NTRD Program Disclaimers

1. Disclaimer of Endorsement:

The posting herein of progress reports and final reports provided to TCEQ by its NTRD Grant Agreement recipients does not necessarily constitute or imply an endorsement, recommendation, or favoring by TCEQ or the State of Texas. The views and opinions expressed in said reports do not necessarily state or reflect those of TCEQ or the State of Texas, and shall not be used for advertising or product endorsement purposes.

2. Disclaimer of Liability:

The posting herein of progress reports and final reports provided to TCEQ by its NTRD Grant Agreement recipients does not constitute by TCEQ or the State of Texas the making of any warranty, express or implied, including the warranties of merchantability and fitness for a particular purpose, and such entities do not assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information,apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights.

New Technology Research & Development Program
Grant Contract 582-5-65591-0007

Task 3 Deliverable Report

The preparation of this report is based on work funded in part
by the State of Texas through a Grant from the
Texas Commission on Environmental Quality.

Task #3
Design of Retrofit System for one Engine Family for CAT 3406B & CAT 3126

Contract No. 582-5-65591-0007

December, 2006

Report Prepared by:
Converter Technology, Inc.
155 Factory Road
Michigan Center, MI 49254

Design of Retrofit System for CAT 3126

This report summarizes engineering, development, and design work related to the Emission Control Strategy developed by Converter Technology Inc. (CTI), including the Mobile Data Acquisition System, for CAT 3406B and CAT 3126 diesel engines.

This report addresses the major components with emphasis on the system upgrade for the CAT 3126. Where it is possible some components could be used for the CAT 3126 and the CAT 3406B; others cannot be utilized for the CAT 3216 diesel engines as explained below. The major components are:

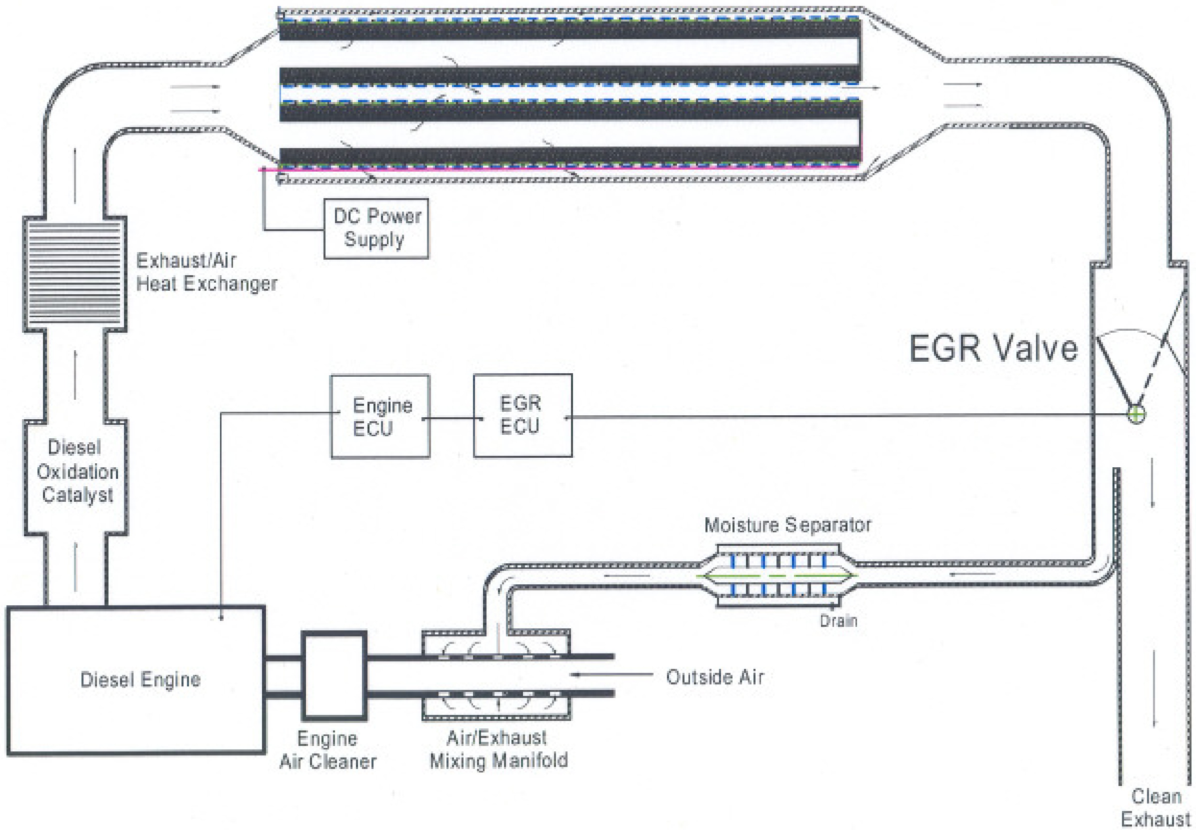
1. Diesel Oxidation Catalyst
2. Particulate Converter & Exhaust Cooling System
3. EGR System & Moisture Separator

The following components were developed and designed for the purpose of verification and measuring actual NOx reduction on-the-road. These are:

4. Mobile Data Acquisition System
5. 3" Venturi Meter for the Measurement of exhaust mass flow in time domain.

The following itemization addresses each component in detail and summarizes the design aspects as well as other issues that relate to construction and operability as needed.

CTI Retrofit System for PM & NOx Reduction



1.0 Diesel Oxidation Catalyst (DOC)

Diesel oxidation catalysts are standard, off the shelf products. Converter Technology investigated at least six suppliers. Of these suppliers, two are considered to have adequate products. These are:

1. Engine Control System (ECS) of Ontario, Canada
2. Aristo Catalyst Technology of Hobart, Indiana.

ECS's oxidation catalyst have been verified by EPA in previous applications by ECS, but their costs are very high (approaching over $1,800 per unit). On the other hand, Aristo Catalyst Technology is willing to supply all of their precious catalyst loading data to CTI and EPA. Their costs, however, are close to $900 per unit. CTI is contemplating the use of Aristo's DOC since the cost of the unit is a major concern and it is CTI's judgment that the role of a DOC in the overall system performance is less critical than with other systems.

Severe Duty AZ Purimuffler™ Product Dimensions

Product Sizing

Step 1: If available, use the actual Engine Intake Airflow (SCFM) from the original engine manufacturer (OEM) and locate this value in the included product charts to obtain the proper product model for your engine. If you do not have the actual OEM Engine Intake Air Flow, use the general equation below to determine the approximate value. Locate this value in the appropriate product sizing chart.

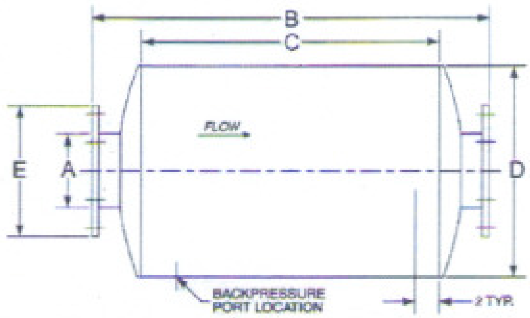
Step 2: If your Engine Intake Air Flow is found in the range of two models of purifier, exhaust backpressure and equipment duty cycle should be used as a guide to choose the appropriate product model. In general, the larger model of purifier will provide improved carbon monoxide (CO) and hydrocarbon (HC) reductions and lower exhaust back-pressure.

$$\text{Engine Intake Airflow (SCFM)} = \frac{\text{Engine Displacement in Liters} \times \text{RPM} \times V_E}{14.16 \times \text{Engine Cycle}}$$

RPM = maximum or governed rated speed of engine

Engine Cycle = 2 for two-stroke engines
4 for four-stroke engines

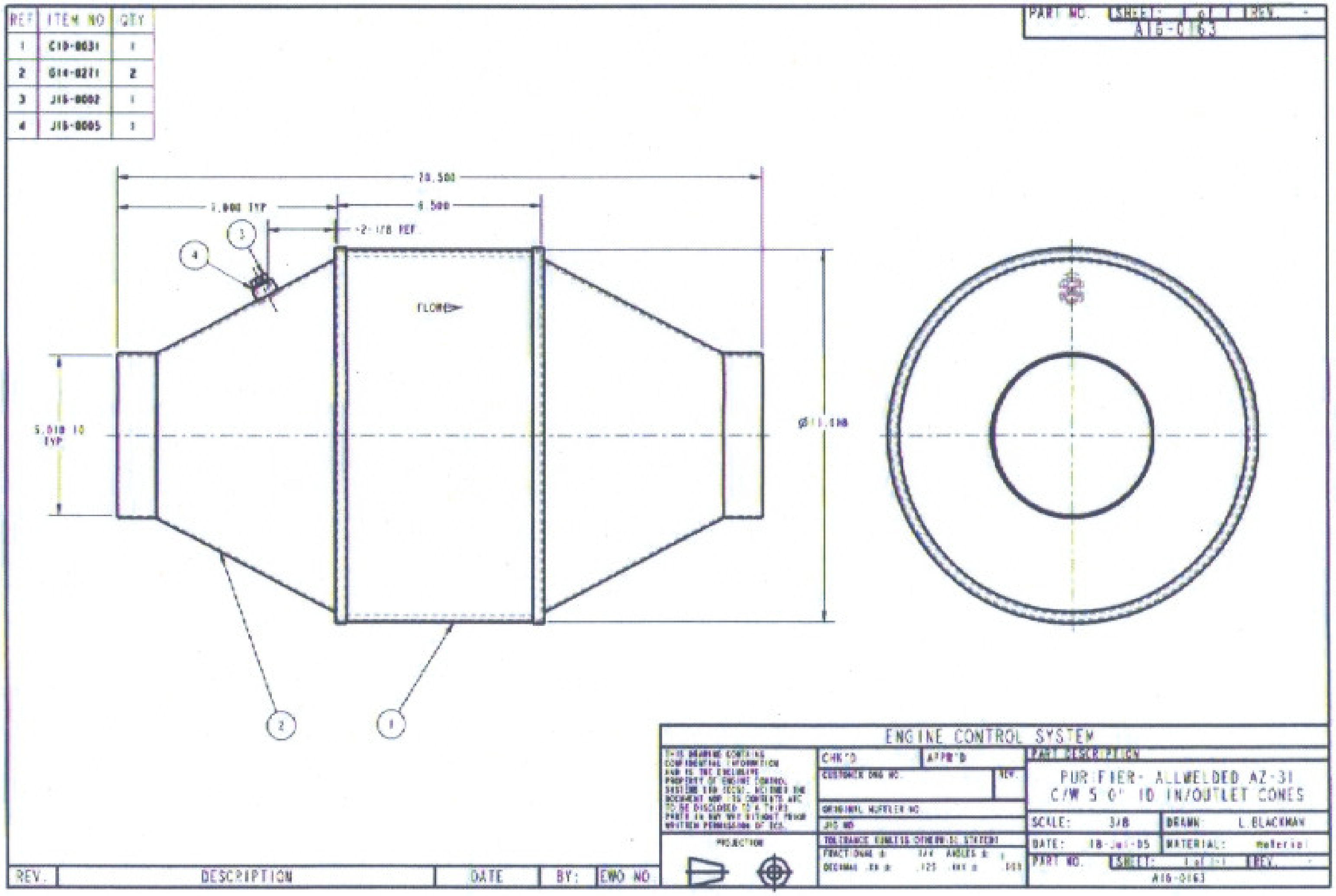
V_E = 0.85 for normally aspirated four stroke engines
1.3 for normally aspirated two stroke engines with blower scavenging
1.7 for turbocharged four stroke engines
2.0 for turbocharged and after / intercooled four stroke engines



Part Number	AZ Catalyst Model	Inlet Outlet Style	A Inlet / Outlet Pipe ID (inches)	B Overall Length (inches)	C Body Length (inches)	D Body Diameter (inches)	E Flange Diameter (inches)	Intake Air Range (CFM)
A17-0313	AZ27M-3S	slip fit	3	27.9	20.8	9		200 - 360
A17-0312	AZ27M-3F	flanged	3	28	20.8	9	7.5	200 - 360
A17-0307	AZ28M-4S	slip fit	4	28.9	21.81	9		315 - 515
A17-0306	AZ28M-4F	flanged	4	29	21.81	9	9	316 - 515
A17-0301	AZ29M-4S	slip fit	4	28.9	21.19	11		450 - 650
A17-0300	AZ29M-4F	flanged	4	29	21.19	11	9	450 - 650
A17-0325	AZ29M-5S	slip fit	5	28.9	21.19	11		450 - 685
A17-0326	AZ29M-5F	flanged	5	29	21.19	11	10	450 - 685
A17-0327	AZ30M-5S	slip fit	5	30.9	22.44	12.85		675 - 830
A17-0328	AZ30M-5F	flanged	5	31	22.44	12.85	10	675 - 830
A17-0303	AZ31M-5S	slip fit	5	30.9	22.44	12.85		800 - 1050
A17-0302	AZ31M-5F	flanged	5	31	22.44	12.85	10	800 - 1050
A17-0329	AZ33M-5S	slip fit	5	31.9	23.5	15.6		1000 - 1250
A17-0330	AZ33M-5F	flanged	5	32	23.5	15.6	10	1000 - 1250

Lubrizol Engine Control Systems, 165 Pony Drive, Newmarket, Ontario, Canada L3Y 7V1
Toll Free 800-661-9963, Tel. (905) 853-5800, Fax (905) 853-5801, Email: ecs@lubrizol.com

PRINTED IN CANADA
M21-0080 JULY 2003


REF ITEM NO QTY
1 C10-0031 1
2 G14-0271 2
3 J16-0002 1
4 J16-0005 1
PART NO. SHEET: 1 of 1 REV. -
A16-0163
20.500
6.500
2-1/8 REF.
FLOW
5.010 ID TYP
ENGINE CONTROL SYSTEM
CHK'D
APPR'D
PART DESCRIPTION
PURIFIER- ALLWELDED AZ-31
C/W 5.0" ID IN/OUTLET CONES
SCALE: 3/8
DRAWN: L.BLACKMAN
DATE: 18-Jul-05
MATERIAL: material
PROJECTION
REV.
DESCRIPTION
DATE
BY:
EWO NO

Diesel Oxidation Catalyst for CAT 3126 engine

2.0 Particulate Converter

2.1 Summary

The particulate collection device developed by Converter Technology Inc. is based on the principle of agglomerating submicron and nano particles into larger particles at very high efficiencies and store them in the media or direct them after leaving the media to and incinerator. CTI employs a composite wire mesh media having almost 99% agglomeration efficiency. In case the particulates are stored in the media, which has a very high affinity for storage, a signal on the vehicle dashboard notifies the need for rejuvenation of the media. This is accomplished through reverse pulse jet when the diesel engine is turned off. Pulsation takes places every one to four months. The particulate converter efficiency can be improved by cooling the exhaust gasses. Exhaust cooling is critical in that it improves particulate reduction efficiency through the capturing of condensed nano-VOC particles and reduced pressure-drop across the converter. Most important is to maintain a sufficient margin between soot ignition temperature also known as self-regeneration temperature, is about 1200°F, and the maximum exhaust temperature under any engine operating condition is set at 500°F to guard against spontaneous regeneration. Spontaneous regeneration is destructive to the wire mesh media.

Diesel oxidation catalyst may be employed to oxidize the light fraction of VOC's. The particulate converter is a completely passive device, and as such it has long durability, excellent reliability, can operate using conventional diesel fuel. Further, it has the highest reduction in toxicity and nano particle count industry-wide. These claims are yet to be proven through emission testing.

2.2 Diesel Particulate Control Options

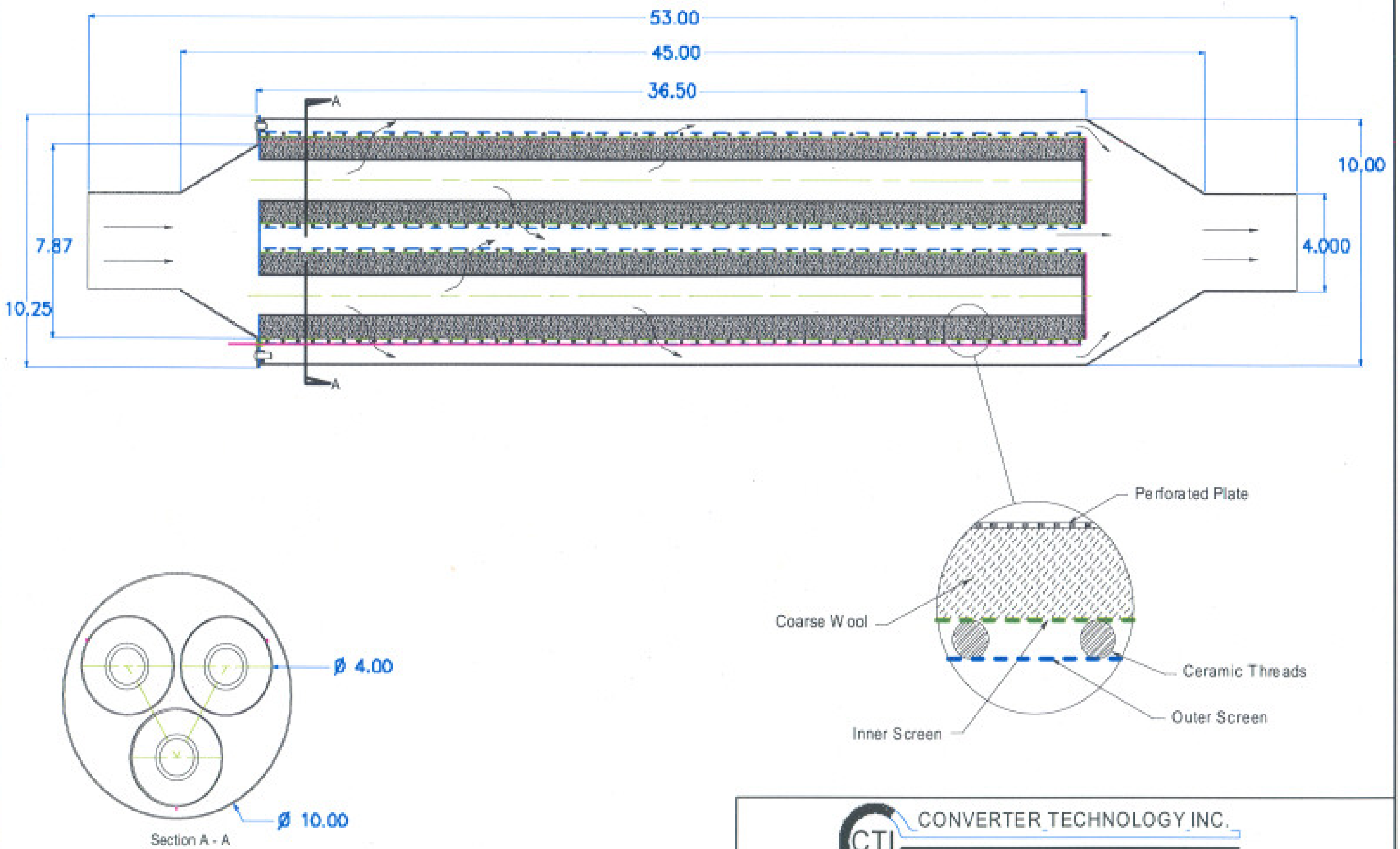
-Reverse Pulse Jet Option.

The composite wire mesh media is packaged into cylindrical shapes referred to as "candles". The composite media is about ½" to ¾" thick and is designed to have optimum characteristics for the capturing and storage of nano-size and submicron particles. The composite wire mesh media is constructed from specialty high-grade stainless steel mesh and screens and can stand temperatures up to 1000°F, although the maximum operating temperature of the converter is around 500°F. The exhaust gas velocity is substantially reduced as it flows through the composite media. The media has the capacity to trap large quantities of soot (retention capacity) before the pressure drop reaches the threshold level necessitating the removal of the soot. The media is rejuvenated through a "reverse pulse jet" service cycle after turning the engine off. Through pulsation of 10 gallons of compressed air at 90-100 psiq pressure on the downstream side of the media, the bulk of retained soot is blown off the media and removed into an external collection tank. A sufficient amount of soot is left on the media to maintain high agglomeration and to start a new cycle of soot collection, but at a lower pressure drop. The wire mesh media is internally supported to handle reverse jet pulsation as well as the pressure drop experienced in operation without loss of structural integrity. Converter Technology Inc. encountered significant delays and complications with CARB during the verification process. As a result, CTI embarked on the development of the incineration option.

-Incinerator Option.

This option has some attractive features and therefore might be desirable in OEM applications, it virtually eliminates the maintenance process in the pulse jet system. Further, it eliminates the need to comply with the treatment of soot collected in a tank as a hazardous waste substance. The wire mesh design strategy is different in that it allows agglomerated particulates to leave the media faster than the previous option. The particulate-laden stream is directed to a proprietary incinerator comprised of very thin gap (0.020") sandwiched between two screens, one is grounded and the other is connected to a 24V power supply. Particulates accumulated in the gap once they reach a threshold valve to close electric circuit will be incinerated (in seconds). By-product of incineration, which is referred to as ash, will leave the screens and does not accumulate as does the ash in ceramic filters.

Due to enormous difficulties encountered with CARB in obtaining verification for the reverse pulse jet system, CTI had no choice but to proceed with the development of the incineration option which took place from late 2005 through September 2006. It is CTI's belief that the incineration option has unique attractive features that makes it more appealing in the market place. The most attractive feature is the elimination of maintenance processes relating to pulsation of the soot to soot collection drums. The following is the summary of the design features of the incineration option as well as the power supply device to incinerate soot in the most efficient way and associated test data. CTI conducted both lab and on-the-road testing to enhance the incineration process including various DC and AC power supplies from 12V through 110V. The outcome led to the development of incinerator power supply system. Full description of the DC power supply system follow in this section.



CTI CONVERTER TECHNOLOGY INC.
Advanced Technologies for Particulate and Air Pollution Control

Drawing Name: Converter - 3 Candle Assembly			
Drawing Part No.:	Rev.: A	Scale: 1 : 6	Drawn: T.Prendel
	Date: 10-21-06		Approved: R.Kammel

Photo of 3 Candle Assembly and Casing

2.3 Converter DC Sequencer-Chopper Power Supply

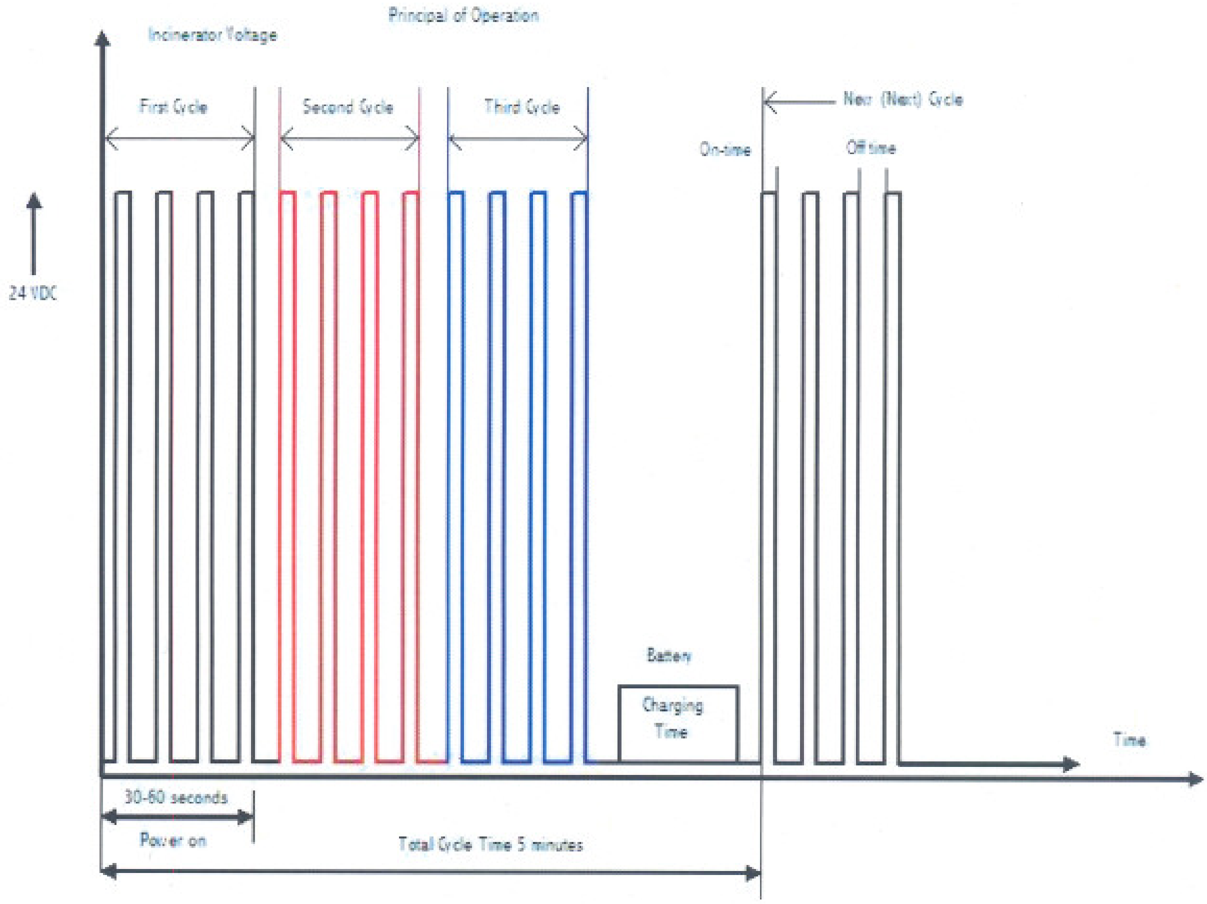
Based on our testing of the incineration in the shop and on-the-road, CTI developed what we call "Power Supply Chopper". This electronic small device helps with:

1. It enhances the incineration process through interruption of the direct current applied to the incinerator. We found that AC is preferable to DC power supply. As such, the chopping process is similar to AC and it can take place at 5 to 10 Hertz (cycles per second) and it can be adjusted through a screw (pot) inside the electronic box.
2. It allows for adding another 12 VDC battery to work in conjunction with the vehicle electrical system to generate chopped 24 to 28 volt power supply, which we found to be effective in the incineration process.
3. It turns power off to the incinerator after (50 to 60 seconds), and start again after (5 to 6 minutes) to save electric power consumption (estimated at 70% to 80% in savings). This would render power consumption for incineration insignificant in terms of fuel penalty.
4. It allows for charging the 12 V battery during incinerator power off time.
5. The device can operate on sequencing 3-4 candles, which is estimated to be the maximum number of candles for mobile applications. This is desirable for multi-candles since sequencing limits the maximum current draw for incineration (same whether a converter has one/two/three or four candles).

The chopper is small, it is about 2 in x 1 ½ in x ½ in.

<u>Attachments</u>

1. Principle of operation.
2. Electronic Schematic of Diagram
3. Digital Photo of a chopper

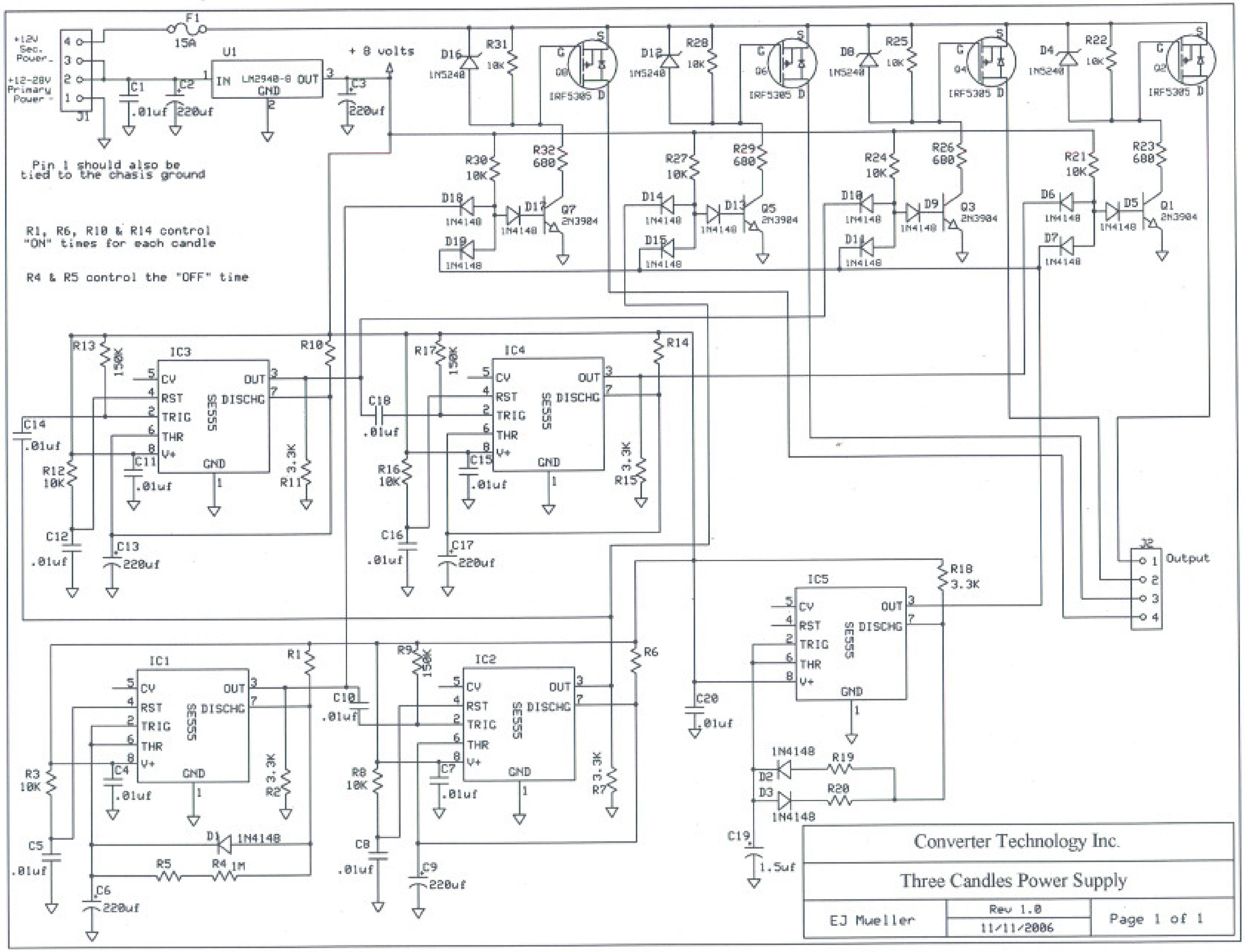


Operation Mode and Definitions for a single and three candle particulate converter

$$\text{Duty Cycle} = \frac{\text{on-time}}{\text{on-time} + \text{off-time}} \times 100\%$$

Preferred Range 80-90%

Pots Adjustments: 1) Duty cycle
2) Frequency of DC chopping
3) Power-on duration time
4) Total cycle time



Converter Technology Inc.
Three Candles Power Supply
EJ Mueller
Rev 1.0
11/11/2006
Page 1 of 1
Pin 1 should also be tied to the chasis ground
R1, R6, R10 & R14 control "ON" times for each candle
R4 & R5 control the "OFF" time
+12V Sec. Power
+12-28V Primary Power
J1
F1
15A
U1
LM2940-8
IN
OUT
GND
+ 8 volts
C1
.01uf
C2
220uf
C3
220uf
IC1
IC2
IC3
IC4
IC5
SE555
CV
RST
TRIG
THR
V+
DISCHG
GND
IRF5305
2N3904
1N5240
1N4148
J2
Output
C19
1.5uf

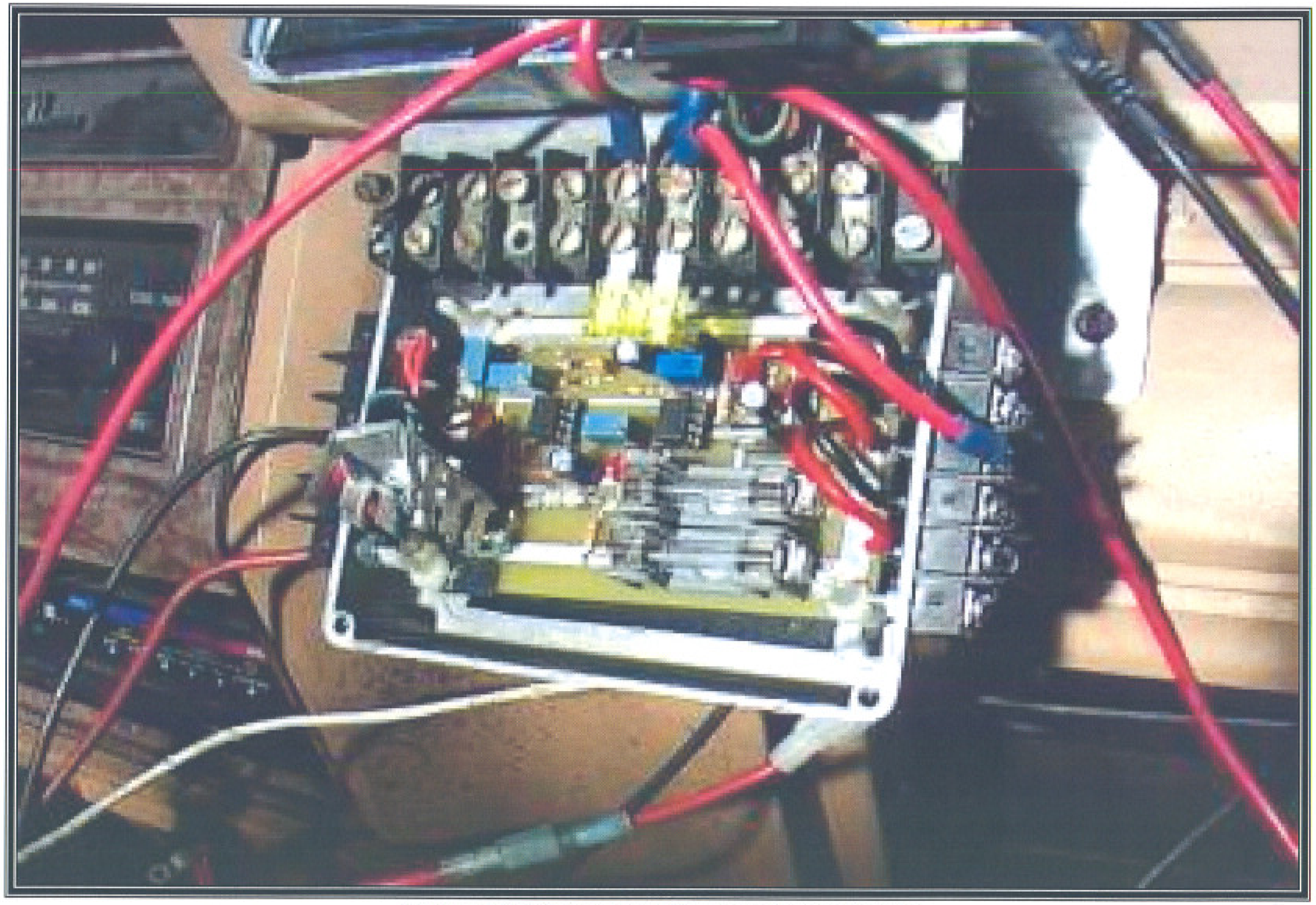


Photo of DC Sequencer-Chopper Power Supply

2.4 On-the-Road Smoke Opacity Testing Data

On-the-Road Test, Single Candle

Time	Speed (mph)	Back Pressure Inches H2O	Smoke Opacity		Temp. at Converter Inlet (F)
			Raw	Clean	
1:00 PM	2	2	8.4	0.6	210
1:03 PM	30	10	24.1	5.8	299
1:07 PM	15	8	15.2	0	316
1:13 PM	40	12	41.5	9.6	318
1:19 PM	50	18	14.2	0	379

Notes:

1. Test were conducted in Michigan Center, MI

2. Date of testing: 8/31/2006

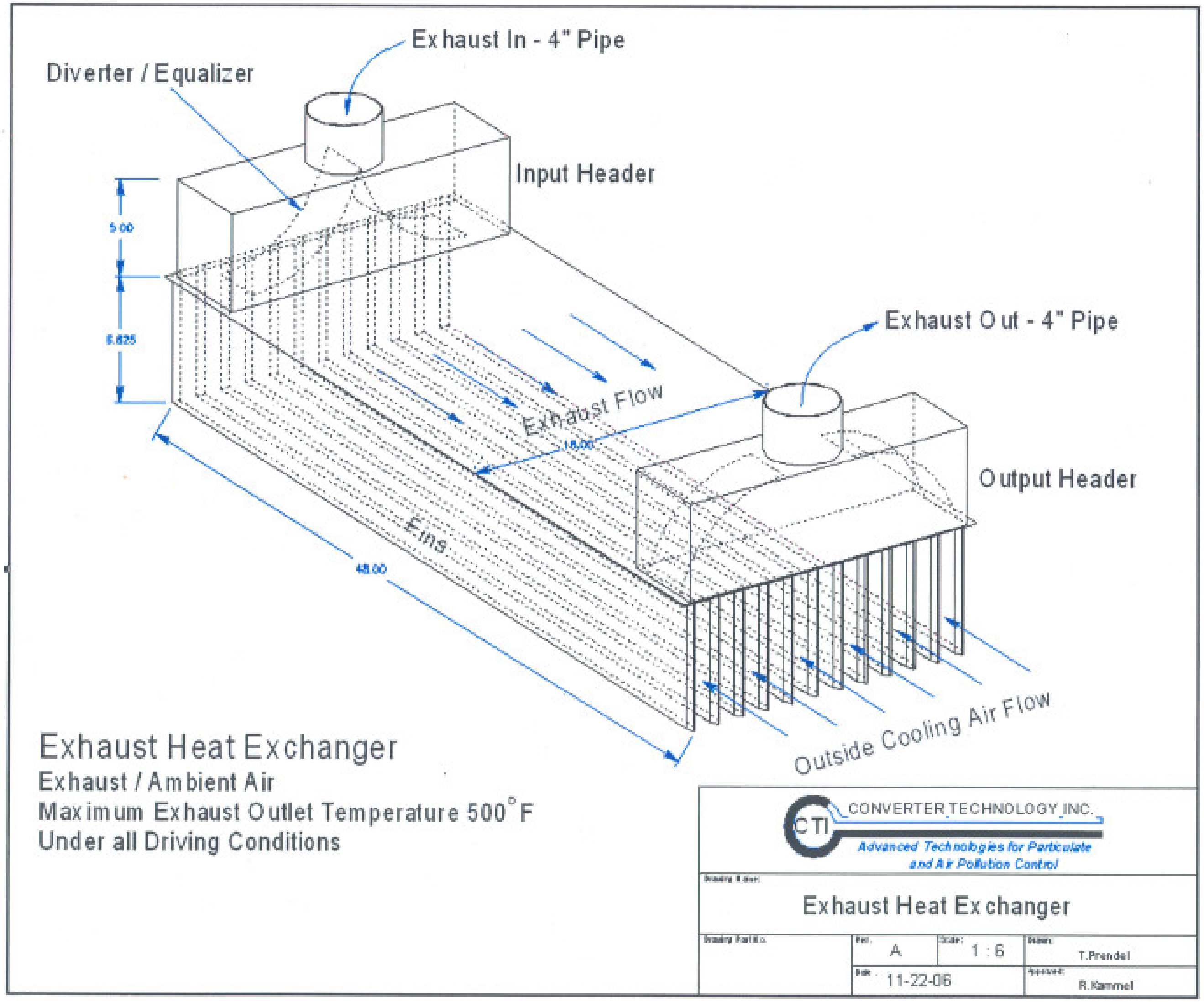
3. Attendees: Francis O'Connor and
Troy Prendell, CTI

4. Smoke opacity are typical for on-the-road testing

5. Test was conducted on Ford 150 having International 6.9 L and naturally aspirated diesel engine

6. Note smoke opacity on the clean side represents fine and agglomerated particulates. The agglomerated particulates (over 10 microns) are not considered particulate pollution.

2.5 Exhaust Air Heat Exchanger



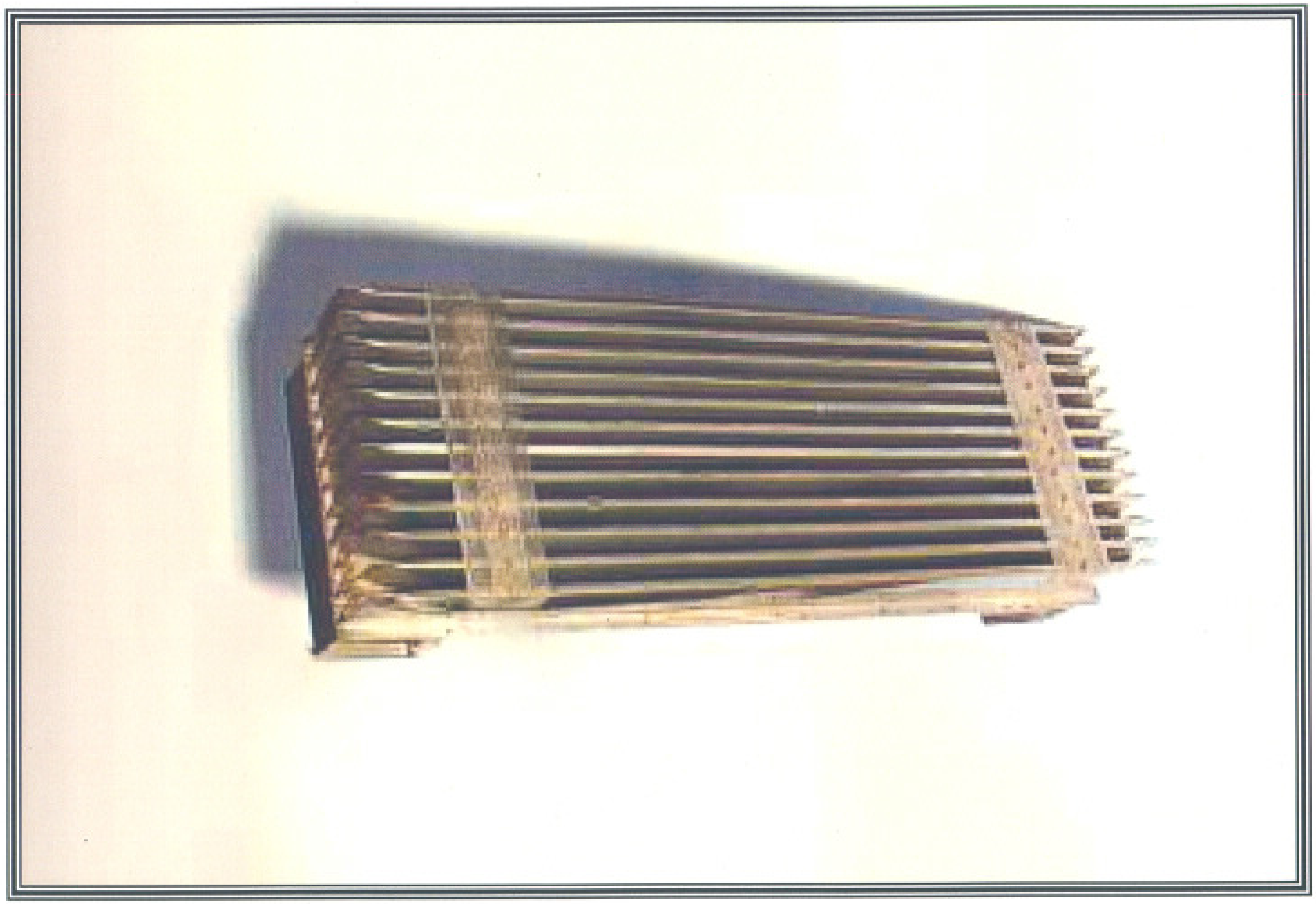


Photo of Exhaust/Air Heat Exchanger

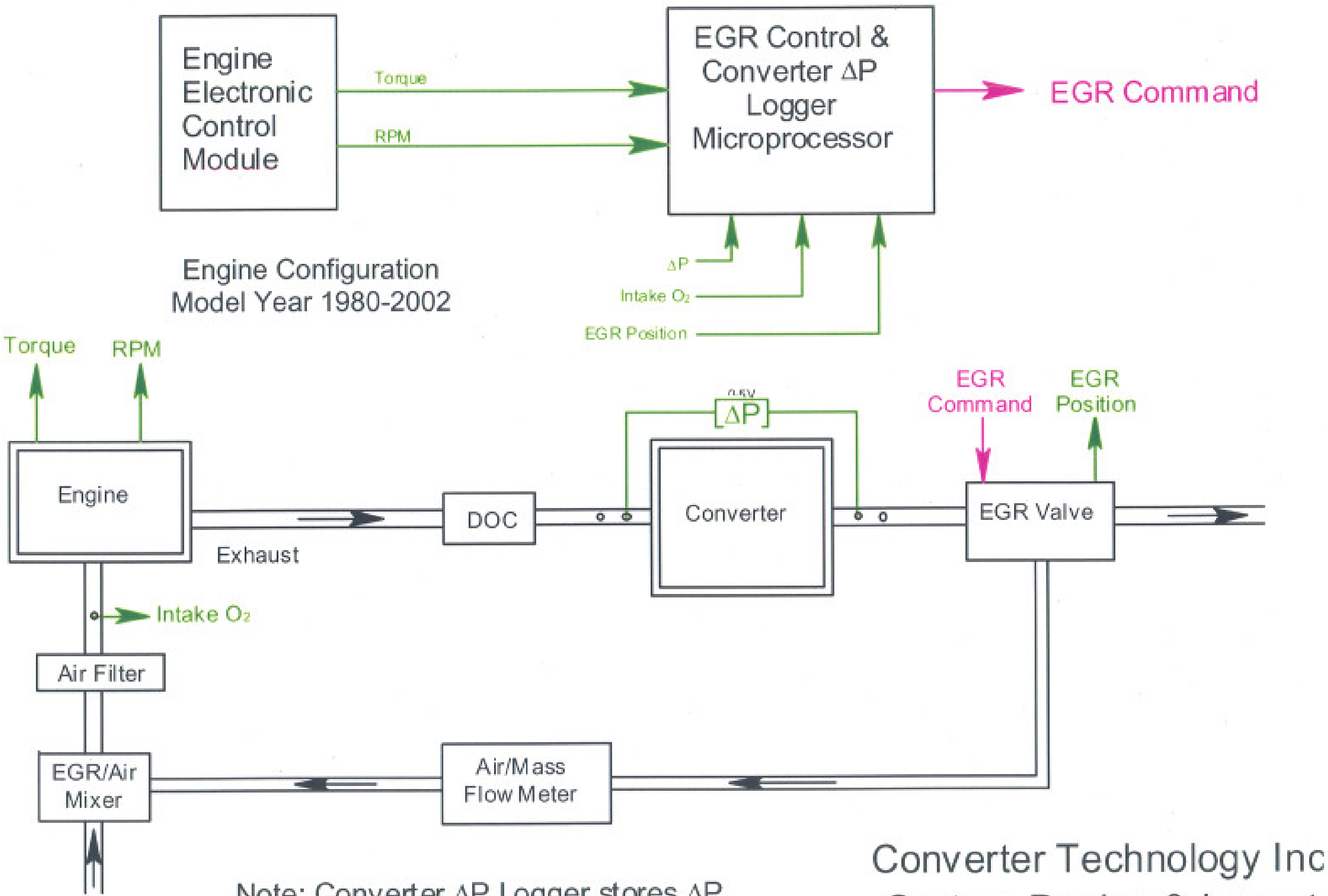
3.0 EGR

EGR is a low pressure exhaust gas recirculation. The system has few exhaust ages over the commonly popular high pressure exhaust gas recirculation used in most OEM applications.

CTI has designed an EGR system for the CAT 3406 engine. The design had been upgraded to rely on hardware commonly used in OEM applications as outlined in the next section.

The EGR control logic and microprocessor design are shown in the next.

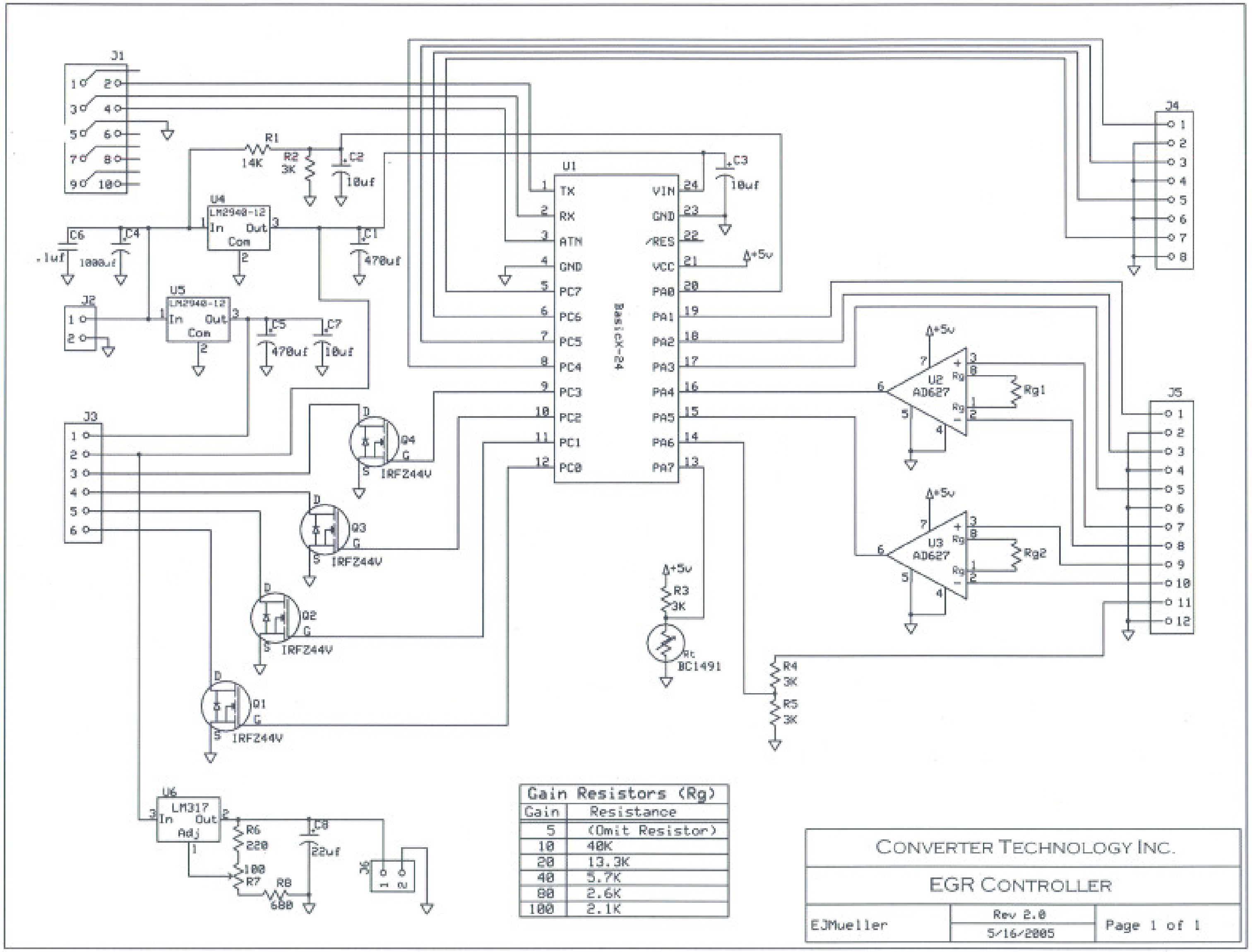
EGR mapping was provided before in a report on Task #5.



Note: Converter ΔP Logger stores ΔP value once per second for the last hour of vehicle operation.

Revision Date
3/16/05

Converter Technology Inc
System Design & Layout
Converter & EGR System
Truck & Bus



Gain Resistors (Rg)	
Gain	Resistance
5	(Omit Resistor)
10	40K
20	13.3K
40	5.7K
80	2.6K
100	2.1K

CONVERTER TECHNOLOGY INC.

EGR CONTROLLER

EJMueller	Rev 2.0 5/16/2005	Page 1 of 1

4. Mobile Data Acquisition System

The Mobile Data Acquisition System developed by CTI is dedicated for the measurement of PM, NOx, HC and CO among other gasses. The system is capable of interfacing with the CAT 3126 engine and downloading various engine operating parameters such as RMP, engine load, vehicle speed, among other data. To convert emission data in PPM into mass emissions (grams/second), CTI developed two Venturi meters, 3" and 5". The 3" Venturi is suitable for the CAT 3126 engine, while the 5" Venturi is suitable for the CAT 3406. Data calibration regarding the 3" Venturi meter is presented.

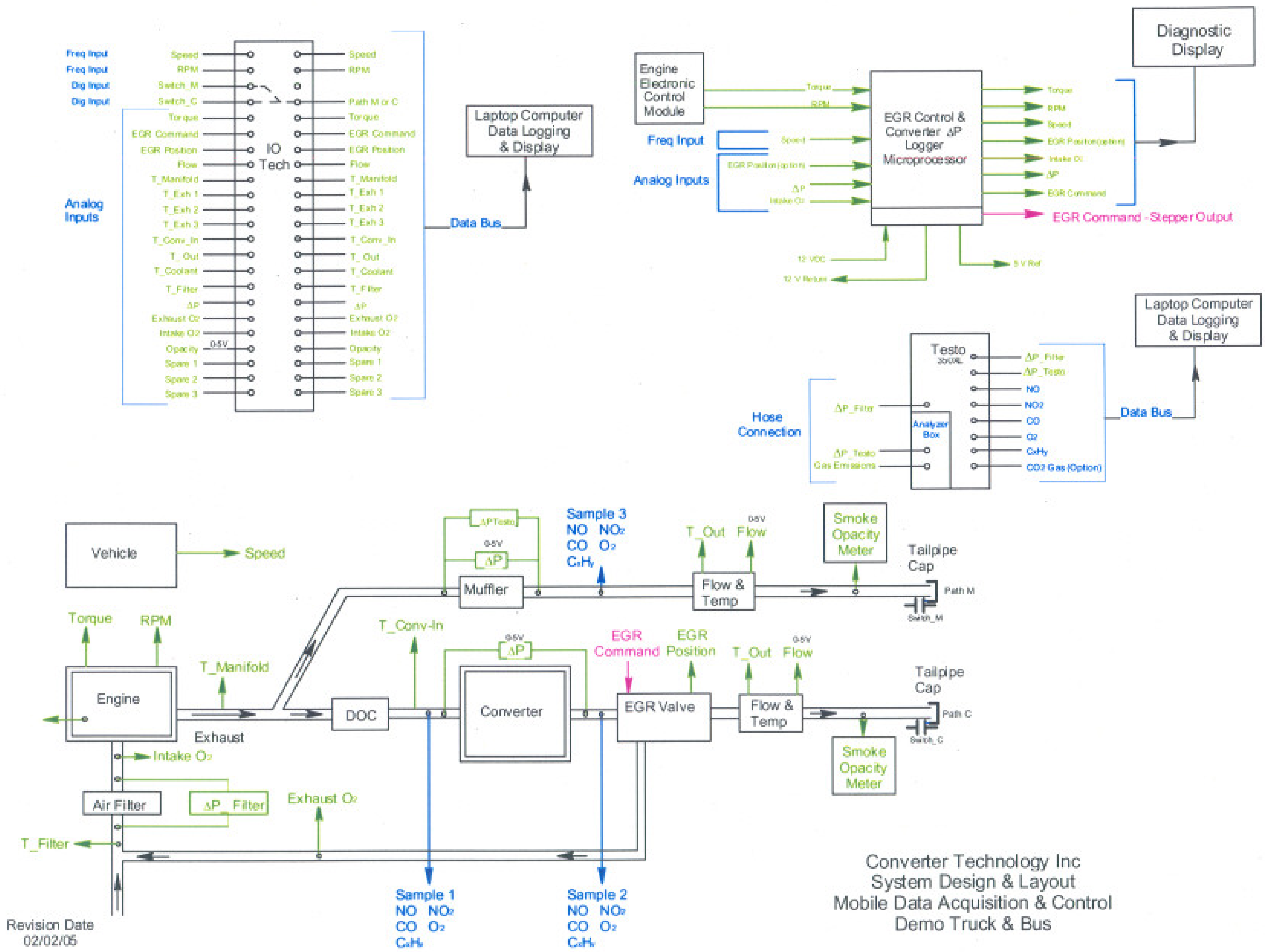
The Mobile Data Acquisition System monitors and computes parameters every 2 seconds during operation. Custom made software can generate specialty reports on the road with particular emphasis on specific emissions. In addition, the system monitors EGR operation and performance, exhaust temperatures at various locations, pressure drops, etc.

A schematic diagram for the mobile data acquisition input signals is presented. Also, electronic block diagram shows the major components. A photo of two of the three data acquisitions is shown. The data acquisition system is owned by Truck Emission Control Technology and an outside financing company. Their units are available for lease to CTI for the data collection and processing on the road.

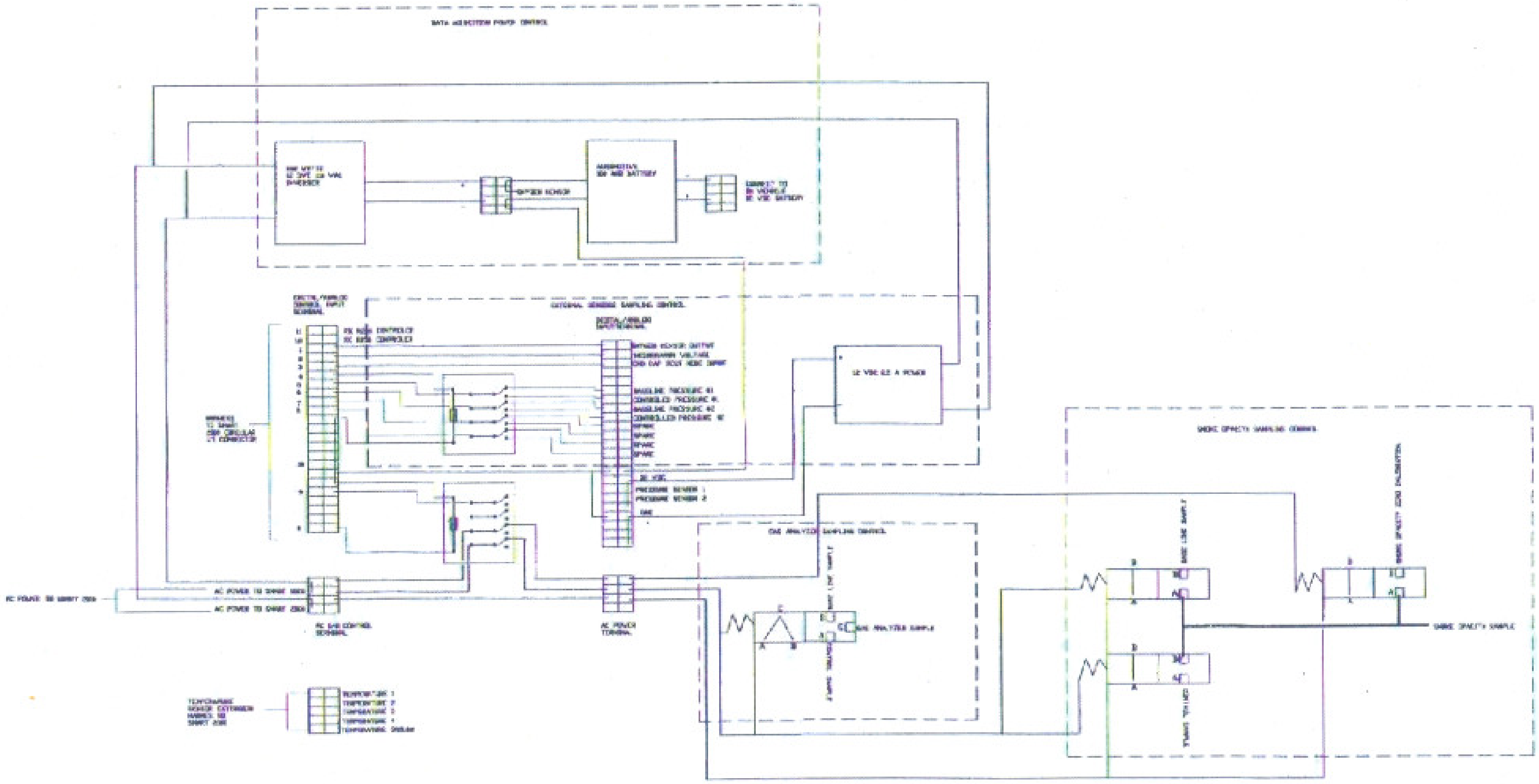
Of particular emphasis in the results obtained from the system is the fact that emission reduction generated from such a system during on-the-road testing would be different from the reductions obtained from Federal emission testing to be conducted at SWRI. Such differences are due to the fact that engine transient test cycle is a selected test cycle that seldom represents test cycles encountered in a given application (such as ours which represents urban testing cycle/ bus testing cycles). The test results will follow in a separate report.

5. <u>3" Venturi Meter</u>

This Venturi meter was designed and constructed by CTI. It is custom-made to meet our specific needs and is capable of withstanding shock loading on the road. Attached is the calibration chart and photo.



Freq Input
Dig Input
Analog Inputs
IO Tech
Speed
RPM
Switch_M
Switch_C
Path M or C
Torque
EGR Command
EGR Position
Flow
T_Manifold
T_Exh 1
T_Exh 2
T_Exh 3
T_Conv_In
T_Out
T_Coolant
T_Filter
ΔP
Exhaust O2
Intake O2
Opacity
Spare 1
Spare 2
Spare 3
Laptop Computer Data Logging & Display
Data Bus
Engine Electronic Control Module
Freq Input
Analog Inputs
EGR Control & Converter ΔP Logger Microprocessor
Diagnostic Display
EGR Command - Stepper Output
12 VDC
12 V Return
5 V Ref
Testo
Hose Connection
Analyzer Box
ΔP_Filter
ΔP_Testo
Gas Emissions
NO
NO2
CO
O2
CxHy
CO2 Gas (Option)
Vehicle
Speed
Torque
RPM
Engine
T_Manifold
Exhaust
Intake O2
Air Filter
ΔP_Filter
T_Filter
Exhaust O2
DOC
T_Conv-In
Converter
Muffler
ΔPTesto
ΔP
Sample 3
NO NO2
CO O2
CxHy
T_Out
Flow
Flow & Temp
Smoke Opacity Meter
Tailpipe Cap
Path M
Switch_M
EGR Command
EGR Position
EGR Valve
Path C
Switch_C
Sample 1
Sample 2
Revision Date 02/02/05
Converter Technology Inc
System Design & Layout
Mobile Data Acquisition & Control
Demo Truck & Bus



Mobile Data Acquisition System Block Diagram

Photo of Two Mobile Data Acquisition Systems

Photo of the Interface Connection on side of Mobile Data Acquisition System

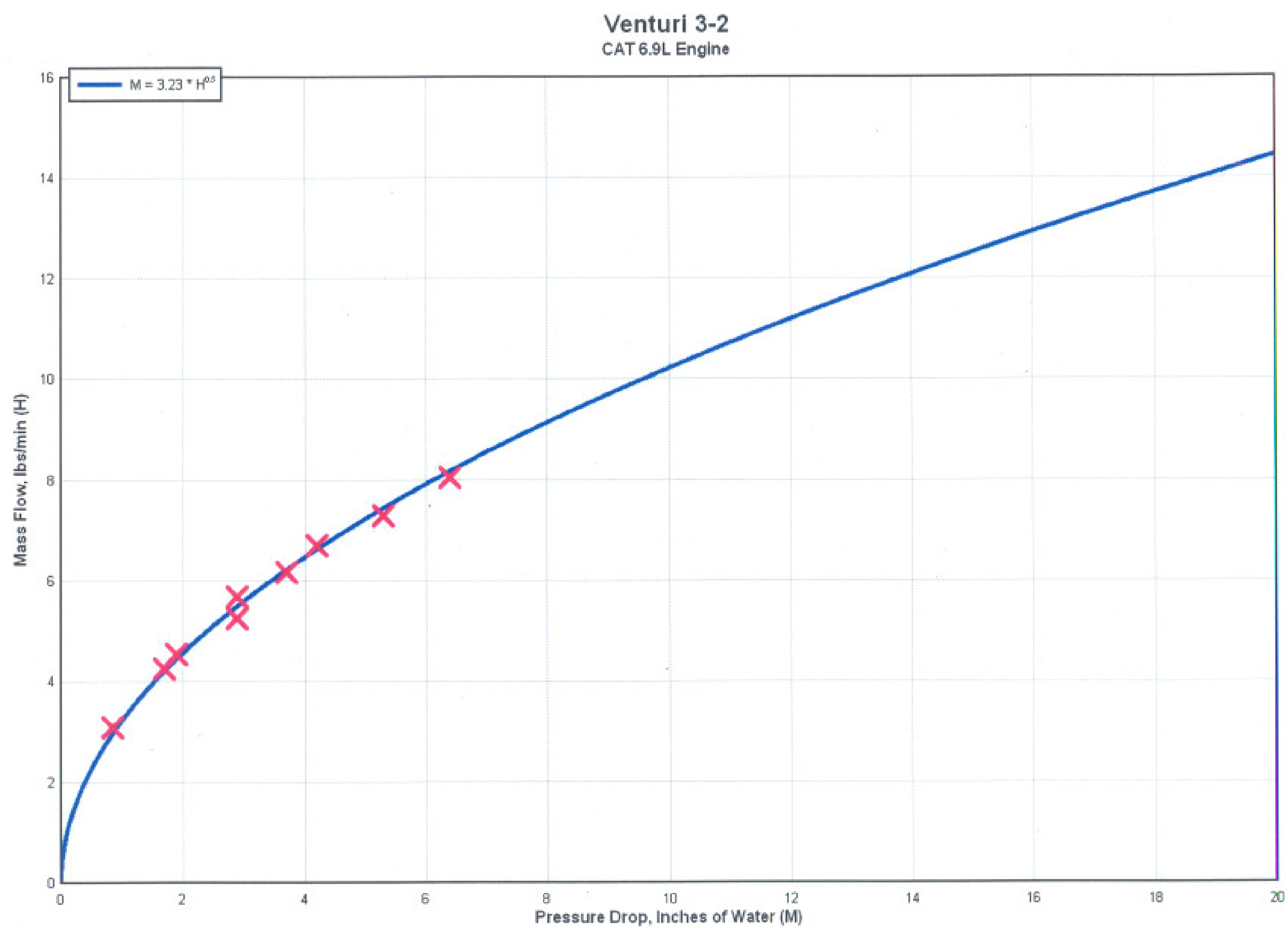

Venturi 3-2
CAT 6.9L Engine
M = 3.23 * H^0.5
Mass Flow, lbs/min (H)
Pressure Drop, Inches of Water (M)
0
2
4
6
8
10
12
14
16
18
20

Photo of Venturi Meter