DOE Sensors & Automation 2006 Annual Portfolio Review+

High-Speed Gas Analysis with PHASED* MGA Gen.1 on NeSSI**

* Phased Heater Array Structure for Enhanced Detection; MGA=μGas Analyzer
** Micro Gas Analyzer; New Sampling and Sensor Initiative by CPAC
Part B of "Wireless and Sensing Solutions Advancing Industrial Efficiency"

Ulrich Bonne, PI
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\+ Black Headers = DOE-requested info
Purple Headers = Advisors-requested info
Blue Headers = Technical paper presentation

High-Speed Gas Analysis with PHASED MGA Gen.1 on NeSSI*

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Abstract

As part of the DOE-OIT project on "Wireless and Sensing Solutions Advancing Industrial Efficiency", this sensor and sampling system's development goal is to field test of PHASED* MGA and other microanalytics on NeSSI-II** in the plants of collaborating members of the processing industries. The presentation of progress on this project will cover: 1) Further development of film materials such as Nanoglass and DB-5; 2) Experimental evaluation of such materials with diverse analytes (C1–C10); 3) Micro-machining and performance evaluation (preconcentration and separation) of PHASED chips and associated electronics; 4) Detector development to improve the performance of the on-board TCD, integrate the MDD as a two-dimensional detector, and development of an alternative CID; 5) Finalization of system packaging; and 6) Design and development of the NeSSI hardware and software for field testing, communication component selection and evaluation, and preparation for pilot-plant tests, all of which help to realize this cross-industry micro-analytical platform of the future, which will save capital, installation, maintenance, and plant operation costs.

Acknowledgments: This project is made possible with cost-shared funding by DOE-OIT, Honeywell, and technical collaborators: Michelle Cohn, UOP; Rob DuBois, Dow Chemical; Jeff Gunnell, ExxonMobil; Frank Schweighardt / Dean Chin-Fatt, Air Products; Joe Andrisani, DuPont; Mel Koch, CPAC; Steve Doe, Parker-Hannifin; and David Simko, Swagelock, under the project entitled "Wireless and Sensing Solutions Advancing Industrial Efficiency"

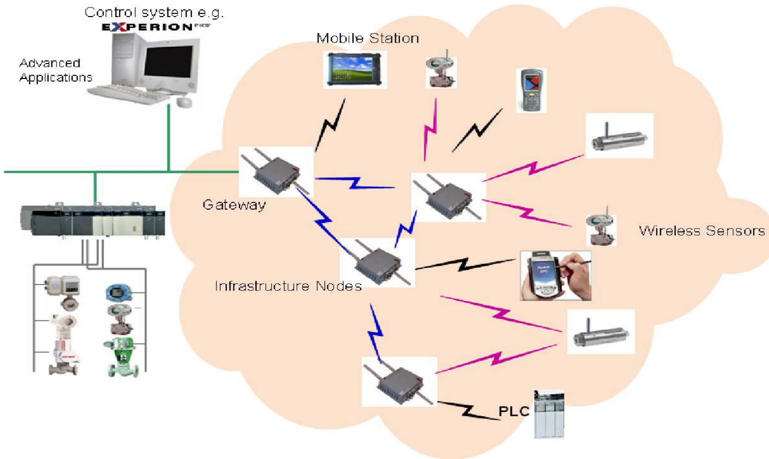
•PHASED =Phased Heater Array Structure for Enhanced Det.; NeSSI = New Sampling Sensor Initiative; MGA=μGas Analyzer

Presenter Bio: Ulrich Bonne, Sr. Research Fellow, joined the Honeywell Labs at Plymouth, MN, in 1965, and received his MS and PhD in Chemical Physics from the University of Göttingen, Germany. His present R&D interests are focused on micro gas analyzers and sensors for industrial, environmental and medical applications.

Project Description

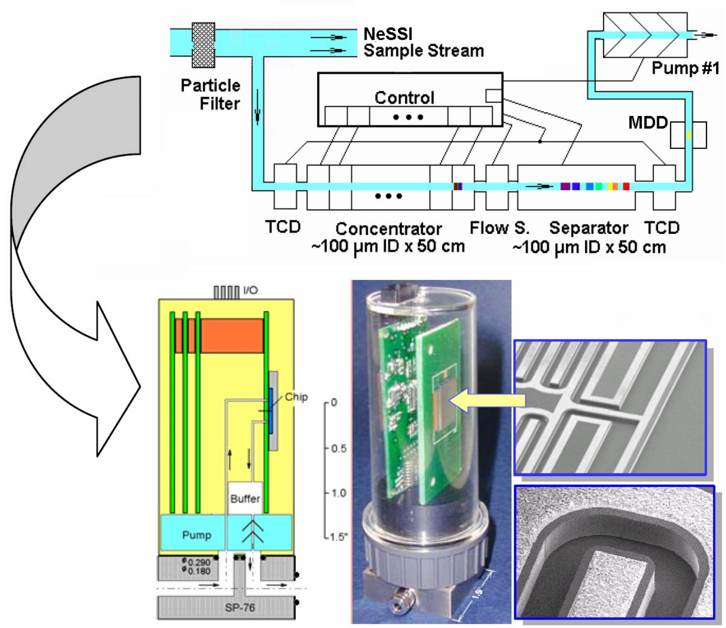
- **Need:** Modular, standardized, IS and networked sampling system (NeSSI-II) to support composition analyses of process streams
- **Goal:** Field testing of PHASED and other microanalytics on NeSSI-II in the plants of collaborating members of the processing industries
- **Core Technology:** Hi-Speed, Multi-Stage Pre-Conc., Affordable µGC; NeSSI-1.5 configuration meeting mini-VOC needs
- **Novel/Transformational Element(s):** PHASED µGC on SP-76 of NeSSI-II
- **Initial Industry for Application:** 2 fiels test sites: 1) Helium production, and 2) HCl in butane
- **Crosscutting Applicability:** Industrial applications in Refining/Petrochemical/Chemical, Mining/Minerals/Materials, Food/Ag/Forestry, Pharmaceutical, Natural Gas, Air Quality and Medical Diagnostics
- **Key Project Deliverable(s):** Report on results from 2 field tests

Wireless & Sensing Solutions for Improved Industrial Efficiency



Part A: Wireless Network for Secure Industrial Applications
- Robust industrial wireless infrastructure
- High data security
- Lowest total cost of ownership
- Low power requirements and extended battery life
- Enhanced availability and coexisting with other RF systems

Part B: PHASED Gas Composition MicroAnalyzer
- MEMS based micro gas chromatograph
- Real-Time, on-/by-line measurement of process streams
- High-Speed, 1-10 seconds analysis time
- 20-50-Stage, sub-second pre-concentration
- NeSSI-Compatible Microanalytics
- Low-Power requirements
- Affordable



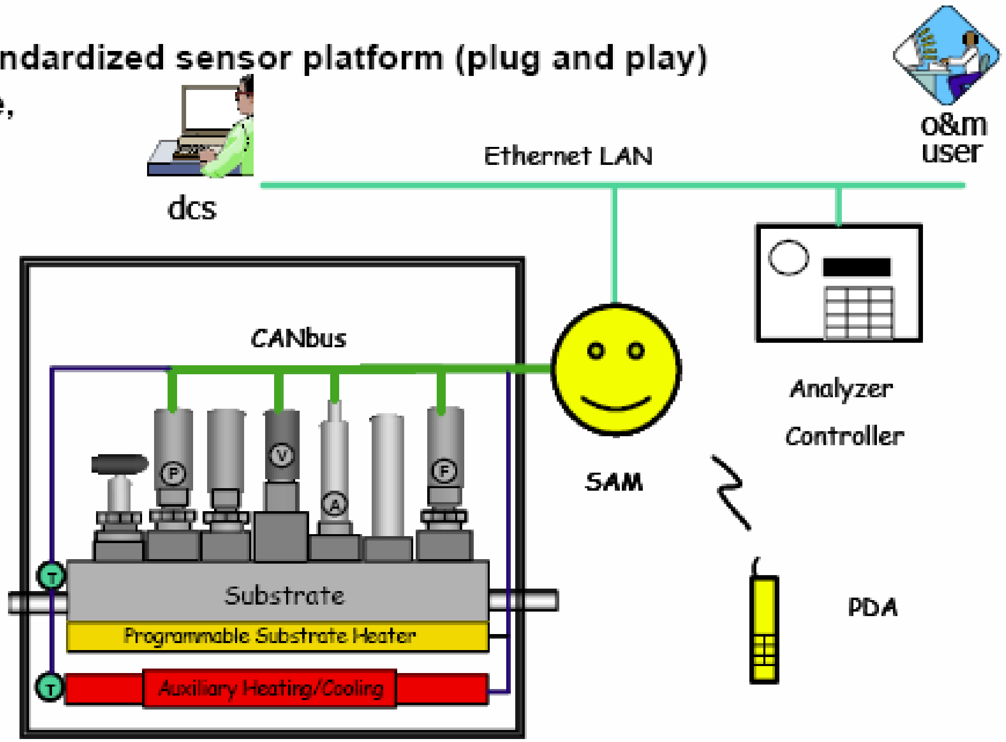
NeSSI and PHASED

Microanalytics for Process Control Solutions

Technical Concept – NeSSI-I, -II, -III

- NeSSI-III Sampling System:
  - Modular, IS, networked, standardized sensor platform (plug and play)
  - Pressure, flow, temperature, and composition
  - Micro-components with lower-cost life cycle
  - Supports microanalytics:

    PHASED μGC



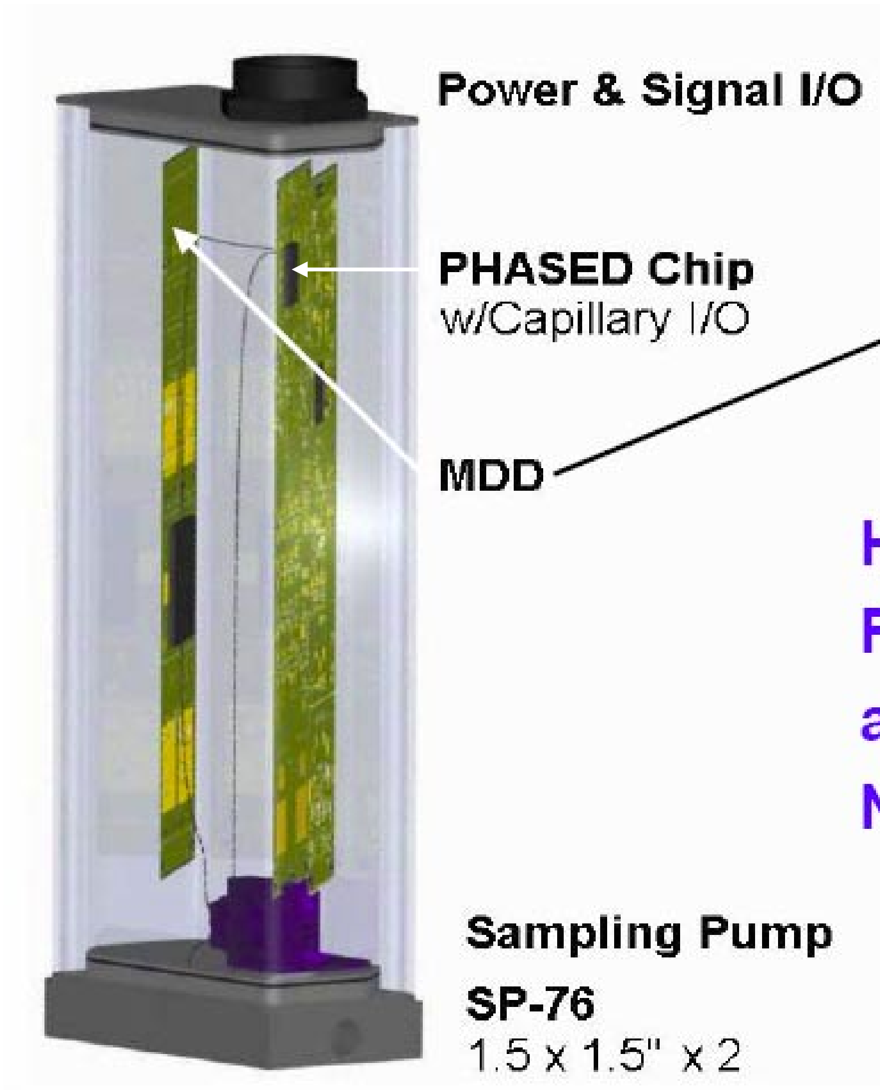
Applications:
- In-situ process stream monitoring
- Ind. process control and automation
- Petroleum refineries, chemical processing plants, metals & food processing

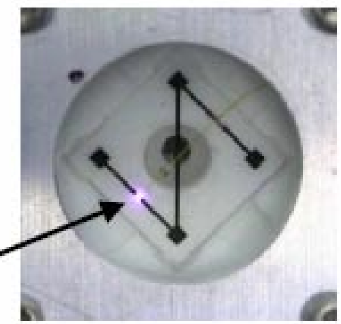
Process monitoring with lower-cost of life-cycle and improved safety

Technical Progress

- **Progress this year has been made across all areas of the project, and is detailed in the following slides**
  - **Separation – New column materials have substantially improved separation performance**
  - **Detection – A 50-70x more sensitive TCD has been designed and 90% processed. Likewise, a new Chemical Ionization Detector (CID) has been designed and 90% processed, and a more compact version of the Micro-Discharge Detector (MDD) has been completed to fit into the PHASED-on-NeSSI SP-76 housing**
  - **Test Configuration – The hardware configuration for the test system and the NeSSI platform is complete; software to support the test configuration is designed and is in development**

PHASED on NeSSI: Design





Housing for PHASED w/TCD and MDD on NeSSI

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PHASED on NeSSI: Fabrication

Top Cover

Side Cover

Circuit Boards

Buffer Volume
on Base Cover

2 SP-76 Blocks

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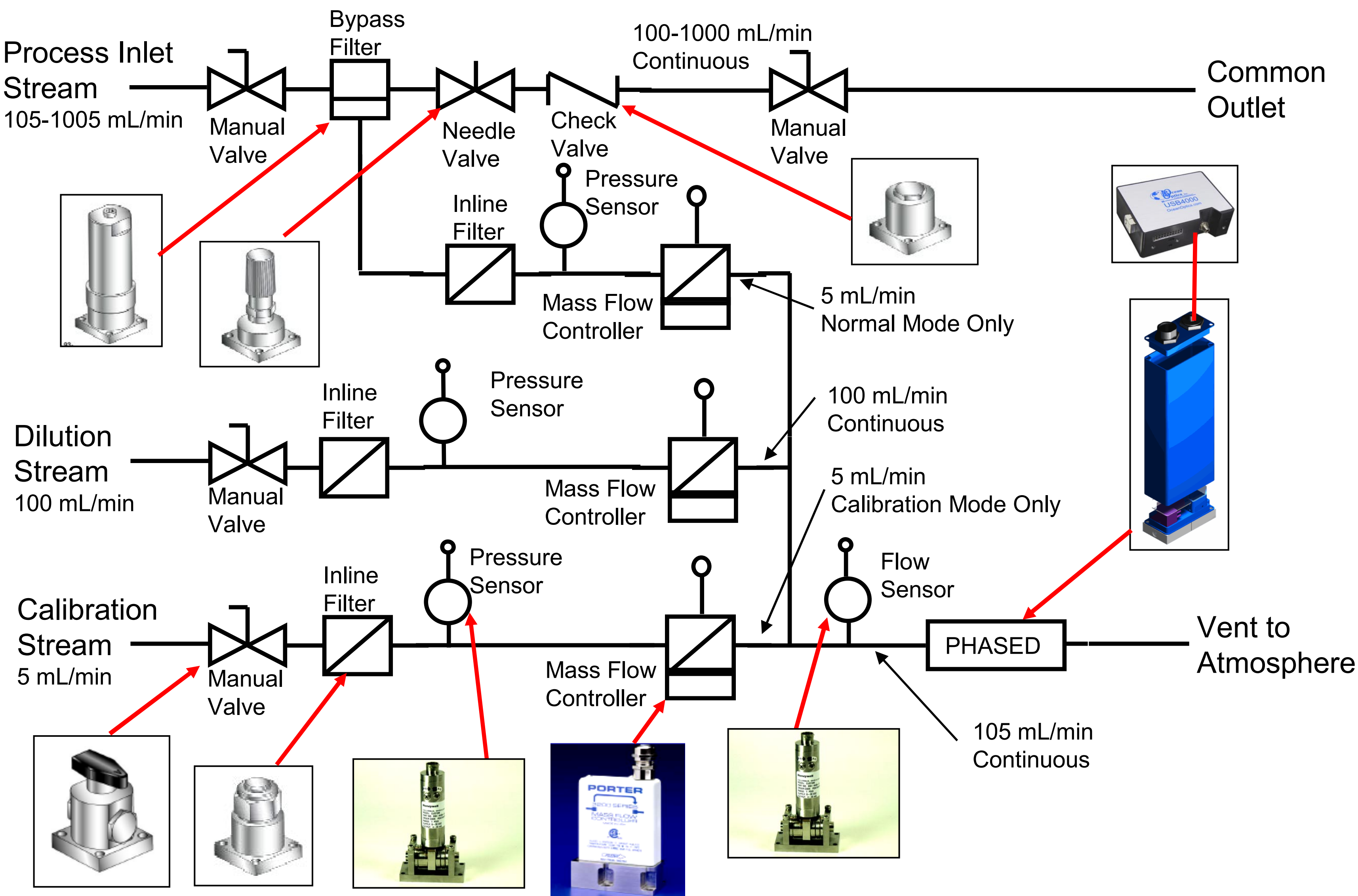
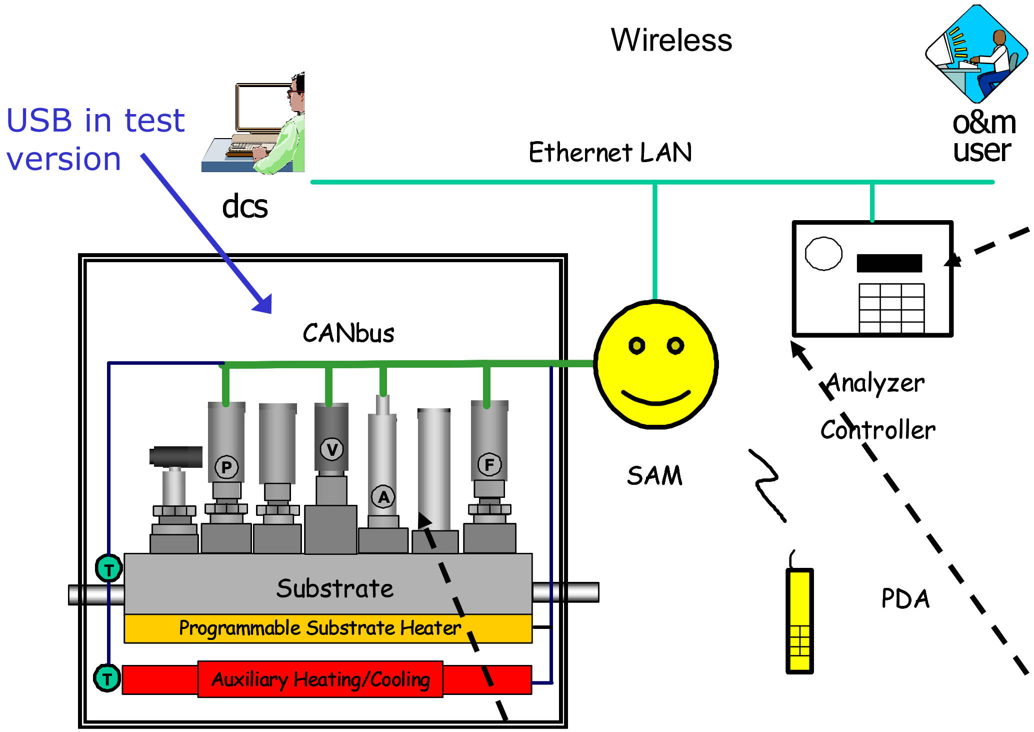
Ulrich Bonne@Honeywell.com

Honeywell Laboratories

Flow Diagram of PHASED-on-NeSSI



PHASED-on-NeSSI Software Architecture



PC (Purchased & HLabs):

- Chromatography set-up
- Maintenance and error reporting
- Communication
- Cycle control
- Integration
- 2-D Quantification
- Calibration

These functions move to SAM in production versions

SAM (Purchased):

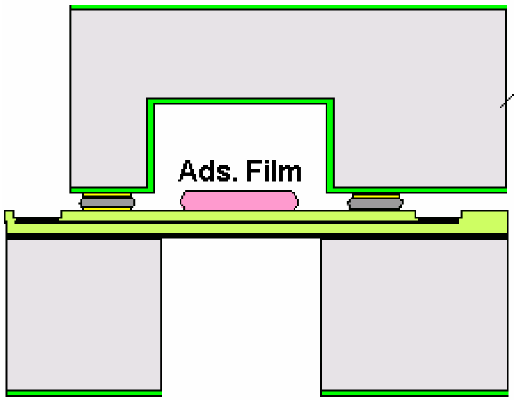
- Communication
- Analog I/O

All SAM functions move onto PHASED in non-NeSSI versions

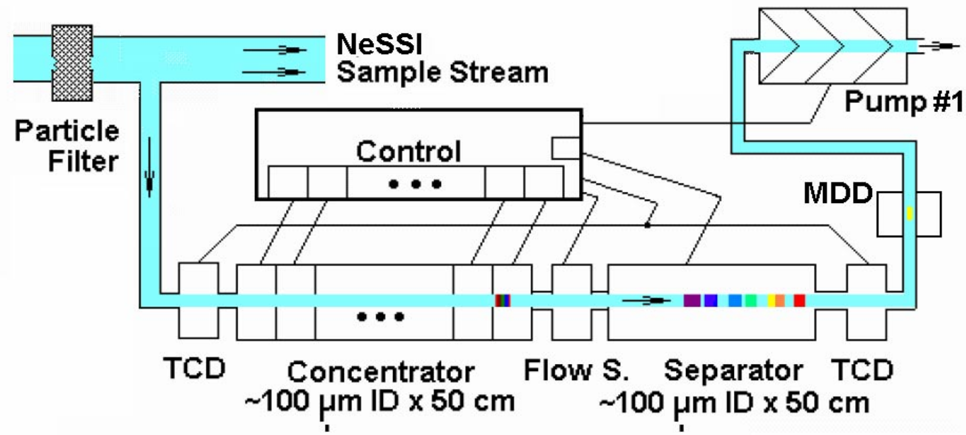
PHASED (HLabs):

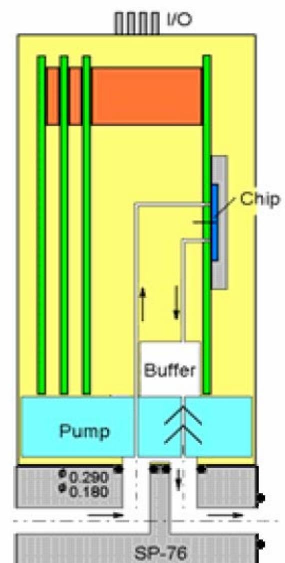
- Device control
  - Temperature
  - Pulse rate
  - Injection
- Communication

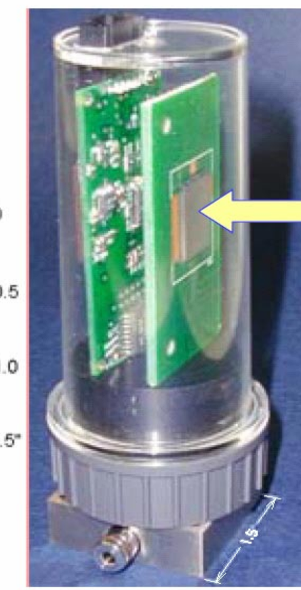
PHASED Analyzer and Device Packaging

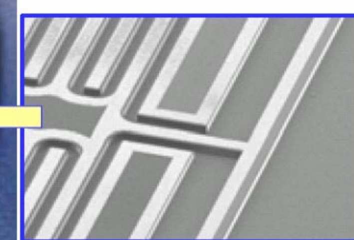


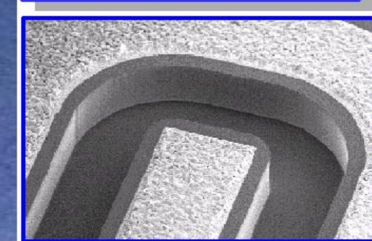
PHASED Cross Section





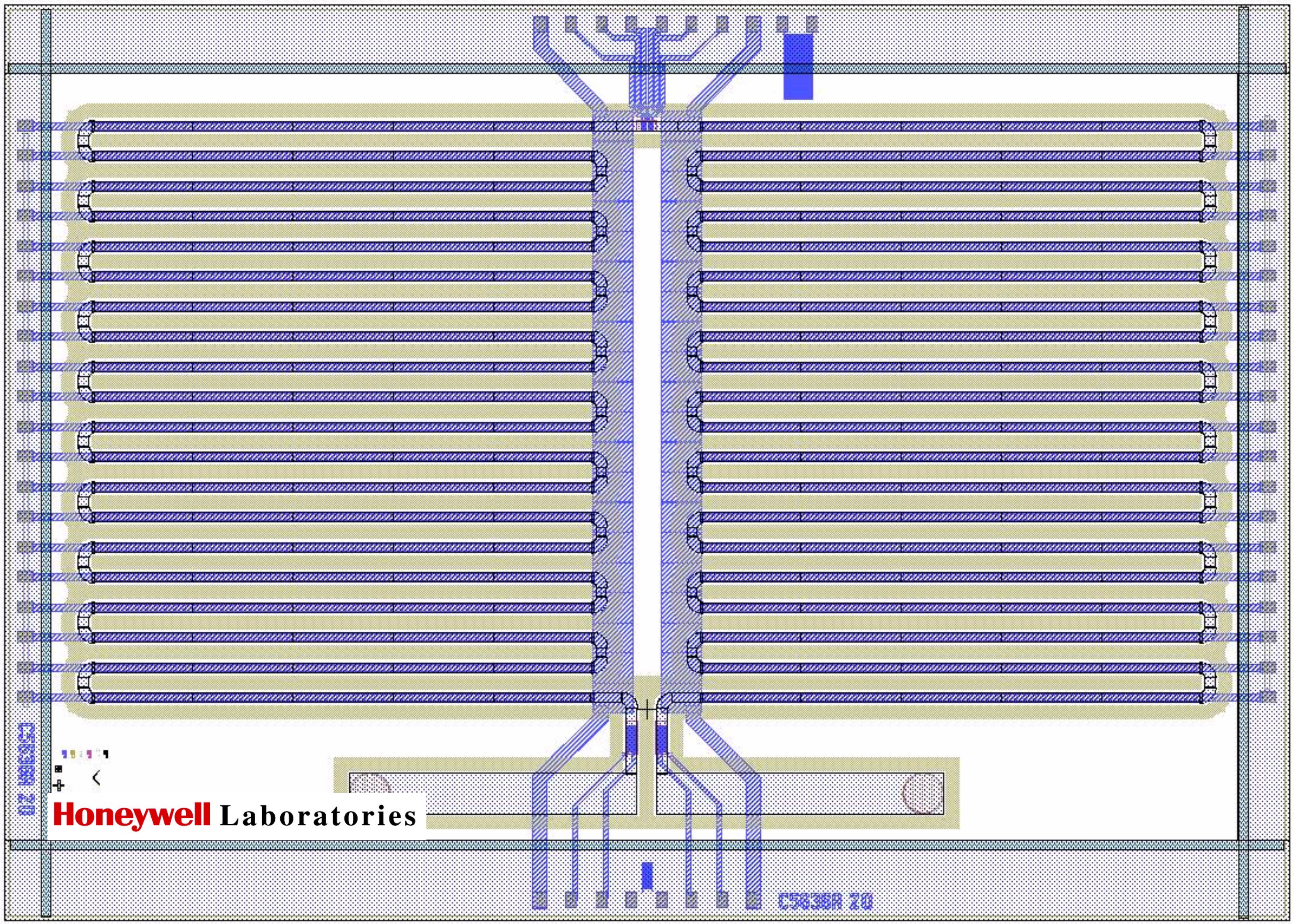






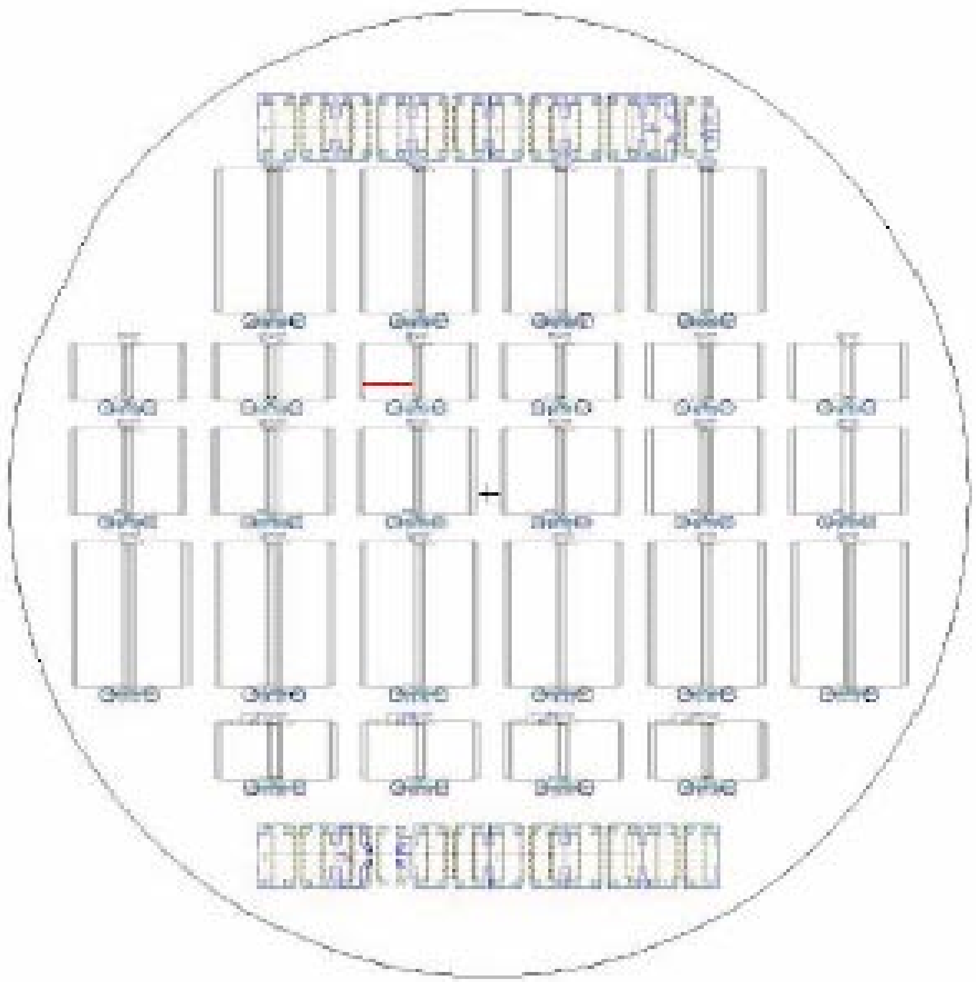
NeSSI

PHASED MGA Gen.1, with Integrated Sensors, Concentrator and Separator.

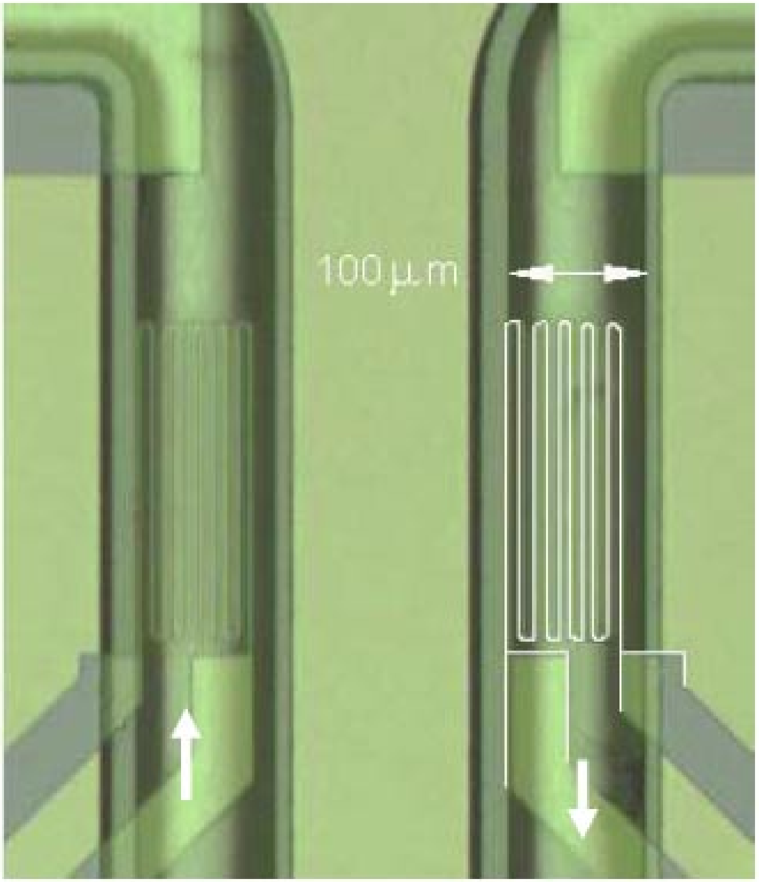


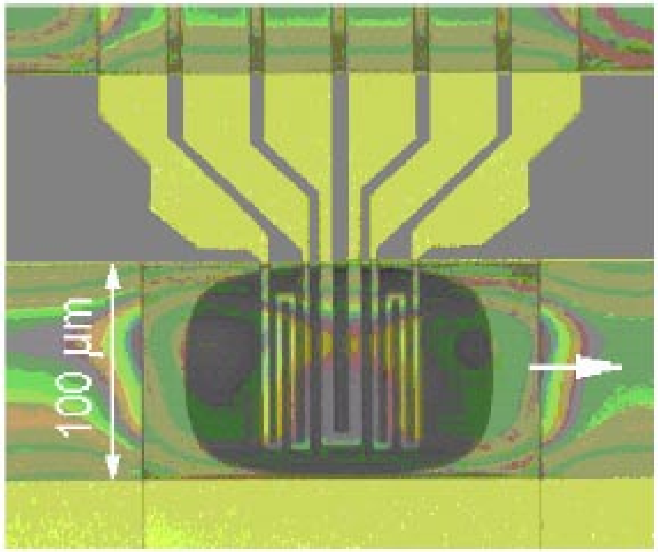
20-Element Pre-Concentrator, Diff. TC, 20-Element Separator

Layout of PHASED on a 4” Wafer



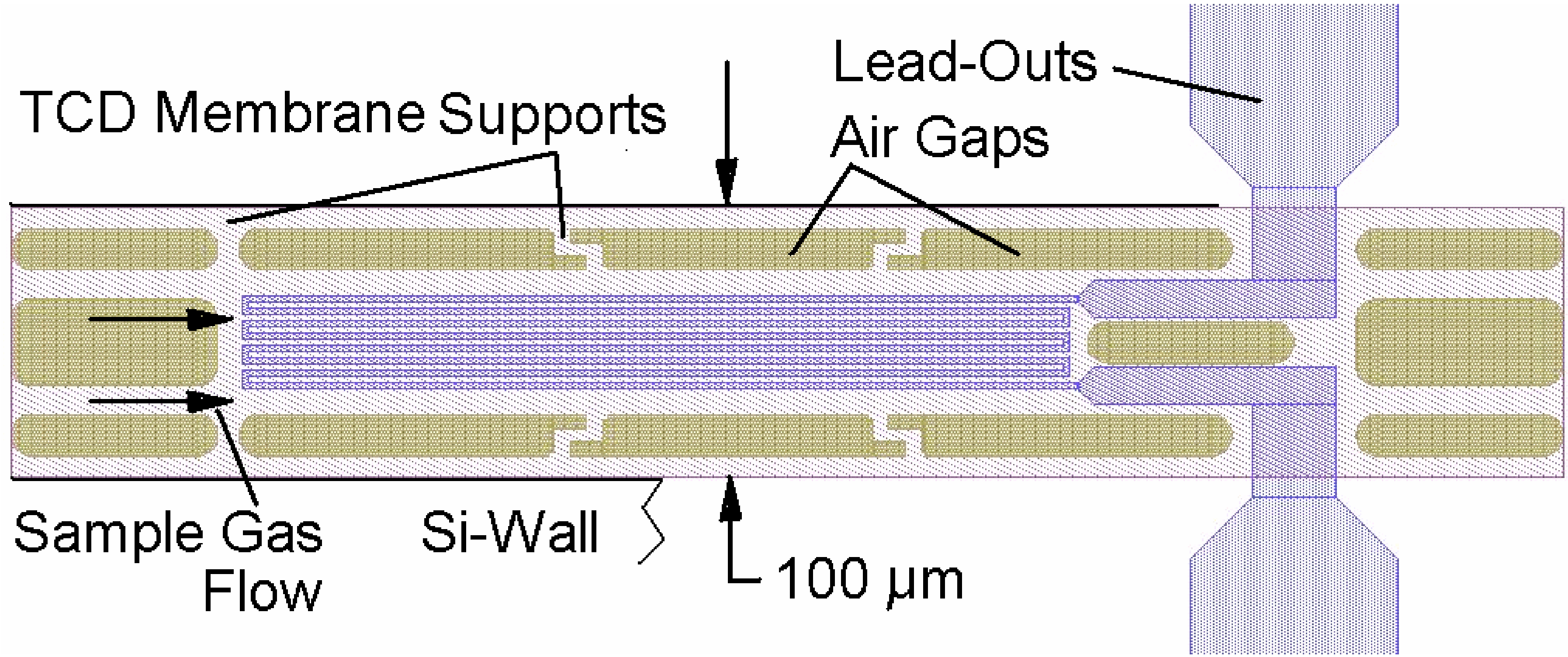
Sensors Integrated into PHASED





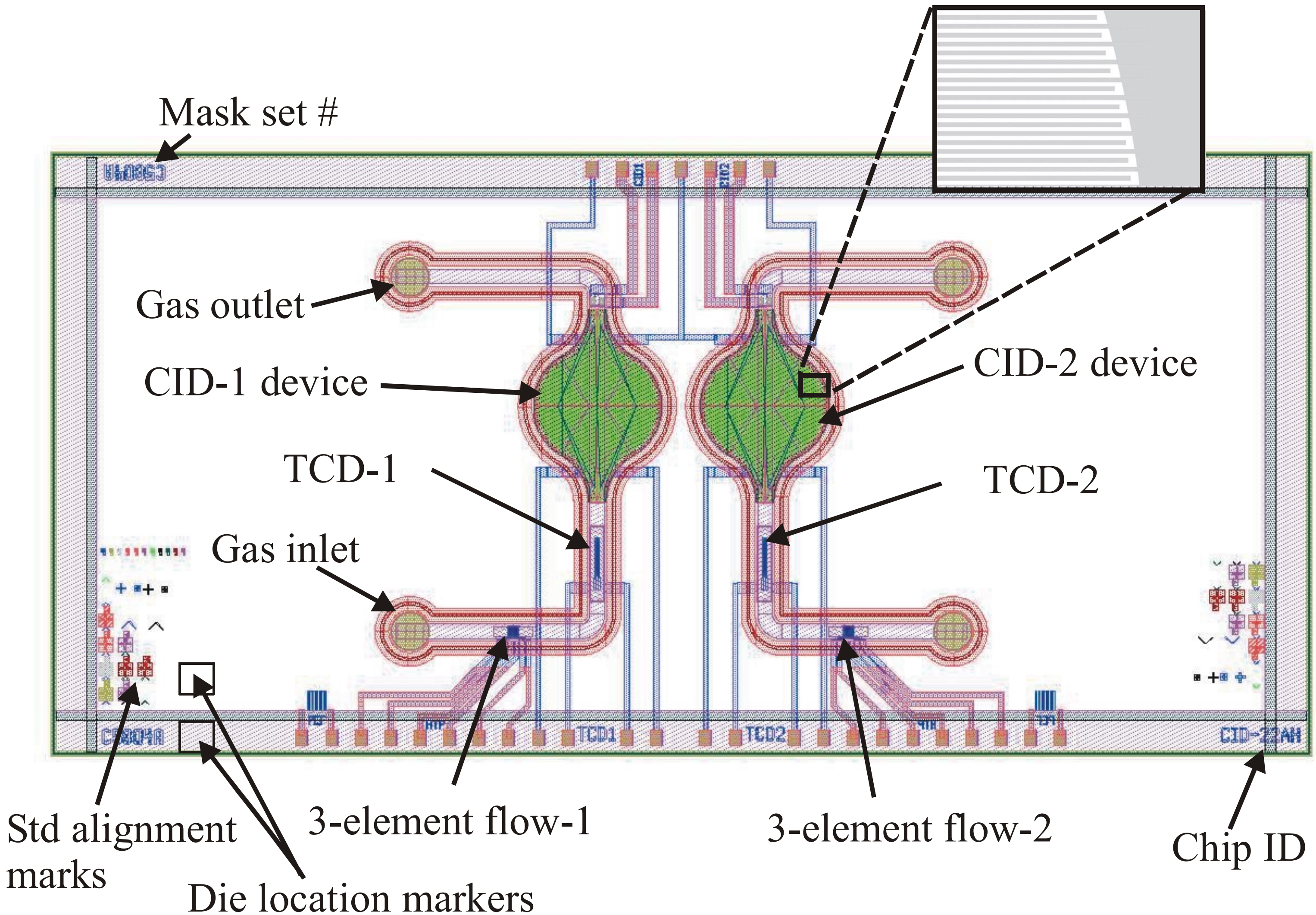
PHASED ~100x250 µm TCD & 100x72 µm Flow Sensors
on a 1-µm Membrane, in a 100-µm Channel

Improved TCD Design: Better Thermal Isolation

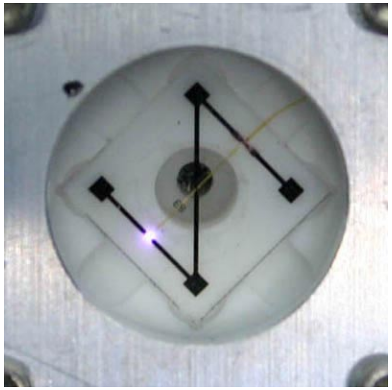


Sensitivity gain due to: Thermal barrier created by air gaps.
Two-sided gas contact

New Chemical Impedance Detector Design

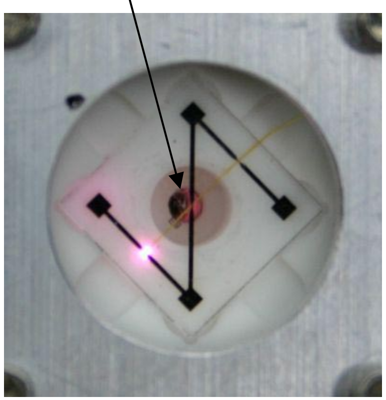


Micro-Discharge Detector Performance



CO_2 Discharge

Fiber Optic Cable



He Discharge

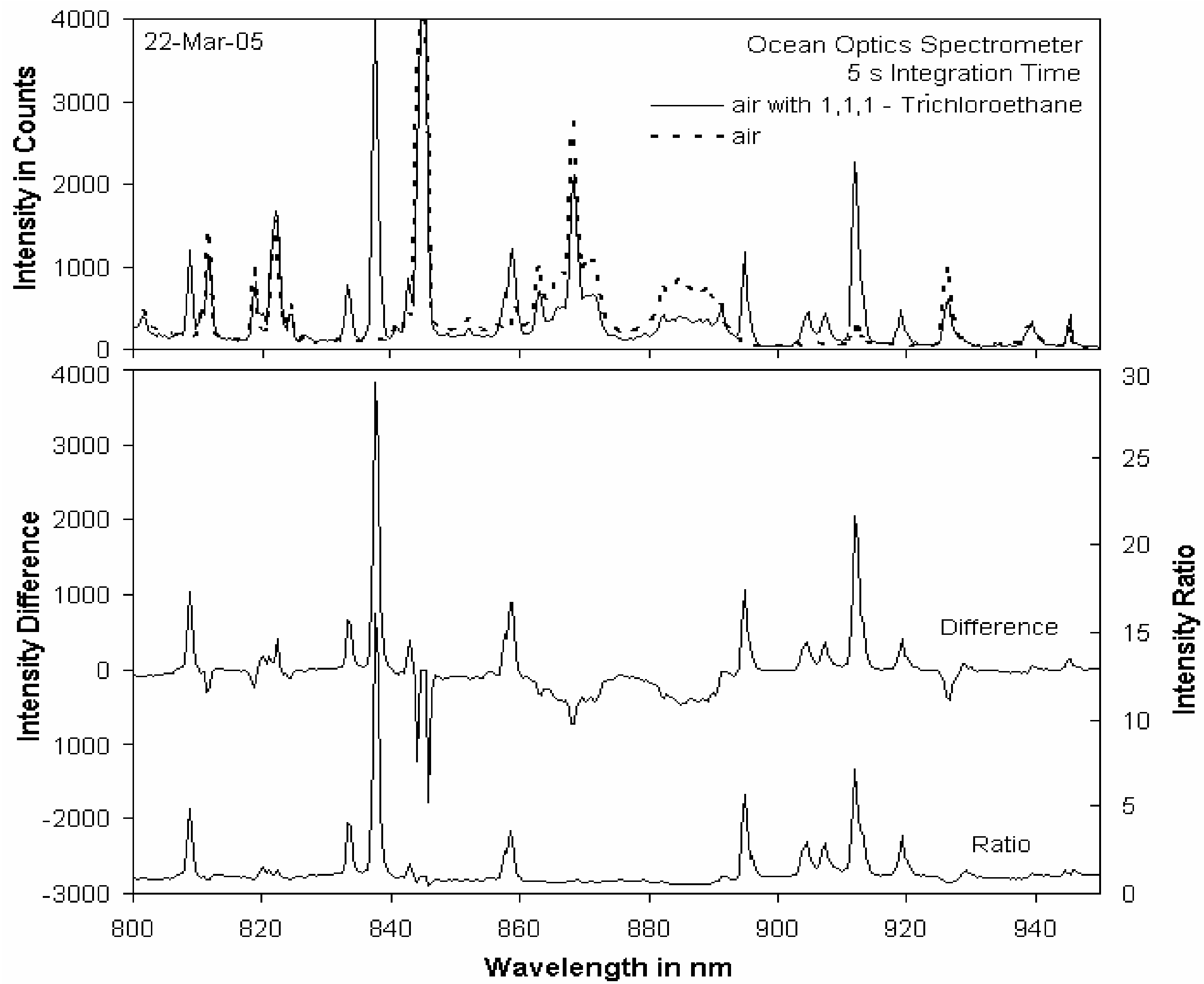
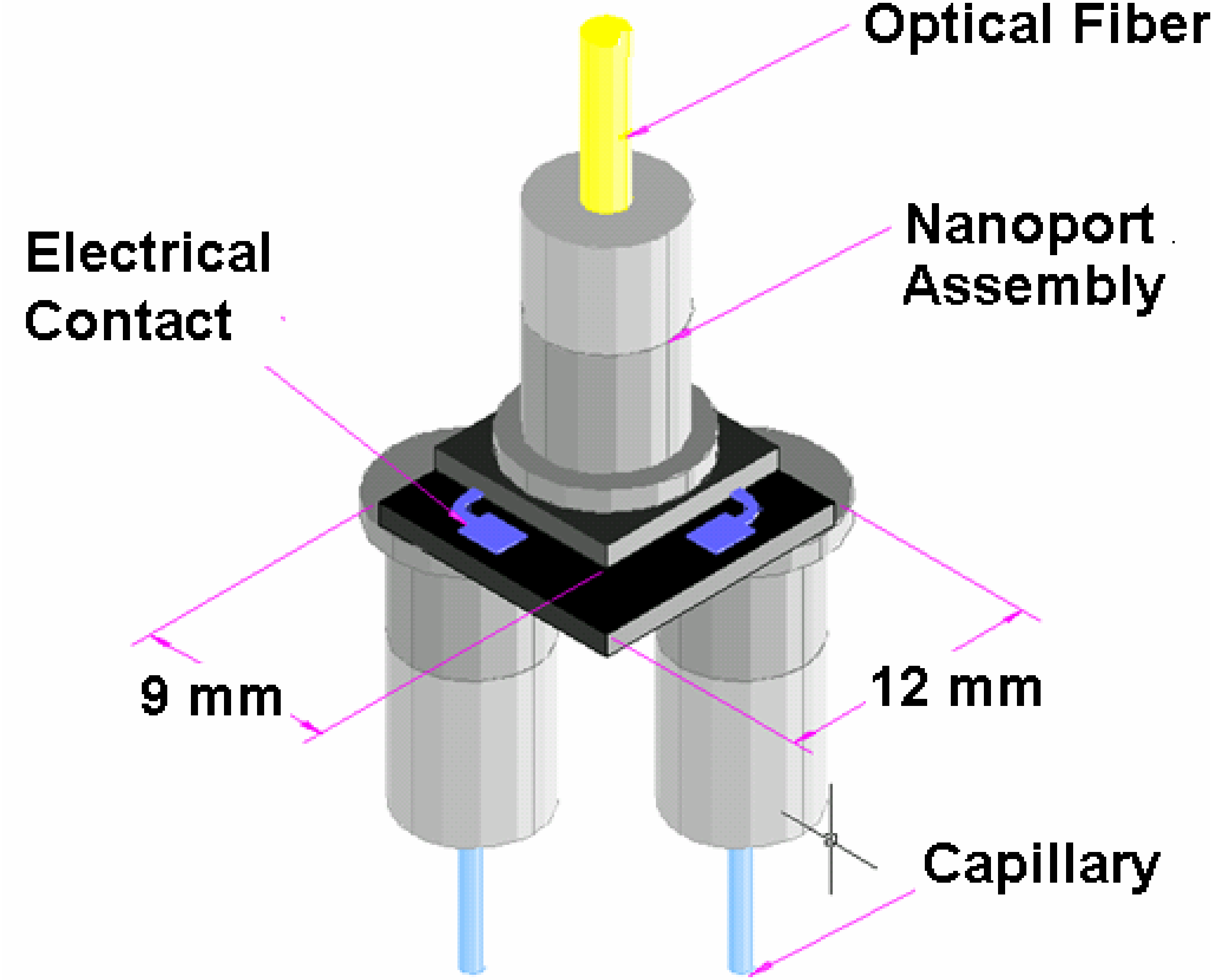


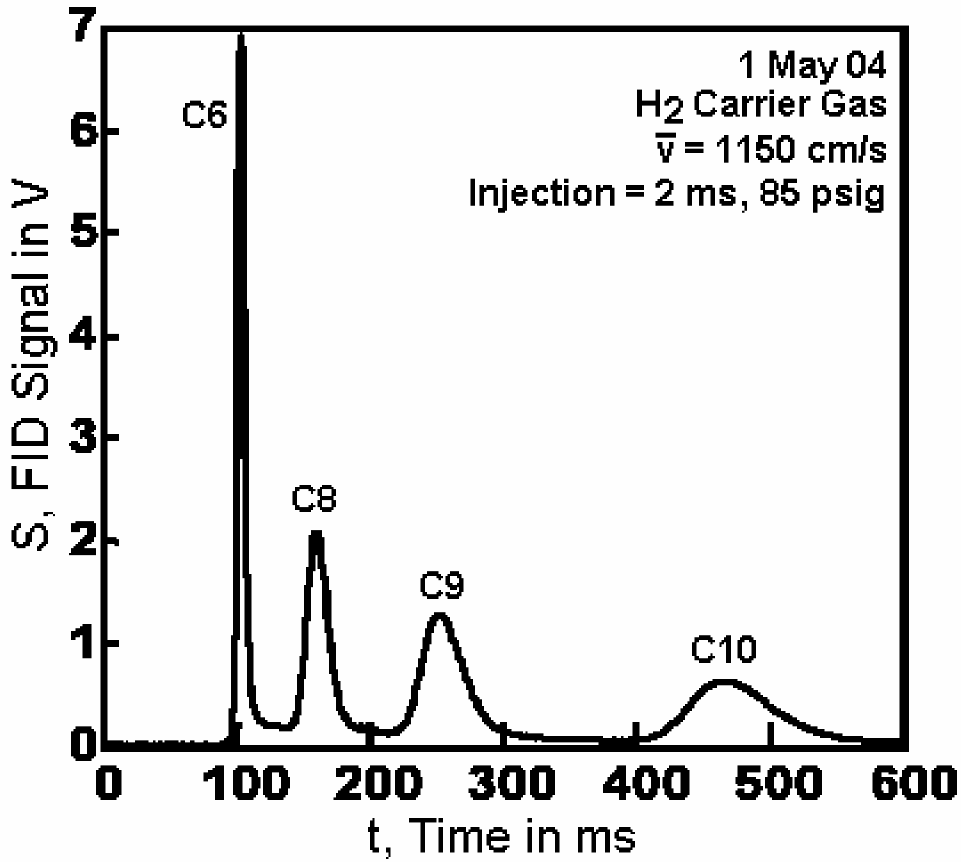
Fig. 3. MDD Trichloroethane Detection In Air. By Caviton, Inc.

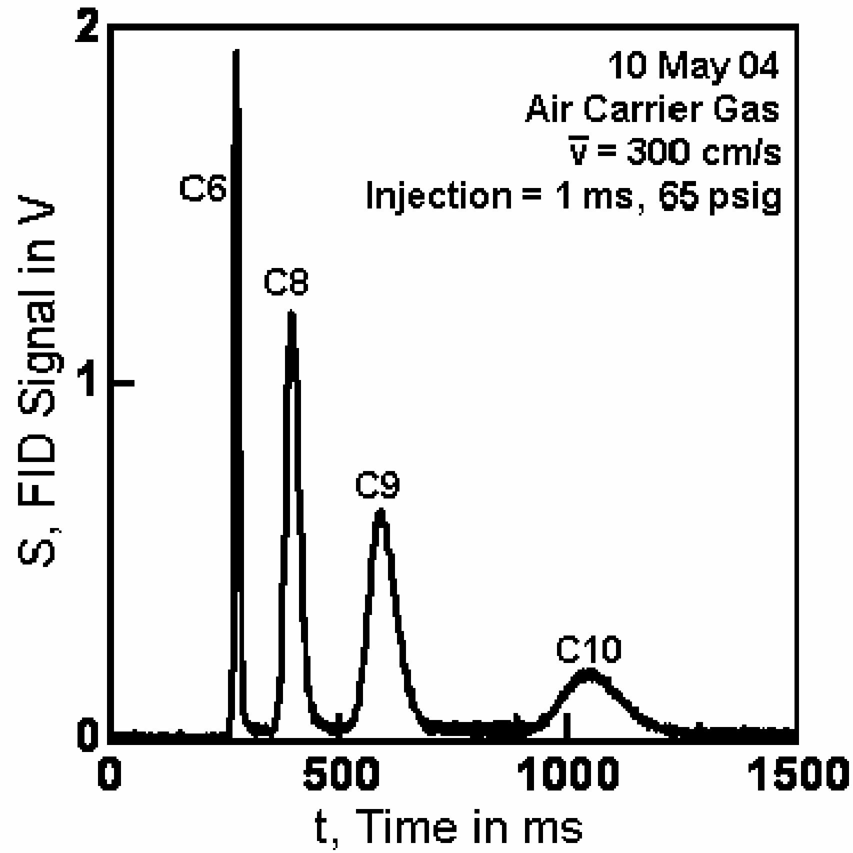
Improved MDD Package Design



Separation Performance – Nanoglass, 2004

•Separation Performance: H2 vs. Air Carrier Gas

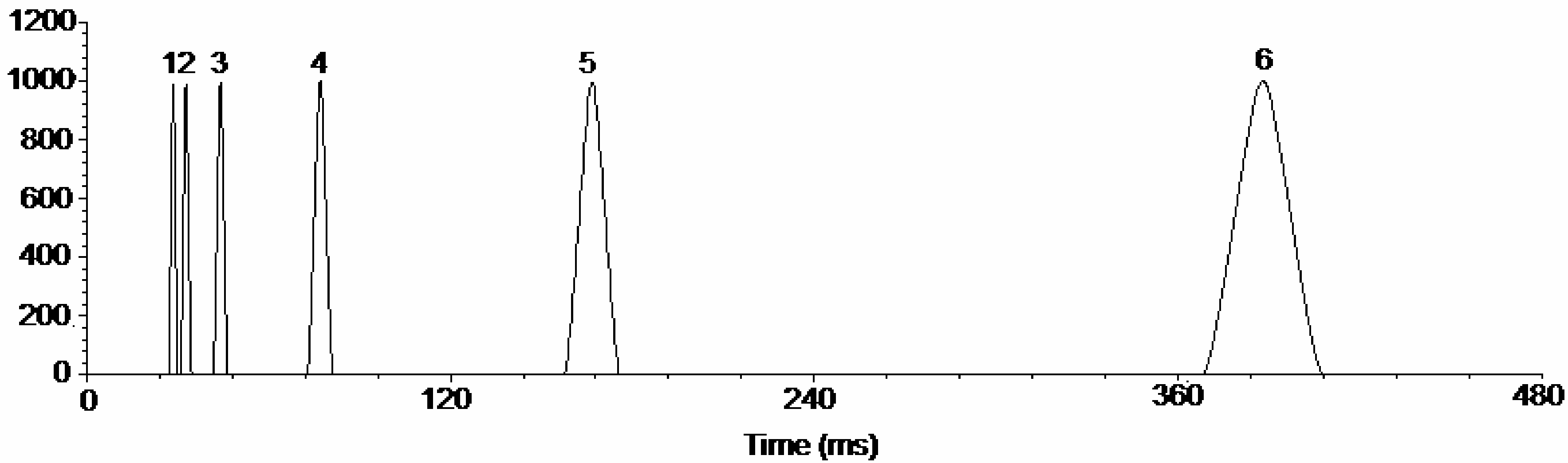




Separation of Hexane, Octane, Nonane and Decane.
Capillary #3: 1-m in length,100 μm ID, 3 μm film, 100°C, FID at 250°C, Data Rate: 20 kHz.
*Evaluation Data Courtesy G.Gross and R.Synovec, CPAC

Separation Performance Model – OV-5

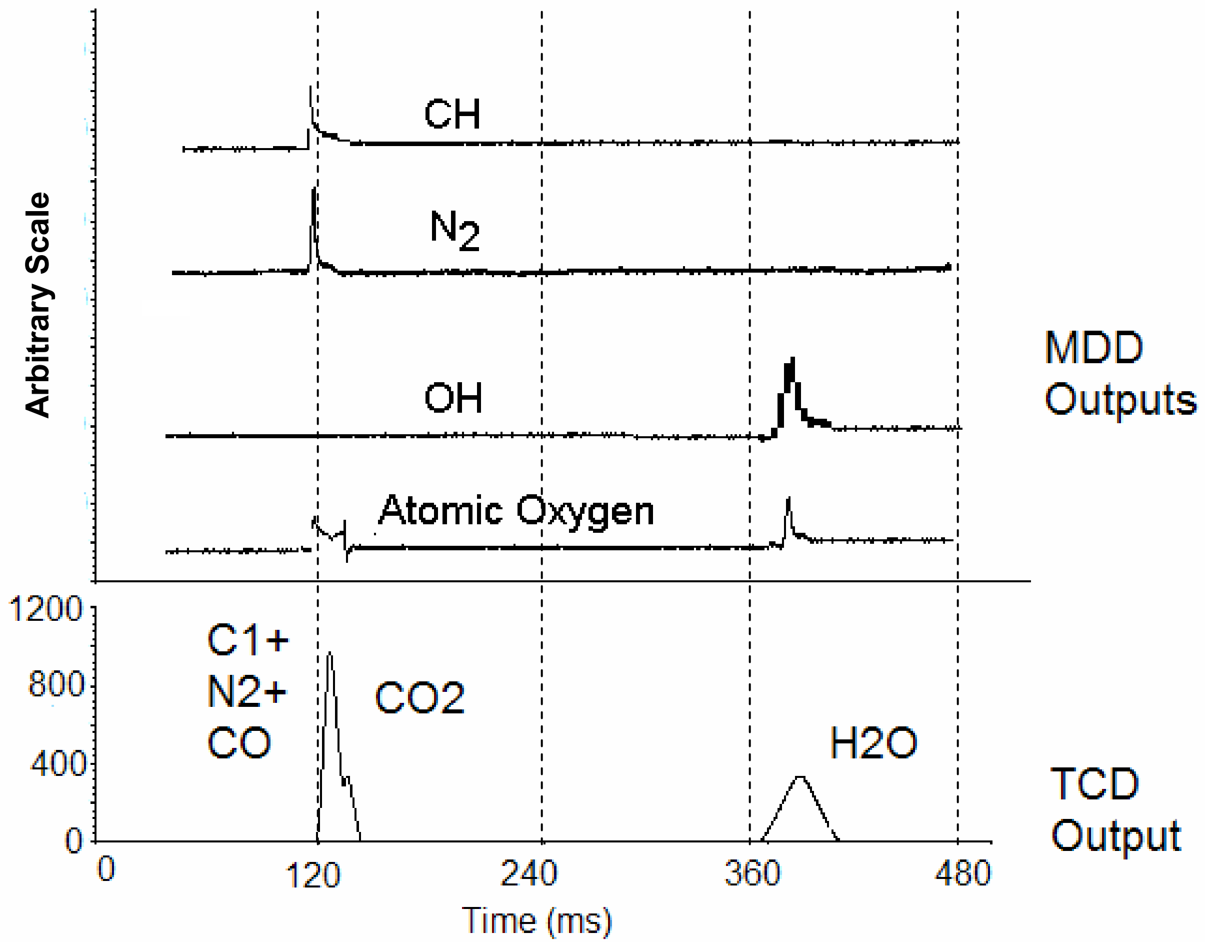
Hydrocarbon Application: Capillary: 25cm/100µm/400nm OV-5
35 to 200 °C @200 °C/min; Linear Velocity: 100 cm/s



# Component Name	tR (sec)	Width (sec)	Rs
1. Hydrogen Chloride	0.28	0.0297	1.38
2. C4 butane	0.33	0.0342	1.38
3. C5 pentane	0.44	0.0460	3.11
4. C6 hexane	0.77	0.0806	6.79
5. C7 heptane	1.67	0.175	10.54
6. C8 octane	3.88	0.376	12.11

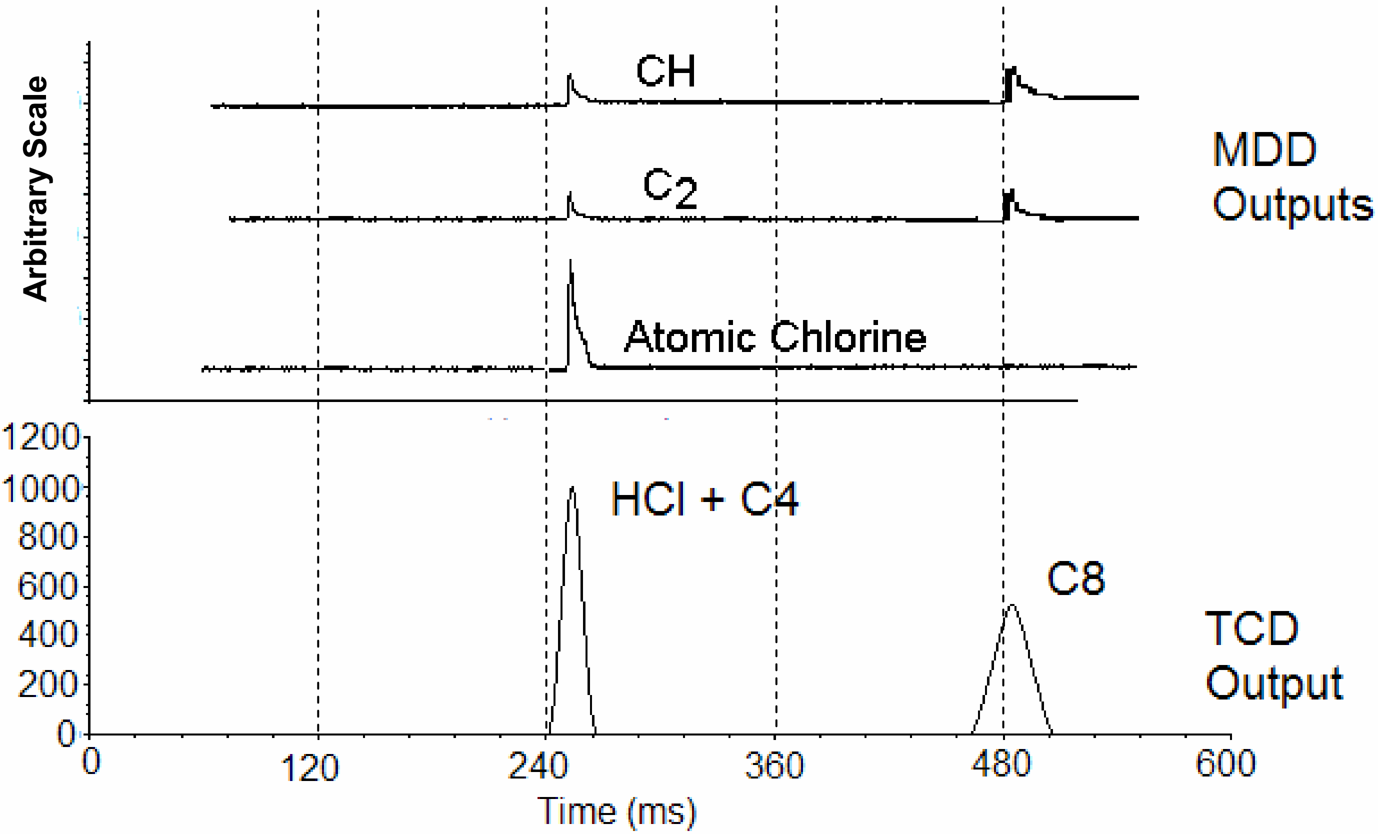
Separation and MDD Output Model – Appl. 1

Air Products Application: Capillary: 25cm/100μm/100nm OV-5
30 °C Linear Velocity 100 cm/sec



Separation and MDD Output Model – Appl. 2

UOP Application: Capillary: 25cm/100µm/20nm OV-5
30 °C Linear Velocity 100 cm/sec



Barriers and Pathways

- **PHASED:**
  - Presently available stationary phases (PDMS) were developed for coating capillary columns and not for MEMS processing and patterning for μGCs
  - FID incompatible w/MEMS microminiaturization and portability
- **NeSSI:**
  - Communication protocol
  - Availability of components and IS certifications

- **PHASED:**
  - Interim use of new, patter-nable nano-porous organo-silicate film; processing of PDMS now also possible, with better thickness control
  - Alternatives such as TCD and MDD offer integratability, speed, sensitivity and greater orthogonal channel capacity (OCC)
- **NeSSI:**
  - USB to SAM, Ethernet to PC
  - Use available, safe area components and limit test sites to safe areas

Energy Savings

- How will energy be saved? Industrial Process Plants benefit from in-situ sampling, more affordable and faster sensing, tighter control, fewer upsets, less product waste. We analyzed 8 specific applications to determine the total energy savings, resulting in:
  - **Tighter control of operational parameters: 78 TBtu/year**
  - **Upset avoidance: 3.7 TBtu/year**
- Assumptions used in calc.:
  - **Extrapolation based on ratio of energy used in example cases to energy used in the industry total**
- How much energy will be saved? The following slide shows the total for each example and the extrapolation
  - **Total savings for examples = 81.8 TBtu/year (62.0 w/o fired heaters); extrapolated total = 256 TBtu/year**

Energy Savings Summary

Table 5. Summary of Energy Savings

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Application	Ind.Group (NAICS Codes)	Type of Savings	Total Energy Consumed (MMBtu/yr)	Energy Savings (MMBtu/yr)	Energy Savings (%)	Total Energy for Industry Group (MMBtu/yr)	Saving for Industry Group (MMBtu/yr)	Energy Savings (%)	Sensors Required
Ethylene Prod.	324110	Upset Avoid. & Proc. Improv't.	656,372,200	3,692,094	2.06%	2,146,155,922	44,264,466	2.06%	Acetylene, CO, CO_2, C_1 - C_8
Metals Process.	331, 332	Waste Avoidan.	352,000,000	35,200,000	10.00%	3,005,000,000	88,260,000	2.94%	H_2O, CO, H_2, CH_4, O_2, CO_2, N_2, THC
H2 Production	325	Proc. Improv't.	283,202,150	2,347,100	0.83%	6,064,000,000	50,256,731	0.83%	CO, CO2, H_2, O_2, N_2, N_2O, C1 - C_7
TiO_2 Drying	325	Proc. Improv't.	888,462	44,423	5.00%	N/A	N/A	N/A	H_2O
Fired Heaters	324110	Proc. Improv't.	1,524,240,000	19,815,120	1.30%	4,983,844,078	64,789,973	1.30%	O_2
Al Production	3313	Proc. Improv't.	490,000,000	7,350,000	1.50%	N/A	N/A	N/A	Al_2O_3:TC Ratio
Pulp Production	322110	Proc. Improv't.	83,904,000	3,508,713	4.18%	198,000,000	8,280,000	4.18%	Inorganic Ions
TOTAL			3,390,606,812	71,957,449	2.12%	16,397,000,000	255,851,170	1.56%	
TOTAL INDUS. CONSUMPTION			23,798,000,000	71,957,449	0.30%		255,851,170	1.08%	

DoE Energy Savings Calculator Results

Summary of DoE Energy Savings Calculator Results

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Application	Industry Group (NAICS Codes)	Type of Savings	2010 Savings (TBtu)	2015 Savings (TBtu)	2020 Savings (TBtu)
Ethylene Production	324110	Upset Avoidance & Process Improvement	2.14	10.26	18.25
Metals Processing	331, 332	Waste Avoidance	2.45	6.96	16.20
Hydrogen Production	325	Process Improvement	0.52	2.73	5.35
TiO_2 Drying	325	Process Improvement	0.01	0.04	0.06
Fired Heaters	324110	Process Improvement	2.14	10.26	18.15
Aluminum Production	3313	Process Improvement	0.39	1.12	2.61
Pulp Production	322110	Process Improvement	0.45	2.06	3.49
Refigerant Production	325	Upset Avoidance	0.00	0.02	0.04
TOTAL			8.11	33.44	64.14
Petroleum Refining	324110	Upset Avoidance & Process Improvement	18.59	86.48	149.36
Metals	331, 332	Waste Avoidance	4.41	12.54	29.20
Chemicals	325	Process Improvement	7.95	38.13	67.83
Pulp Mills	322110	Process Improvement	1.06	4.84	8.19
TOTAL			32.01	141.99	254.58
% of 1998 TOTAL INDUSTRIAL CONSUMPTION			0.13%	0.60%	1.07%

Anticipated Economic Impact

- **For Helium and Hydrogen Production (one of two test sites)**
  – Total energy savings = 5.35TBtu in 2020 (**$32M/year**)
  – Total emissions reductions in 10^6 lbs/y:
    193 - Carbon, 1.419 - NOx, 0.315 - CO, 0.031 - VOCs and 0.014 - Particulates
- **For All Industries**
  – Energy Savings of = 254TBtu in 2020 (**$1.5B/year**)
  – Total emissions reductions in 10^6 lbs/y:
    10233 - Carbon, 74.63 - NOx, 12.28 - CO, 1.663 – VOCs and 1.885 - Particulates
- **For Honeywell, such data will be presented in the private session**

Value Proposition for End User

PHASED μGC on NeSSI-II provides:

- Availability, for the 1st time ever, of a GC analyzer function in the form and cost of a sensor (size, speed, simplicity, ruggedness, power, maintenance, environmental protection, cost)
- Greater affordability, speed and sensitivity, which equates to tighter process control, energy savings and lower product cost
- Wired or wireless communication with its dedicated SAM (Sensor-Actuator Manager, a local computer), which can have a wireless interface of low installation cost with the plant control room and with other plant sensors.

Other Important Metrics

of the PHASED mGC:

- **Compactness ~ 12 in.3 ~ 250 cm3 to fit on NeSSI**
- **Speed: Analysis time < 2 s, incl. pre-concentration**
- **Sensitivity: MDL < 0.1 ppm / PC Gain**
- **No carrier gas**
- **No mechanical injection valve**
- **100-300x lower power (2-5 W) than desk-top GC**
- **10x lower cost**

of the NeSSI systems:

- **Standard modules of 1.5 x 1.5" foot-print (SP-76)**
- **4 SP-76 spaces for microanalytics**
- **Communication with SAM**

Completed & Future Milestones

▪ Preconcentration feasibility	3/31/04
▪ Separation feasibility	3/31/04
▪ Demonstrated 90% wafer yield	5/ 1/05
▪ NeSSI package design	4/30/06
▪ PHASED on SP-76 Demonstration	6/30/06
▪ PHASED on NeSSI lab test	7/31/06
▪ PHASED on NeSSI field test start	9/30/06
▪ PHASED on NeSSI field test compl.	4/30/07
▪ Final Report	6/30/07

Project Status

Milestone	2003	2004	2005	2006	2007
Project Start	Δ				
Preconcentration feasibility	–Δ				
Separation feasibility	–Δ				
Development of microstructures	———	———	——Δ		
Demonstrated 90% wafer yield			Δ		
NeSSI package design			———	Δ	
PHASED on SP-76 Demonstration				–Δ	
PHASED on NeSSI lab test				–Δ	
PHASED on NeSSI field test start				Δ	
PHASED on NeSSI field test compl.				——	Δ
Final Report					–Δ

Accomplishments to Date

- **Prior Years**
  - **Demonstrated high-speed μGC pre-concentrator & separation**
  - **Demonstrated separation of H_2O, CH_4, C_3H_8, C_4H_{10}, CO_2, …., C9, C10**
  - **Modeled feasibility of separation up to C18, w/temp. ramp**
  - **Calculated adsorption enthalpies on dry & hydrated films**
  - **Demonstrated PC gain of 63x for hexane, and ~100x for CO_2; modeled PC gains >10,000 for high MW compounds**
  - **Increased PHASED chip fabrication yield to >90%**
  - **Determined that a complete PHASED μGC with electronics will fit into one NeSSI's SP-76 modules**
  - **Agreed with Users to base NeSSI device communication on Wireless or FieldBus; *however, since NeSSI components to support this are not yet available the field test uses USB***

Accomplishments to Date

- **Current year**
  - **Identified 2 test sites and applications; agreed with field test participants on gases to be pre-concentrated, separated and detected**
  - **Completed the design and fabrication of 2 PHASED µGC packages for NeSSI**
  - **Improved preconcentration with heated connections**
  - **Improved separation with OV-5 thin film material**
  - **Improved TCD with thermal isolation**
  - **Integrated MDD into PHASED-on-NeSSI for 2-D detection**

Next Project Steps

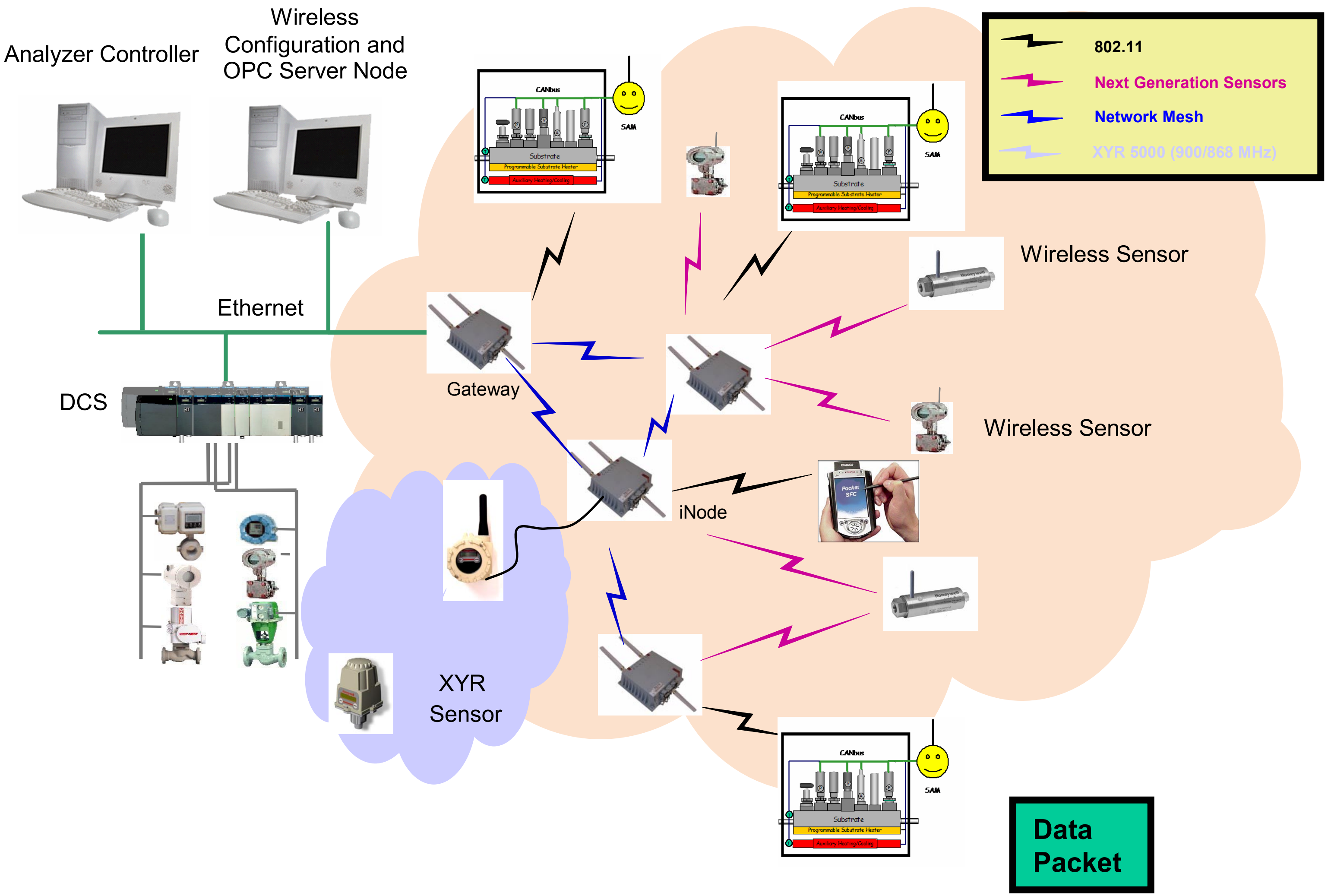
- **Current Year (Cont)**
  - Started development of a Chemical Impedance Detector as an alternative to the TCD
  - Developed electronics for PHASED in NeSSI package
  - Designed, started programming and debugging the PHASED-μGC output software
  - Designed, programmed and debugged the PHASED-NeSSI-SAM interface software
  - Developed commercialization plan for all markets

- **Remaining**
  - Complete the assembly, testing and setup of 2 PHASED μGC packages for field test
  - Start and complete field tests
  - Final report

Continuation after ITP-Sponsored Project

- **The technology developed under this project will be commercialized, provided the PHASED-on-NeSSI field tests are completed successfully.**
- **Discussions with BUs about PHASED and NeSSI manufacturing, and marketing, distribution, sales and service have been held and internal Honeywell funding is being sought to deploy PHASED into a wide market area.**

PHASED MGA with Wireless Communications



Technical Risks Remaining

- **PHASED Applications: Demonstrate the ability of PHASED to perform the needed separations, sensitivities and service life**
  - **Reaching a broad set of applications requires a selection of column phase materials. To date, we have successfully deposited two (OV-5 and Nanoglass). Some form of granular material such as a HayeSep variant, Molesieve, or a CarboPack material would be helpful, but experiments to date have not produced sufficiently smooth depositions.**
  - **For analysis of liquids, the development of a PHASED vaporization capability would be needed**
- **Sampling via NeSSI: A family of appropriate NeSSI components must exist. This is currently assumed but is developing very slowly – however, PHASED can be deployed without NeSSI.**
- **Certifications: Appropriate certifications must be met for each major market. An IS version of NeSSI may evolve; demonstrate an IS version of PHASED.**

Commercialization Plan

- **PHASED represents a new and significant commercial opportunity to Honeywell and it's customers.**
- **A partnership with Parker-Hannifin is in place to develop, integrate and commercialize NeSSI hardware and its communication links (wired and wireless).**
- **Microfabrication of PHASED and its electronics will be transferred to one of three in-house Si-foundries**
- **Further development of PHASED as a commercial set of products will be transferred to Business Units that have strong positions in industrial, air quality, medical and defense applications.**
- **Both NeSSI and non-NeSSI products are envisioned from PHASED.**
- **A more detailed presentation is scheduled for the private session**

Competitive Comparison – Traditional Suppliers

Comparison between PHASED and Traditional Competitors							
	Units	PHASED	Baseline	Emerson 700	Siemens uSAM	Yamatake	ABB
Approach	-	GC in Si	Std. GC	Standard GC	Standard GC	BTU GC	Standard GC
Integration	-	PCB	Portable/Bench	EXP Box	EXP Box	Exp Box	Purged
Preconcentration	Stages	20-50-Stages	None	None	None	None	None
Injection Method	-	2-6-ms Thermal Desorb	Valve	Mechanical	Valveless	Mechanical	Mechanical
Volume	nL	< 50	500?	500+	500+	500+	500+
Carrier Gas	Gas	None/Air		H2, He or N2	H2, He or N2	He	H2, He or N2
Size	-	2 NeSSI Slots	18 X 16 X 9"	15"x7"x36"	10"x9"	3.9"x4.5"x9.6"	19.5"x13.4"46.3"
Analysis time	sec	1 to 4	60-300	60-300	60-300	300	60-300
Column Length	cm	10 to 25	Various	Various	Various	Various	Various
Col./Channel ID	µm	100	Std Capillary or Packed	Std Capillary or Packed	Std Capillary	Std Capillary or Packed	Std Capillary or Packed
Film Thickness	µm	<0.1	Various	Various	Various	Various	Various
Stationary Phase	-	OV-5	Many	Many	Many	Several	Many
Column Temp.	C	25 - 400	25-150	25-100	??	??	25-289
Temp Program		Yes	No	No	No	No	Option
Detector		TCD, Ion Trap, MDD	PID, FID, TCD	TCD, FID	TCD	TCD	TCD, FID, FPD
Flow Rate	sccm	0.5 - 1	Appl Dep	Appl Dep	Appl Dep	50	Appl Dep
Energy/Analysis	J	1 to 10	?	1980 Min	900 Min	7500 Typ	50,000 Min

Competitive Comparison – Emerging Devices

Comparison between PHASED and Emerging Competitors						
	Units	PHASED	SLS	AFSI	Sandia	Graf Z-Nose
Approach	-	GC in Si	GC in Si	GC in Si	GC in Si	Std. GC
Integration	-	PCB	PCB	Portable	Portable	Portable/Bench
Preconcentration	Stages	20-50-Stages	None	Yes	Yes	Yes
Injection Method	-	2-6-ms Thermal Desorb	Mechanical	Pump, Thermal Desorb	Thermal Desorb	Valve/Thermal Desorb
Volume	nL	< 50	500	?	?	?
Carrier Gas	Gas	None/Air	H2, He or N2	H2, He or N2	Air	He
Size	-	2 NeSSI Slots	3 x 5" PCB	16 X 9 X 5"	8 X 4 X 2"	12 X 10 X 7"
Analysis time	sec	1 to 4	< 60	< 60	30-60	< 60 Cycle
Column Length	cm	10 to 25	86	500 - 2000	100	?
Col./Channel ID	µm	100	~100	100 - 200	Micro-machined, 50-100	?
Film Thickness	µm	<0.1	?	?	Variable	?
Stationary Phase	-	OV-5	Several	DB-1, DB-5, DB-54, DB-Wax	Several, coated or packed	?
Column Temp.	C	25 - 400	25 - 250	25 - 350	25 - ?	25-125
Temp Program		Yes	Yes	Yes	Yes	Yes
Detector		TCD, Ion Trap, MDD	FID	Glow Discharge, TCD	SAW	SAW
Flow Rate	sccm	0.5 - 1	0.1 @ 30 psia	?	?	Appl Dep
Energy/Analysis	J	1 to 10	480	?	?	?

Overview of Commercialization Plan

- **The Commercialization Plan covers many aspects of getting PHASED from a government funded research project to a series of product development projects, and then into commercial production**
- **The areas covered are**
  - Market size estimates
  - Manufacturing approach
  - Industrial markets (refining, petrochemical and chemical; natural gas; mining, metals and minerals; pharmaceutical)
  - Air Quality markets (buildings, commercial aircraft and military platforms)
  - Handheld (chemical weapons detection and medical breath diagnosis)

Commercial Risks Remaining

- **New MicroAnalytics: Despite past sales of industrial GCs, launching new microanalytics devices requires investment to establish marketing, distribution, sales, and service support, especially across the number of markets identified for PHASED**
- **NeSSI: Wide adoption of NeSSI in the conservative industrial marketplace is slow. According to a mini-VOC conducted by Honeywell, support for NeSSI at the plant level is still emerging; this Project could have helped to provide more of the needed field test data, before cutting back from 12 to 2 NeSSIs. Without a standard sampling systems such as NeSSI, deployment at many measurement points may require some additional packaging development.**
- **Competition: Competitors are continuing to develop products that could threaten PHASED. We are tracking a number of both new and established competitors. However, many customers demand multiple-source supply.**

Showcasing Opportunities

- **Two field tests are being prepared and will be in place by October 2006**
  - Air Products, **Helium impurities**, in Manalapan, NJ
  - UOP (Honeywell), **HCl in alkanes**, in Des Plaines, IL

Addendum – Discussion Items If Needed

- **The following slides are provided as backup only**

Electronics for PHASED on NeSSI

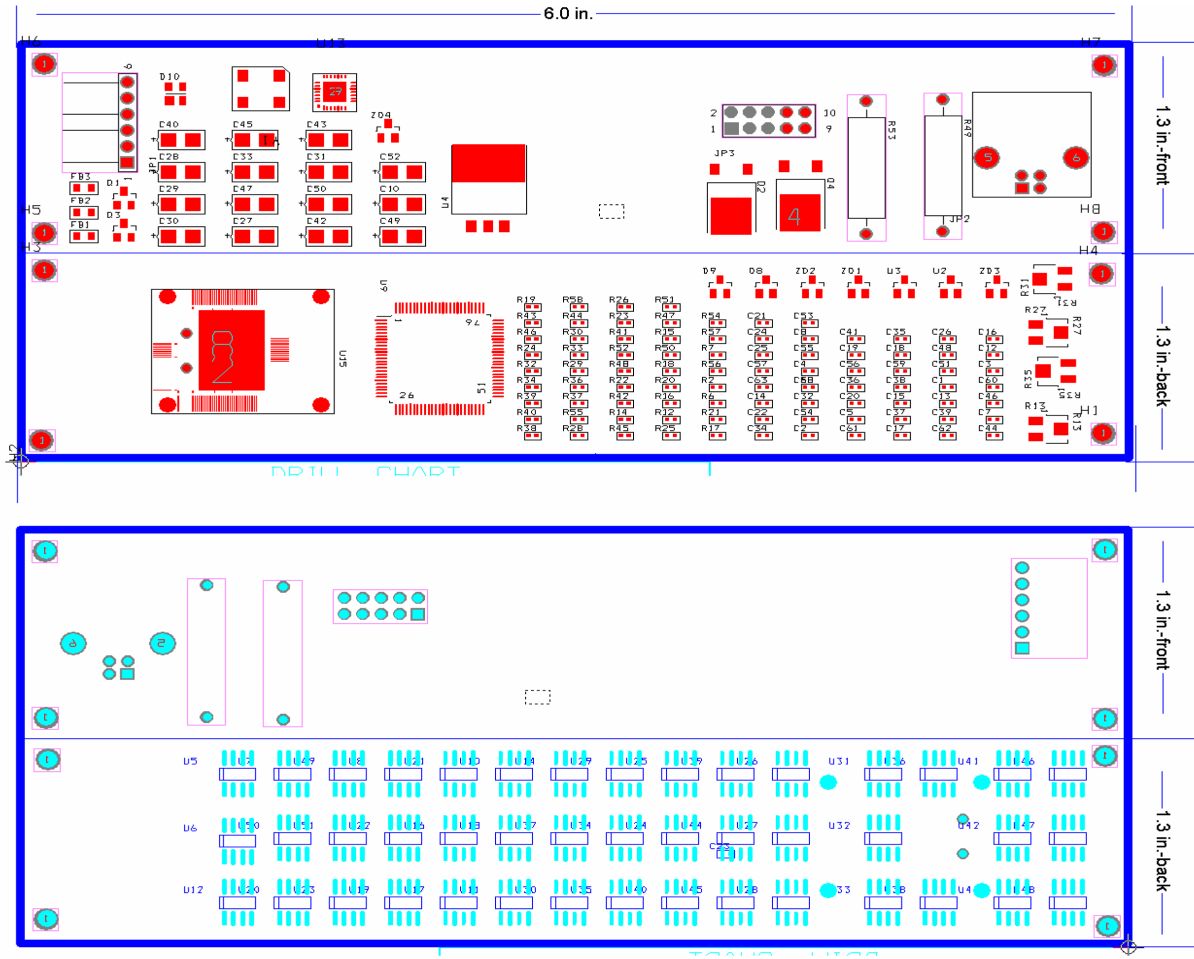
Features:

- Individual control for concentrators, up to 30
- Integrated 12-bit A/D, up to 8 channels
- TCD, flow, CID, and temperature sensor circuits
- Dual power supply (+10V up to +30V/ -5V down to -12V)
- USB/RS232/SPI
- Ramp up temperature of separators
- Variable voltage for separators and PCs
- All package components are standard. except for PHASED chip

Issues:

- Coupling of capillary from PHASED chip to detectors and pump
- Circuits for MDD and MESO-Pump are not included (see next slide)

2 (6X1.3 in) boards -1.5 cm apart



Circuit by F.Nusseibeh

Validation of Separation Model