EPA OTM 33A Appendix A

Examples of GMAP-REQ-DA Systems

By

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List of Acronyms

ASI	Atmospheric Stability Indicator
BETX	Benzene, Ethyl Benzene, Toluene, Xylenes
bLs	backwards Lagrangian stochastic
C_2H_2	Acetylene
CH_4	Methane
CO_2	Carbon Dioxide
CM	Concentration Mapping (as in GMAP-CM)
CMI	Concentration Measurement Instrument
CRADA	Cooperative Research and Development Agreement
CRDS	Cavity Ring-Down Spectroscopy
DA	Direct Assessment (as in GMAP-REQ-DA)
DQI	Data Quality Indicator
DQO	Data Quality Objective
EPA	Environmental Protection Agency
GIS	Geographic Information System
GMAP	Geospatial Measurement of Air Pollution
GPS	Global Positioning System
HAP	Hazardous Air Pollutant
H_2S	Hydrogen Sulfide
MFC	Mass Flow Controller
NEIC	National Enforcement Investigations Center
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
OAQPS	Office of Air Quality Planning and Standards
PSG	Point Source Gaussian
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
REQ	Remote Emissions Quantification
RPD	Relative Percent Difference
R5	EPA Region 5
SOP	Standard Operating Procedures
TC	Tracer Correlation (as in GMAP-REQ-TC)
VOC	Volatile Organic Compound

1. Introduction to OTM33A Appendix A

1.1 Purpose of Appendix A. The purpose of Appendix A is to provide examples of the types of equipment used in OTM 33A applications by presenting an overview of three GMAP-REQ-DA systems developed by EPA. These examples are provided for illustrative purposes and do not constitute method requirements. Section 2 of Appendix A describes the systems and components with engineering designs contained in Appendix B. Section 3 of Appendix A illustrates the set up of a front-mounted mast system and some safety considerations. Refer to Section 5 of OTM 33 and OTM 33A for further information on method safety. The three GMAP-REQ-DA systems described here are referred to as (1) the Office of Research and Development (ORD) system, (2) the EPA Region 5 (R5) system, and (3)the EPA National Environmental Investigations Center (NEIC) system. Each of these platforms has unique capabilities and features and serve to illustrate different aspects of GMAP-REQ technology.

1.2 General Disclaimer. OTM 33A and its appendices have been reviewed by U.S. EPA and approved for posting as a Category C draft method for potential outside use and comment. Posting does not signify that the contents reflect the views or policies of the Agency. The engineering and equipment descriptions contained here are illustrative and mention of trade names or commercial products do not constitute endorsement or recommendation for use. The equipment designs and software examples contained in this method and its appendices are for informational purposes only and are not method requirements. Adoption and or modification of the EPA GMAP-REQ engineering designs, software, or protocols are the sole responsibility of the user. Deployment and safe-use of this method, engineering examples, or variations thereof is the sole responsibility of the user. No engineering or software design performance or safe-use guarantees are given or implied.

2. Examples of three GMAP-REQ-DA systems

2.1 Overview of equipment and common elements. While each possessing unique features, the ORD, R5, and NEIC GMAP-REQ-DA systems are similar in overall design and share many common elements. Section 2.1, Table A2-1 and Figure A2-1, summarize the major equipment groups and describe components that are common to the three GMAP-REQ systems. These common components include: the meteorological station, 3D sonic anemometer, canister acquisition port, high-resolution GPS, and vehicle mast system. Sections 2.2, 2.3, and 2.4 describe some unique aspects of the ORD, R5, NEIC, systems respectively.

Table A2-1. Examples of equipment used in GMAP-REQ-DA-systems

Component	ORD System	R5 System	NEIC System
Meteorological Station	Climatronics AIO	Climatronics AIO	Climatronics AIO
3D Sonic Anemometer	R.M. Young 81000V	R.M. Young 81000V	R.M. Young 81000V
Sampling Port	Quad inlet 0.64 cm dia.,30 cm square,into 0.95 cm dia. main	Quad inlet 0.64 cm dia.,30 cm square, into 0.95 cm dia. main	Quad inlet 0.95 cm dia.,30 cm square, into 1.27cm dia. main
Canister Acquisition Port	Quick connect Entech 1.4L with solenoid	Quick connect Entech 1.4L with solenoid	Quick connect Entech 1.4L with solenoid
High-Resolution GPS System	Hemisphere R100 GPS	Hemisphere R100 GPS	Hemisphere R100 GPS
Vehicle Mast System	EPA Model 2, rotatable	EPA Model 2, rotatable	EPA Model 2, rotatable
Concentration Measurement Instrument (CMI)	Picarro G1301-fc CRDS (CH_4,CO_2)	Picarro G1204 CRDS (H_2S,CH_4)	Los Gatos GG-24-r(CH_4,CO_2) / DUVAS (BTEX)

Control and Communication System	GMAP-REQ-DA (Ver. 5)	GMAP-REQ-DA (Ver. 5)	GMAP-REQ-DA (Ver. 5a)
Battery System	Permanent 9-cell deep cycle	Modular Lithium Polymer	Permanent 9-cell deep cycle

Figure A2-1 and associated text describe several components that are commonly used in EPA GMAP-REQ-DA systems. These components serve as examples of equipment that possess performance and operational characteristics generally acceptable for mobile applications. These components have been used in numerous field campaigns and have been found to be sufficiently robust to withstand the mechanical vibrations and other stresses typically encountered in OTM 33 and OTM 33A mobile measurement applications. No systematic evaluation of potentially useable components was performed by EPA that resulted in the selection of referenced equipment and there are likely similar systems produced by other manufactures that would be meet or exceed performance and robustness exhibited by the referenced components.

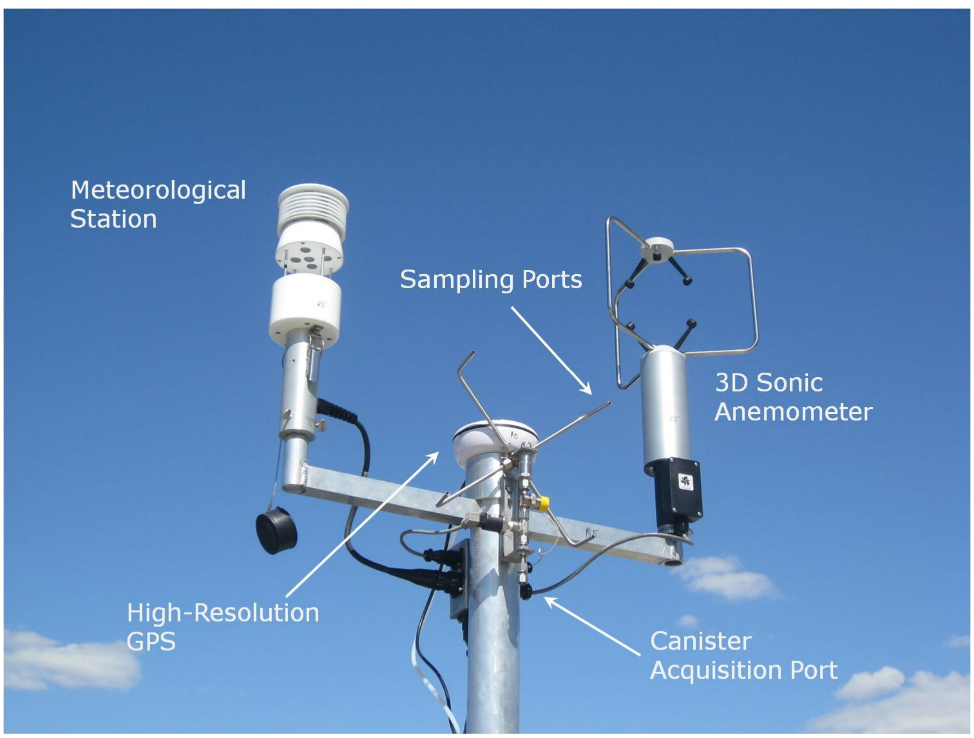

Figure A2-1. Equipment common to EPA GMAP-REQ-DA systems

2.1.1 Meteorological station example. An example of a meteorological station that is used in EPA GMAP systems and by other mobile measurement groups is a Climatronics "All In One" (AIO) compact weather station (Model # 102780, Climatronics Corp., Bohemia, NY). The AIO is a multi-purpose weather instrument that measures temperature, relative humidity, wind speed, wind direction, and barometric pressure in a single portable unit. The AIO consists of a low-power 2-D sonic anemometer, a multi-element temperature sensor, a relative humidity sensor, and barometric pressure sensor. The weather station contains an internal flux-gate compass for automatic alignment of wind direction to magnetic north. The compact size, low power requirements, and robustness of the AIO Compact Weather Station make it well-suited for deployment in mobile monitoring applications. The instrument is capable of collecting meteorological data at a speed of 1 Hz.

2.1.2 3-D sonic anemometer example. The model 81000V Ultrasonic Anemometer (R.M. Young, Inc, Traverse City, MI) is an example of a 3-D wind measurement instrument useful for GMAP-REQ-DA wind field diagnostics. The instrument measures the wind speed and the speed of sound on three non-orthogonal axes. The wind speeds are then converted into orthogonal wind components *u*, *v*, and *w* and sonic temperature. The horizontal wind direction is determined from the *u* and *v* wind components. The instrument can also be used to measure turbulent fluctuations of horizontal and vertical wind flows. Data from the 3-D sonic is logged at speeds of 1 to 10 Hz. As determined from numerous field campaigns, the model 81000V has been found to be sufficiently robust to withstand the mechanical vibrations encountered in typical GMAP applications.

2.1.3 Canister acquisition port example. In many cases the CMI determines the concentration of only a small set of compounds. Frequently it is desirable to acquire a "grab sample" using an evacuated canister or other system allowing subsequent laboratory analysis for compounds not directly measured by the CMI. Typically, near real-time signal from the CMI is used as an indicator to allow grab sample to be acquired while in the source plume. The EPA GMAP-REQ-DA control system and software is designed to facilitate canister acquisition via a user-controlled solenoid value (Figure A2-1, just above canister acquisition port, Figure A2-10 close-up) and by recording the acquisition time canister pressure information in the data file. This allows for later comparison of the canister values with real-time data of the same compounds (if possible).

Typically, a single evacuated canister is connected in a vertical orientation to the canister acquisition port shown in Figure A2-1 using a "quick connect" type interface. Split sampling into multiple canisters is also possible (Figure A2-2) using a Tee connection. The inlet to the canister system is usually a 0.635 cm tube fitted with a 2 micron sintered filter to remove large dust particles. Flow restriction orifices are typically not used. With a single 1.4 l canister configuration, the draw time is approximately 30-40 seconds.

Figure A2-2. Split canister example

2.1.4 High-resolution GPS example. An example of a high-resolution GPS system useful for OTM 33 and 33A applications is a Hemisphere Crescent R100 Series (Hemisphere GPS, Calgary, AB Canada). The GPS antenna is mounted to the top center of the sampling mast (Figure A2-1), with the receiver mounted in the vehicle. Data from the GPS unit are recorded at 1 Hz although the system is capable of higher output rates. The instrument has a manufacturer-stated horizontal accuracy < 2.5 m with 95% confidence in standard mode under most conditions.

2.1.5 Vehicle mast system example. For many Method 33A applications, a vehicle mast system is used to co-locate instrumentation and sampling ports away from the body of the vehicle to allow unobstructed air flow to sampling ports and instrumentation. The need for a mast system depends on the application and many GMAP-CM approaches can forgo a mast. As an example of a mast system, a view of the top of and EPA model 2 mast system is shown in Figure A2-1 with additional details and photos contained in Section 3. The mast system is both rotatable and extendable using inserts with a base sampling port height of approximately 2.7 m depending on the GMAP Vehicle platform. The system designed for ease of use for equipment connection and storage. The vehicle mast system mechanical drawings along with example system wiring schematic requirements are contained in OTM 33A Appendix B. The assembly of the EPA model 2 mast system is described in Section 3 of this Appendix.

2.1.6 Control and communication system example. The example GMAP-REQ-DA systems employ a dedicated control computer to synchronously collect and log data from the meteorological station, 3-D sonic anemometer, CMI, canister acquisition system, and GPS and allow triggering of evacuated cannister acquisitions. The control computer also provides QA and file handling functions, output for real-time user interface on a display laptop and remote communication functions.

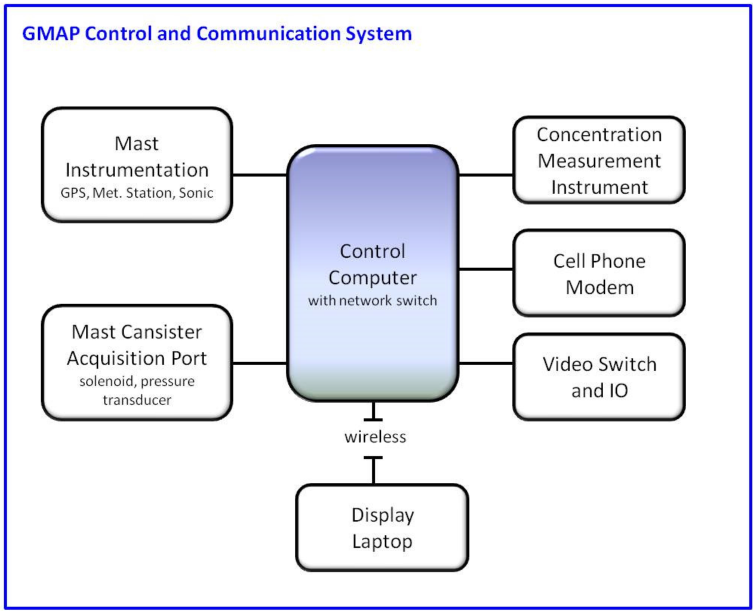

Figure A2-3. Control System Block Diagram

The control computer is part of an overall system that includes both hardware and software components. A block diagram of the control system is shown in Figure A2-3. In addition to communications with instruments, the control computer provides external communication through a cell phone modem. The control computer, CMI, network switches, modem, data terminals, pump controls and surge-protected power supplies are contained in the instrument rack. User control of the system, usually from the front passenger seat, is accomplished through a laptop computer that is connected wirelessly to the control computer that itself has no dedicated video monitor. A wireless video switch allows laptop to access to the control computer or the computer embedded in the concentration measurement system if needed. Appendix B of OTM 33A contains wiring diagrams for the mast and subsystems that connect the control computer to the various components. The data acquisition and control software operating on the control computer for the GMAP systems is a custom program written in LabView™ (National Instruments Corp., Austin, TX) and is provided as supplementary information to Method 33A.

2.2 Descriptions of ORD, R5, NEIC systems

2.2.1 ORD system. This section describes the equipment elements unique to the ORD GMAP-REQ-DA system (Figure A2-4), building on the discussion of the components systems (Section 2.1). The ORD system is based on a Ford™ Excursion class SUV (two-wheel drive) and is the largest of the EPA GMAP vehicle platforms. Its ample interior size was useful in early stages of the GMAP program and provided flexibility

Figure A2-4. ORD GMAP-REQ-DA system

for use of prototype equipment. The interior of the vehicle contains fixed-mounted 19” rack for instrumentation mounting and control systems along with a lead acid battery and charging system described below. The ORD GMAP system is fitted with a front-mounted trailer hitch (Section 3) allowing the mast system to be attached to the front of the vehicle. The purpose of the front mounting is to allow somewhat easier vehicle positioning in the source plume under observation and also improved wind flow around the instruments and sampling system by reducing the obstructions from the body of the vehicle.

A battery package is commonly used to power the instrumentation in a GMAP system. A battery supply provides a dependable, clean power source for the instruments and allow the engine of the GMAP vehicle be turned off during fixed-site sampling to prevent inadvertent contamination of the air sampling by the exhaust of the vehicle. The ORD GMAP uses a dedicated SUV so the battery system can be permanently installed. The ORD system uses nine (9) sealed lead acid batteries and a simple inverter/charger system.

The ORD GMAP system uses a four inlet sampling port made from 0.64 cm dia. stainless steel tubing gathered set into a 30 cm square configuration. The four sampling ports are gathered together into 0.95 cm dia. teflon tube to transport the sample to CMI using the a separate pump described below. The purpose of the quad sampling port arrangement is to provide some spatial averaging of the observed plume which is deemed helpful when in close proximity to sources where less-developed plumes can be encountered. The quad sampling port can also helpful in some configurations for in-field calibration checks by connecting the gas supply to one of the four ports, the other three serve as exhausts to prevent over pressurization of the CMI. The size of the tubing and design configuration used in the ORD system is the same as the R5 system and dictated in part by the sample flow requirements of CMI described subsequently.

<u>ORD GMAP Concentration Measurement Instrument (CMI)</u>

To date, the primary use of the ORD GMAP-REQ-DA system is for detection and assessment of emission form select oil and gas production facilities. For this application, CH_4 is measured as a primary surrogate for emissions. The ORD GMAP system utilizes a Picarro Model G1301-fc cavity rind-down spectroscopy (CRDS) instrument (Picarro, Inc., Sunnyvale, CA, USA) to measure CH_4 and CO_2. The unit also measures and H_2O concentration for spectroscopic inference correction purposes. The Picarro Model G1301-fc is a fast measurement system providing data at a rate of 10 Hz. The particular CRDS instrument in the ORD GMAP system has a tested measurement range from 0 to ≈ 200 ppbv for CH_4, and a specified CO_2 measurement range from 0 to 1000 ppmv in its standard configuration. This instrument also has the capability of operating on a weaker CH_4, absorption feature which can extend the operational range to approximately 800 ppbv. It is noted that the standard operational specification for Picarro Model G1301-fc is 0 to 20 ppbv for CH_4.

Figure A2-5 shows a schematic drawing of the model G1301-fc CRDS instrument which has the same dimensions as the model G1204 CRDS unit used in the R5 GMAP system. The ORD CRDS instrument is secured in the 19" rack inside of the GMAP vehicle. An 8 l/min scroll pump (model xx, make xx) supplies the air sample to the CRDS system through the mast sampling ports. A significant advantage of CRDS technology for fast sampling application is that optical cell sampling volume is small (35 ml) allowing air to be moved through system efficiently allowing smaller sampling lines and pumps to be utilized.

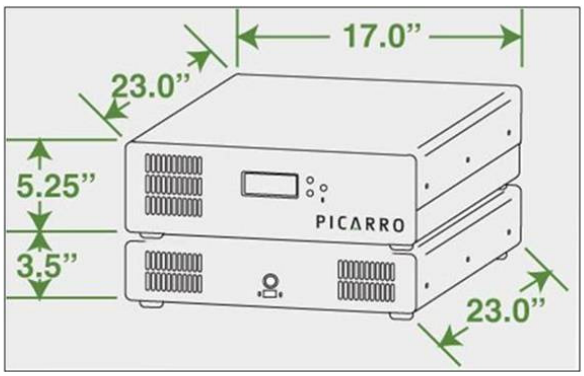

Figure A2-5. Picarro Model G1301-fc and G1204 CRDS Instrument

As a general description of CRDS technology, light from the laser source in the instrument is injected into an optical cavity containing three high-reflective mirrors and the sample gas. The intensity of the light inside the cavity builds up over time and is measured using a photo-detector. The "ring-down" measurement is made by rapidly turning off the laser and measuring the light intensity in the cavity as it decays exponentially over time. The exponential decay of light is illustrated in the following equation showing the calculation of the intensity of the light in the cavity (I) in units of watts per meter squared:

$$I = I_o e^{-t(1-R+A)\frac{c}{L}} \qquad (2\text{-}1)$$

Where:

I_o = initial intensity (watts per meter squared)
e = 2.71828 (Euler’s number)
t = time (seconds)
R= reflectivity
A = the per-pass fractional losses due to some absorbing species in the cavity
c = speed of light (meters per second)
L= cavity length (meters)

The instrument laser is scanned over the wavelengths of the absorption features of the analytes of interest. An optical spectrum is generated showing the area and height of each absorption feature. The concentration of each gas species is proportional to the intensity of each measured spectral feature. The CRDS instrument is capable of parts-per-billion level detection of many chemical species at very fast measurement rates, making it ideal for continuous emissions monitoring. The high-precision wavelength monitor of the instrument ensures that only absorption features from the target analyte are being analyzed, greatly reducing the effects of interfering species on the analysis

It is important to note that ORD CMI (Picarro Model G1301-fc) can also measure water vapor (H_20) in some operational modes and the most accurate measurement of CH_4 is accomplished when H_2O is accounted for by the instrument (Reference 1). The ORD CMI has three operational modes allowing simultaneous measurement of the following species: (1) CH_4 with CO_2, (2) CH_4 with H_2O, or (3) CO_2 with H_2O (but not all three simultaneously). Typically, the ORD CMI is operated in the CH_4 with CO_2 mode to assist in quality assurance of canister acquisitions which can be negatively impacted by mobile source interferences. When operating in this mode, the water vapor correction is not possible leading to a small negative bias on the CH_4 concentration determination and the PSG source emission rate assessment. Specifically, there are two effects of water vapor on the reported CH_4 value: (1) the CH_4 concentration is lower than the actual dry-mole fraction of CH_4 in the atmosphere due to dilution of the mole-fraction by the presence of H_20, (2) the spectroscopic feature of the CH_4 line is broadened H_2O absorption which introduces a slight negatively bias on the reported CH_4 concentration (reference 1). The net effect is to produce an approximate 1% underestimate of the actual CH_4 mole fraction by the instrument for every 1% water vapor in the atmosphere. This is a 1% to 3% effect in typical field conditions.

2.2.2 EPA Region 5 system. The R5 system GMAP-REQ-DA system (Figure A2-6) differs from the ORD and NEIC units in two primary ways. The R5 GMAP is designed to be modular so that it does not require a dedicated GMAP vehicle platform. The GMAP system and battery supply are packaged in custom vibration isolated shipping containers so the unit can be easily stored and then fitted to any mobile measurement vehicle equipped with a trailer hitch to support the mast. The modularity of the equipment also allows it to be easily transitioned to fixed-site monitoring applications so long-term ambient measurements can be conducted. Another difference of the R5 system is that the CMI can measure hydrogen sulfide (H_2S) and CH_4 in near real time using a model G3304 Picarro CRDS system.

R5 GMAP Vehicle

Because, the R5 GMAP package is modular, the mast can be fitted to any vehicle with a trailer hitch with large enough large enough interior room to carry the control and battery packages. Figure A2-6 shows the installation of the R5 GMAP package fitted to a rear-mounted trailer hitch on two small SUVs.

Figure A2-6. R5 GMAP-REQ-DA mast on two different vehicles

Figure A2-7 shows the R5 modular control package that contains the CMI, control computer, and other data acquisition, control and communication hardware. The modular control package is built around a specialized shipping box containing a vibration-isolated 19” instrument rack. The containers come equipped with protective covers (shown removed) for sealing the system for shipping and storage. The mast system and battery package have similar containers, so the R5 GMAP package can be shipped to a study location and then easily fitted a locally acquired vehicle for use thereby reducing deployment costs.

Figure A2-7. R5 GMAP modular control (A) and Battery Packages (B)

R5 Battery System

The R5 GMAP power supply is also modular (Figure A2-7B). To reduce size and weight, the R5 system is based on a 12.8 volt lithium ion phosphate prismatic battery (BatterySpace.com/ AA Portable Power Corp., Richmond, CA), instead of lead acid batteries used in the ORD and NEIC systems. Lithium batteries are more expensive than the lead-acid alternatives but provide an approximate 2 to 1 weight to charge ratio advantage. The R5 battery system, which includes a built-in charger weighs approximately 70lbs and can power the R5 system for over eight hours of continuous operations.

R5 Sampling Port

The R5 GMAP system uses the same sampling port configuration as the ORD unit, a four inlet sampling port using 0.64 cm dia. stainless steel tubing gathered set into a 30 cm square configuration. The four sampling ports are gathered into 0.95 cm dia. main tube which is made of teflon. Additional information on mast components is contained in Section 3.1.4.

R5 Concentration Measurement Instrument (CMI)

The R% CMI is a Picarro Model G1204 CRDS instrument (Picarro, Inc., Sunnyvale, CA) to collect H_2S and CH_4 concentration data. The unit is capable of measuring analyte concentrations at a rate of 0.3 Hz. The instrument measurement range is 0 to 500 ppbv for hydrogen sulfide, and 0 to 20 ppmv for methane. The approximate minimum detection limits for hydrogen sulfide and methane are 10 and 2.5 ppbv, respectively.

2.2.3 EPA NEIC GMAP system. The EPA NEIC GMAP system (Figure A2-8) is based on a Ford Explorer (mid-size) SUV. Because the NEIC system has a dedicated vehicle, the battery system and control package are permanently installed. The NEIC GMAP-REQ-DA system differs from the ORD and R5 DA systems as it utilizes different CMIs. The EPA NEIC system uses a near infrared-based CH_4 measurement instrument manufactured by Los Gatos Research (Mountain View CA, USA) and an ultraviolet-based instrument manufactured by DUVAS Ltd. (London, UK) for speciated benzene, ethylbenzene, toluene and xylenes (BTEX). These concentration measurement systems require higher sampling flow rates compared to CRDS systems due to the optical cell volumes present in the instruments. For this, the sampling system has a slightly different design and as detailed below.

Figure A2-8. NEIC GMAP-REQ-DA system

NEIC Battery System

The NEIC GMAP system uses a permanently installed battery and charger package consisting of quantity 6 cycle 12V, 100 amp-hr sealed lead acid batteries fitted with Xantrex model PROsine 2.0 inverter/charger combination (Xantrex Technology Inc., Elkhart, IN). The battery package for the NEIC system is installed in a custom steel rack at the position of the back seat of the SUV (removed). Figure A2-9 shows a picture of the NEIC battery enclosure located just behind the control rack. With the LGR concentration measurement system and associated equipment, the NEIC battery package will provide in excess of 12 hours of continuous operation. Continual power availability is provided by a redoubt on the PROsine 2.0 which. This combination charger/inverter also allows recharge from any 110v source and tailors the draw from the outlet to match the available supplied amperage to prevent service issues.

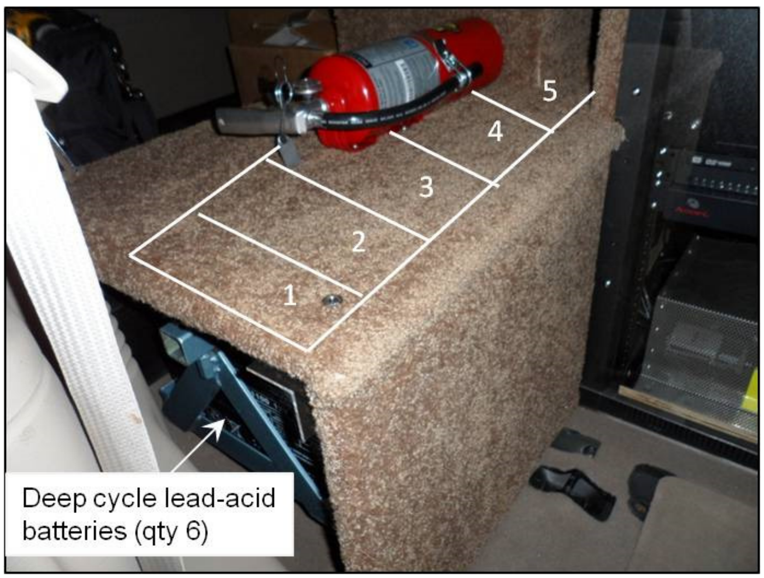

Figure A2-9. NEIC GMAP-REQ-DA system

<u>NEIC Sampling port and mast close-up</u>

As with the ORD, R5, and WM units, the NEIC GMAP system uses a four inlet sampling port using however the tubing size is larger than the other units to accommodate higher flow speeds necessary for the NEIC CMIs. The sampling ports for the NEIC system are 3/8” dia. stainless steel tubing set into a 30 cm square configuration. The four sampling ports are gathered into into a ¾" dia. main tube made of teflon. A close-up of the NEIC mast is shown in Figure A2-10. The purpose of the quad sampling port arrangement is to provide some spatial averaging of the measured plume which is helpful when in close proximity to sources. The quad sampling port is also helpful for in-field calibration checks by connecting the gas supply to one of the four ports, the other three serve as exhausts to prevent over pressurization of the CMI. The six of the tubing used in the ORD system is dictated by the CMI described subsequently

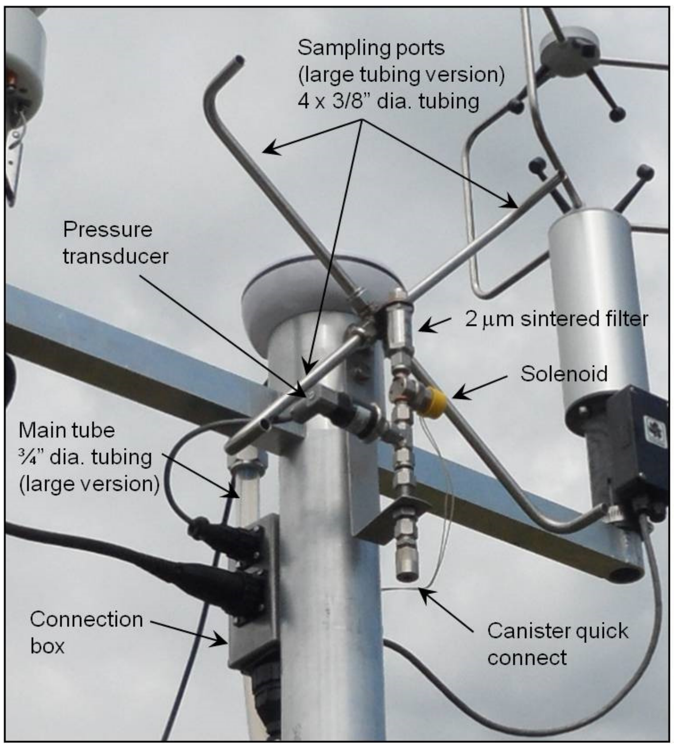

Figure A2-10. Close-up of NEIC Q-DA system

NEIC Concentration Measurement Instruments

The NEIC unit is outfitted with two CMIs. The first is a model FGGA-24r Greenhouse Gas Analyzer [Los Gatos Research (LGR), Mountain View, CA] which provide simultaneous measurement of CH_4, CO_2, and water vapor concentrations. The analyzer uses LGR's patented Off-axis ICOS technology, a fourth-generation cavity enhanced laser absorption technique which is claimed such as being simpler to build, more rugged and alignment insensitive, and provides measurements over a wide dynamic range compared to other spectroscopic techniques. Figure 3-10 shows components of the NEIC system in the rack mounted enclosure. Due to the cell volume sizes of the concentration measurements systems in the NIEC require a blower system to move the air through the cells.

Figure A2-11. EPA NEIC GMAP equipment

The NEIC GMAP unit is also equipped with a protptype UV spectrometer model D1000 (DUVAS Technologies, London, UK) capable of measuring a variety of compounds but current EPA research efforts focus on benzene and toluene. The D1000 uses a nominal 14 m folded path and has an approximate 2 L cell volume so a blower system is required for air handling. The D1000 is fitted with high resolution fast response (millisecond-level data acquisition)spectrometer, and the current EPA prototype is capable of measuring benzen and toluene at signal levels around 10 ppbv at measurement speeds of 1 Hz.

3. Example of Mast system setup

The vehicle mast system (or sampling mast) allows instruments and sampling ports to be co-located and supported away from the body of the vehicle so that the probe and instruments encounter unimpeded wind flow. This section briefly describes the set up procedures for the mast system and illustrates some design features that are pertinent for this type of sampling. This discussion is illustrative in nature and other embodiments of a probe system may vary.

The EPA model 2 vehicle mast system engineering design is described in OTM 33A Appendix B). The mast is constructed of aluminum and consists of three sections in default configuration placing the sampling probe nominally 2.7 m above the ground. Two additional sections (1 m each) are provided allowing the probes to be extended to a nominal height of XX m above the ground. Among other dangers, overhead power lines could impact the mast when extended causing extreme hazard. In default configuration (no mast extensions installed) the mast should be low enough so that power lines should not be a hazard under normal conditions.

> **<u>Warning:</u> The vehicle must remain stationary with mast extension sections installed.**

Prior to field deployment, the measurement vehicle must be equipped with a trailer hitch with a minimum ¾" ball to support the mast. The hitch can be deployed at either the front or rear of the vehicle, and installed according to the hitch manufacturer's instructions. Deploying the mast on the front of the vehicle provides somewhat improved operational visibility for positioning the vehicle (although the drivers view is partially impacted while driving) and more importantly, somewhat better wind flow to the instruments. Front mounting puts the probes farther away from the exhaust of the vehicle decreasing the chance for self-contamination of the sample stream during mobile applications. Front mounting also allows the operator to monitor the condition of the mast and instruments to ensure they remain properly secured and that overhead clearance is acceptable for low hanging tree limbs that may be encountered on secondary roads.

The mast is secured to the trailer hitch by the mast plate assumingly (Figure 4-1, Appendix A). The base of the mast is attached to the vehicle using the trailer hitch. The mast must be secured with a 3/4 "fine thread grade 8 or larger bolt with a nylock nut.

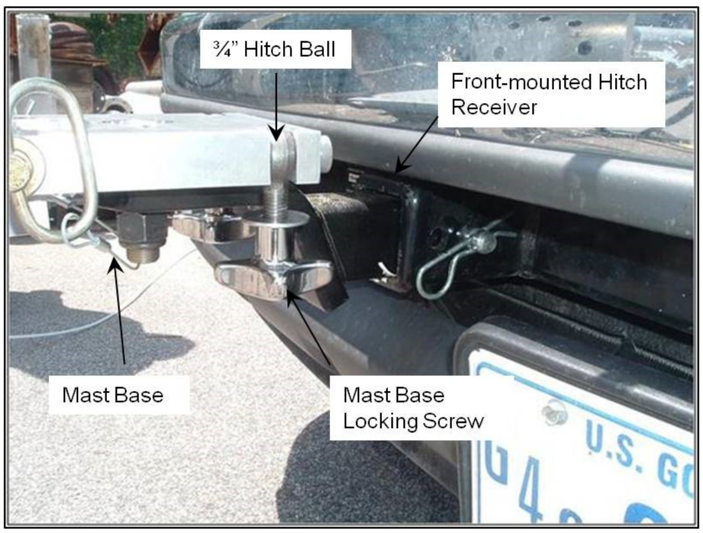

Figure A3-1. Front-mounted hitch and mast base plate

The mast base is hinged to make it easier to install the components on the top of the mast. After installing the primary tube sections of the mast, the hinge can be open to allow the mast to be lowered parallel to the ground by releasing two lock nut fasteners. Figure 4-2 shows the mast in the lowered position, after the mast equipment has been installed and connections made. Care should be taken to lower the mast gently to prevent damage to the hinge or instruments. The lowered mast should not rest on the instruments, support with a box if necessary.

Support of the lowered mast will always be necessary when mast extensions are installed.

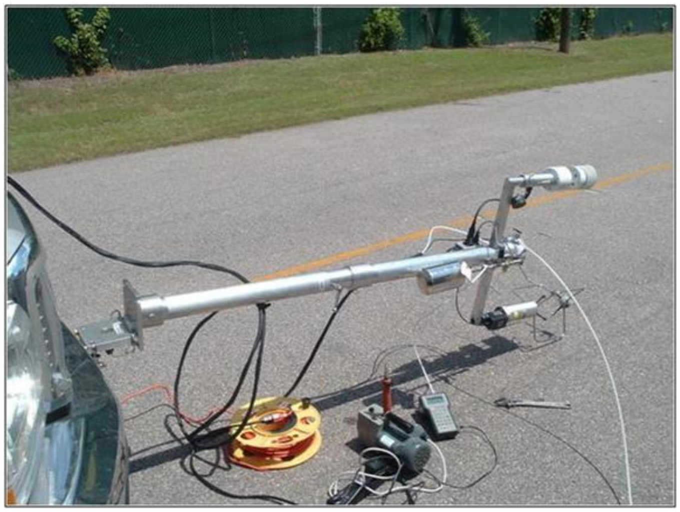

Figure A3-2. Mast in lowered position for assembly of components

After installing the components and making connections in the lowered position the mast must be returned to vertical position and the lock nut fasteners must be firmly tightened (Figure 4-3).

Warning: **Failure to secure the mast base plate locking nuts could result in serious injury or and equipment damage. It is recommended that two persons raise and lock the mast to help ensure safe operation.**

Figure A3-3. View of locked mast base plate

With the mast in the lowered position, components are attached and cable connections are made (Figure 4-4). The 3-D sonic anemometer and met station are mounted to a custom cross bar which is secured into a slot on top of the mast by a spring-pin locked cap. The GPS antenna is secured to this cap at the center of the mast with the four-point sampling probe and canister port directly below. After the instrumentation has been mounted to the mast, the connection to the junction box and the bundled cable are made. Each instrument is connected using a unique 9-pin twist connector to the junction box. The Teflon sampling line is then connected to the back of the inlet port using a Swagelock® connector and a BNC cable is connected to the GPS antenna.

The 100-foot bundled cable usually contains both the sampling line and power/data cables. With one end of the bundled cable secured at the mast top, the cable is usually guided through an open window of the measurement vehicle and attached to the pump and instrument controls. Due to its sampling line size, the NEIC vehicle’s air handling is permanently routed underneath the vehicle. The Waste Management GMAP uses the back of a truck for mounting instruments. The bundled cable is attached to the side of the mast using the mounting clips and to the vehicle body using mounting magnets. Inside of the vehicle, excess bundled cable is stowed and the appropriate connections to the instruments and pump are made. The connections will vary based on installed components.

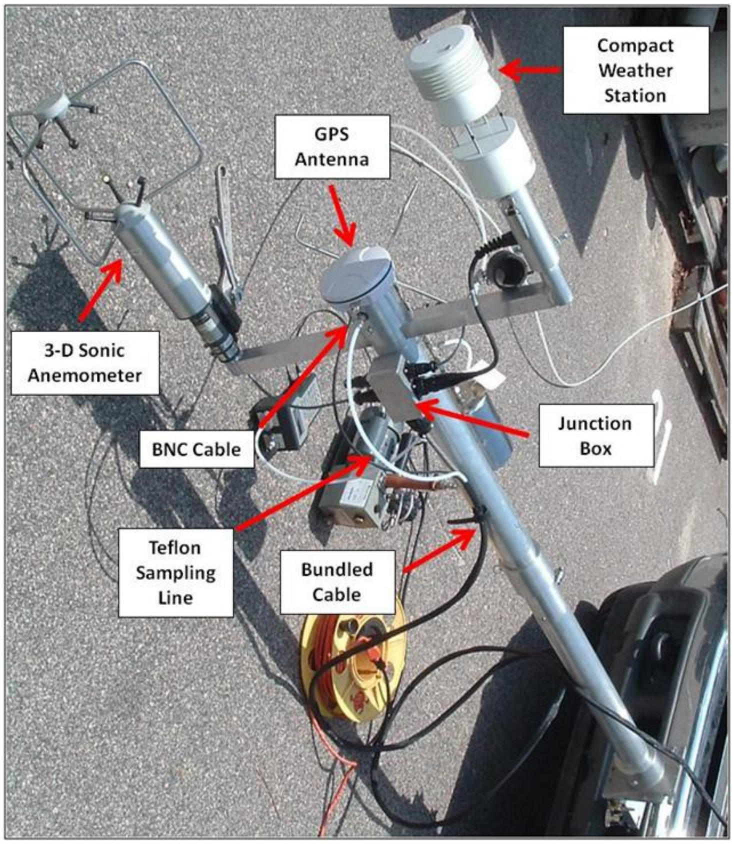

Figure A3-4. View of mast components and cable connections

References:

(1) Rella, C. W., Chen, H., Andrews, A. E., Filges, A., Gerbig, C., Hatakka, J., Karion, A., Miles, N. L., Richardson, S. J., Steinbacher, M., Sweeney, C., Wastine, B., and Zellweger, C.: High accuracy measurements of dry mole fractions of carbon dioxide and methane in humid air, Atmos. Meas. Tech., 6, 837-860, doi:10.5194/amt-6-837-2013, 2013.