date for first B-layer flex	15-Jul-04
237		B-Layer flex testing complete	17-Dec-03

Production Schedule *(continued)*

- PRR in the summer doesn't look likely
  - ► Probably won't have had time to test, debug, analyze, irradiate, test, analyze....
  - ► Also not likely to have settled on required components until above is complete, delaying initial buy date
  - ► Is there any difference between B layer and other flex hybrids?
- Does delaying start of flex production till FY'03 help with FY'02 budget? Does it hurt funding? (Keep in mind that the UOK funding year start April 1)

Production Schedule *(continued)*

- Entire flex hybrid production and testing likely to be complete withi 1 year of order placement
  - ► Biggest delays with flex hybrid prototypes has been
    - Redesign after "final" version has been released for approval
    - Low numbers of flex being built, making it necessary for vendors to "re-climb" the learning curve for these very aggressive designs
  - ► Flex hybrid assembly could easily be finished within 160 days after production go ahead, provided we don't use CERN
- This could free up considerable resources at the time module assembly production is beginning
- Once final flex hybrid design is in production, 1 FTE EE at OU is free from all but supervision

MANPOWER ESTIMATE SUMMARY IN FTEs

WBSNo: 1.1.1.4 | Funding Type: Project | 11/2/01 10:13:33 AM

Description: Flex Hybrids/Optical Hybrids | Institutions: All | Funding Source : All

PROFESSIONAL	*FY 96* *FY 96*	*FY 97*	*FY 98*	*FY 99*	*FY 00*	*FY 01*	*FY 02*	*FY 03*	*FY 04*	*FY 05*	*Calcu-* *lated* *Total*	*Entered* *Entered*
Software Prof.											.0	.0
Engineer - EE											.0	.0
Engineer - ME											.0	.0
TECHNICAL												
Design & Draft								.3			.3	.0
Electrical Technician							.3	.8	.1		1.2	.0
Mechanical Technician											.0	.0
Admin. Supervisor											.0	.0
Other Admin.											.0	.0
TRADES												
Contract Labor							.1	.0			.1	.0
Shops							.0				.0	.0
Technical Services											.0	.0
Student						.0	2.2	1.2	.0		3.4	.0
TOTAL LABOR	.0	.0	.0	.0	.0	.0	2.6	2.3	.1	.0	5.0	.0

Trades Legend:
Contract Labor = Job Shopper
Shops = Fabrication (in-house facility) from raw materials
Technical Services = Rigging, electricans, etc.

MANPOWER ESTIMATE SUMMARY IN FTEs

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Description: Flex Hybrids/Optical Hybrids | Institutions: All | Funding Source : All

PROFESSIONAL	*FY 96 FY 96*	*FY 97*	*FY 98*	*FY 99*	*FY 00*	*FY 01*	*FY 02*	*FY 03*	*FY 04*	*FY 05*	*Calcu- lated Total*	*Entered Entered*
Software Prof.											.0	.0
Engineer - EE											.0	.0
Engineer - ME											.0	.0
TECHNICAL												
Design & Draft							.3	.2			.5	.0
Electrical Technician											.0	.0
Mechanical Technician											.0	.0
Admin. Supervisor											.0	.0
Other Admin.											.0	.0
TRADES												
Contract Labor											.0	.0
Shops											.0	.0
Technical Services											.0	.0
Student											.0	.0
TOTAL LABOR	.0	.0	.0	.0	.0	.0	.3	.2	.0	.0	.5	.0

Trades Legend:
Contract Labor = Job Shopper
Shops = Fabrication (in-house facility) from raw materials
Technical Services = Rigging, electricans, etc.

MANPOWER ESTIMATE SUMMARY IN FTEs

WBSNo: 1.1.1.4 | Funding Type: Project | 11/2/01 10:36:27 AM

Description: Flex Hybrids/Optical Hybrids | Institutions: U. of Oklahoma | Funding Source : All

PROFESSIONAL	*FY 96* *FY 96*	*FY 97*	*FY 98*	*FY 99*	*FY 00*	*FY 01*	*FY 02*	*FY 03*	*FY 04*	*FY 05*	*Calcu- lated Total*	*Entered* *Entered*
Software Prof.											.0	.0
Engineer - EE											.0	.0
Engineer - ME											.0	.0
TECHNICAL												
Design & Draft											.0	.0
Electrical Technician							.3	.3			.5	.0
Mechanical Technician											.0	.0
Admin. Supervisor											.0	.0
Other Admin.											.0	.0
TRADES												
Contract Labor											.0	.0
Shops											.0	.0
Technical Services											.0	.0
Student							2.0	.6			2.6	.0
TOTAL LABOR	.0	.0	.0	.0	.0	.0	2.2	.9	.0	.0	3.2	.0

Trades Legend:
Contract Labor = Job Shopper
Shops = Fabrication (in-house facility) from raw materials
Technical Services = Rigging, electricans, etc.