DEVELOPMENT OF AN AUXILIARY POWER UNIT SPECIFICATION FOR MEDIUM DUTY SERIES HYBRID ELECTRIC VEHICLES

INTERIM REPORT
TFLRF No. 332

By

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13. ABSTRACT (Maximum 200 words)

As a part of the Defense Advanced Research Projects Agency (DARPA) program to develop hybrid and electric vehicles, a specification for medium duty auxiliary power units (APUs) was developed. The scope of this work defines the interface requirements of an APU or range extender for use in series hybrid electric vehicles. Intended applications include medium duty commercial vehicles and buses. For the purposes of this specification an APU is defined as a device that converts a stored source of potential energy to electrical power. The specification addresses safety, environmental, electrical interface, message interface, control, analogue interface, and mechanical interface.

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EXECUTIVE SUMMARY

The scope of this document is to define the interface requirements of an auxiliary power unit (APU) for use in series hybrid electric vehicles. Intended applications are medium-duty commercial vehicles and buses. An APU is defined as a device that converts a stored source of potential energy to electrical power. The control interface utilizes a digital communication network to link the APU with the electric drive controller for the purposes of this specification. Commands are sent to the APU via this communication link.

This specification covers the application of APU compartment mounted components, power electronic components, APU system controller components, auxiliary drives, and fuel type. The systems meeting this specification shall include at least the following components to be mounted within the space claim defined as the APU compartment: air filter, engine of choice, gearbox (if used), generator, engine and generator cooling systems, and catalytic converter (if used). The specification does not cover any ducting up to the entrance of the air filter, any exhaust routing after the exit flange of the catalytic converter, or mufflers.

The development of an APU specification for series hybrid electric vehicles has been a successful cooperative effort involving all aspects of hybrid vehicle design. The specification is updated regularly based on feedback from persons and companies that have reviewed and/or implemented the specification. There are currently seven APUs in operation under the DARPA program to develop hybrid and electric vehicles, which utilizes the specification in their development programs. Copies of the specification have been sent to over 80 companies, both inside and outside the DARPA program. It is the desire of the specification developers to submit the specification to SAE for approval as a recommended practice.

FOREWORD/ACKNOWLEDGMENTS

The authors wish to acknowledge the many industry participants without whose cooperation this specification would not have been as comprehensive. Thanks in particular to Jim Pollinis of SwRI for his contributions.

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I. INTRODUCTION

The development of the APU specification was the result of a cooperative effort between the following industry experts: APU developers, vehicle integrators, communications and controls, and electric power generator/alternator developers. Several meetings were held, and the specification went through several iterations of peer review. The current version is 3.0.

The scope of this document is to define the interface requirements of an auxiliary power unit (APU) for use in series hybrid electric vehicles. Intended applications are medium duty commercial vehicles and buses. An APU is defined as a device that converts a stored source of potential energy to electrical power. The control interface utilizes a digital communication network to link the APU with the electric drive system. A higher level computer (called the electric drive controller for the purposes of this specification) determines control of the APU. Commands are sent to the APU via this communication link.

Appendix B lists the documents referenced in this specification. In the event of a conflict between the text of this specification and the references cited herein, the text of the specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

This specification covers the application of APU compartment mounted components, power electronic components, APU system controller components, auxiliary drives and fuel type. The systems meeting this specification shall include at least the following components to be mounted within the space claim defined as the APU compartment: air filter, engine of choice, gearbox (if used), generator, engine and generator cooling systems, and catalytic converter (if used). The specification does not cover any ducting up to the entrance of the air filter, exhaust routing after the exit flange of the catalytic converter, or mufflers.

The power electronics components and the APU system controller components may be located outside of the APU compartment. This is to facilitate development by requiring that these components withstand the ambient temperature range rather than the elevated temperature range of the APU compartment.

APU systems meeting this specification shall not be required to have auxiliary mechanical drives. However, such drives are allowable. In support of these drives, communication network messages are reserved for future usage.

Compressed natural gas, diesel fuel, gasoline, and liquid propane gas are supported by this specification.

II. SAFETY AND INTERLOCKING

Due to high voltages present on hybrid electric vehicles, safety is of prime importance. The APU, being a high voltage power generating subsystem, is no exception, and it should adhere to the same safety standards as the rest of the electric drive system. However, it is usually the electric drive controller's responsibility to determine whether it is safe to operate. In this light, the devised interlock signal includes a simple interface that enables APU applications to a wide range of vehicles. This interlock signal consists of a current loop that is controlled by the electric drive controller. The APU merely monitors and responds to that signal. The presence of current signifies a safe system, and the APU is allowed to operate normally. Loss, or lack, of current requires that the APU immediately shutdown and discharge its output voltage to a safe level. At that time, the APU is also required to send a message over the communication link to inform the electric drive controller of the reason for shutting down.

III. ENVIRONMENTAL

An environmental section is included in this specification to ensure that companies new to the commercial transportation industry are aware of the conditions to which their products would be exposed. All conditions, except vibration and shock were obtained directly from the Jan 88 SAE Recommended Practice J1455 Joint SAE/TMC Recommended Environmental Practices For Electronic Equipment Design (Heavy-Duty Trucks. Since J1455 is for diesel-powered vehicles and cab or engine-mounted components, the mechanical vibration and mechanical shock data is not truly representative of hybrid electric vehicles, where components are more likely to be chassis mounted. Data from Allison Transmission is utilized for mechanical vibration and mechanical shock. These curves (Figures 1, 2 and 3) were derived from years of vehicle testing on many different chassis.

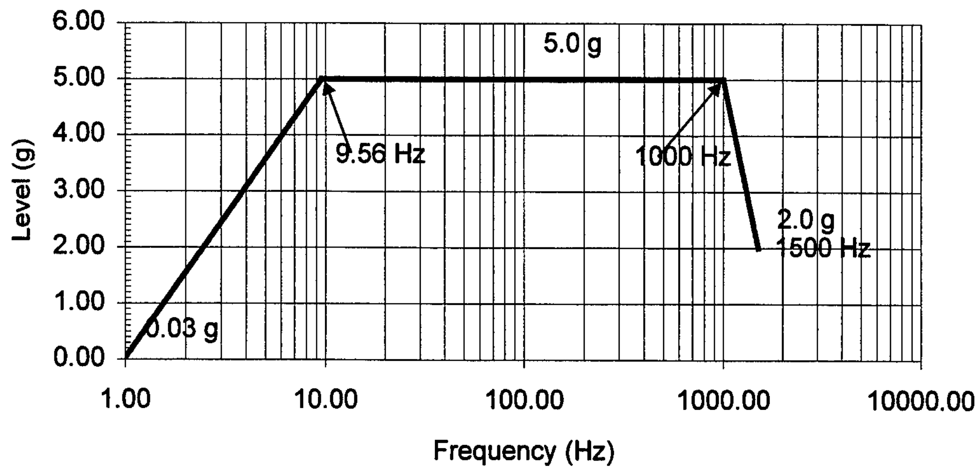

Figure 1. Mechanical Shock as a Function of Frequency Spectrum

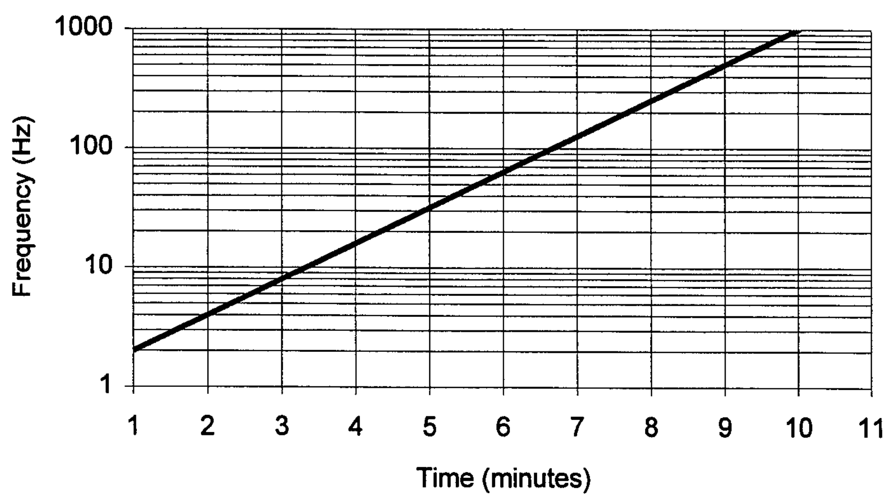

Figure 2. The Duration to be Applied for Each Frequency of Figure 1

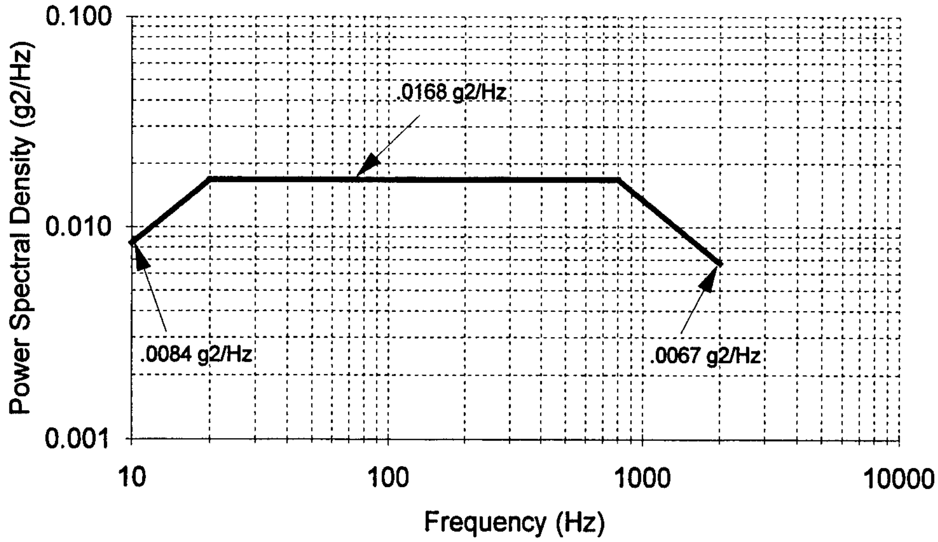

Figure 3. **Power Spectral Density to be Applied Across Frequency Range**

Since the initial publication of this APU interface specification, J1455 has been completely revised. Future versions of this specification should consider using the updated J1455 mechanical vibration and mechanical shock data. In any case, J1455 should be referenced, but not detailed, in this APU interface specification.

IV. ELECTRICAL

A. Voltages

The output voltage range for full power operation is specified to be 240 - 360 volts DC (Figure 4). This range will accommodate battery packs of 20 – 30, 12-volt modules, typical of commercial vehicles. The maximum output voltage (hardware limit) at which any APU power is produced must be specified on an application-by-application basis as a function of nominal battery pack voltage (number of modules) and possibly battery type. Below this hardware limit, the specification allows a software voltage limit. This software limit enables the APU voltage limit to be changed during vehicle operation, allowing the system operation to be tailored based on battery state of charge, battery temperature, etc. These voltage limits are also shown graphically in an output power envelope diagram. In addition to the operational voltages, and depending on the high voltage system architecture, the APU may be exposed to higher voltages during stationary battery charging. The APU does not have to operate at these voltages, but must withstand charging voltages that may be as high as 450 volts DC.

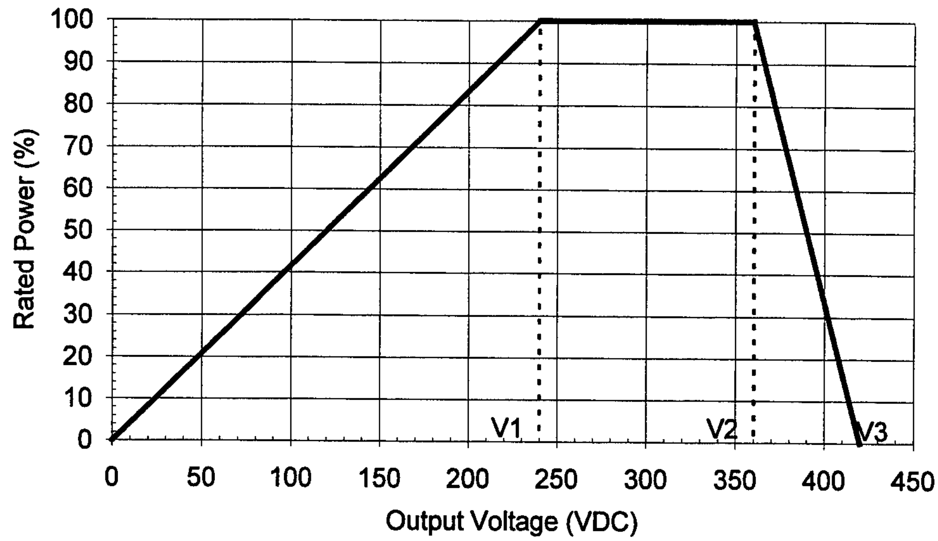

Figure 4. <u>Output Voltage Operating Range as a Function of Rated Power</u>

B. Output Voltage Ripple

The AC output of the APU's generator, being a rotating electrical machine, must be conditioned before it is passed on to the high voltage DC bus. Depending on the extent of the conditioning, some AC component, called ripple, will still be present. Cost and complexity of the conditioning increase as the allowable ripple decreases. Therefore, a compromise must be made between the amount of allowable ripple and the complexity and cost of the conditioning. The ripple is specified for a pure resistive load to enable verification testing. In actual operation, the ripple should be reduced as a result of the system capacitance.

C. Transient Operation

The actual voltage of the high-voltage DC bus of a commercial hybrid electric vehicle can be very dynamic. Heavy accelerations produce voltage drops, and regenerative braking produces voltage increases. During these transient conditions, the APU must continue to operate in a controlled fashion. Voltage and current limits may temporarily reduce the output power; however, the performance of the APU must not be permanently degraded as a result of these voltage variations.

D. High Voltage Bus Equalization

Depending on system architecture, the combination of high voltage bus capacitance and sudden connection of the APU outputs to the high voltage bus could result in large in-rush currents that could potentially damage components. To prevent this damage from occurring, the APU can be equipped with hardware that blocks this in-rush current. Alternatively, a procedure can be defined that allows the system capacitance to be charged up in a controlled fashion. If a slow charge procedure is utilized, system architecture differences dictate that this procedure be coordinated on an application-by-application basis.

E. High Voltage Isolation

From a safety standpoint, commercial hybrid electric vehicles typically have floating high voltage systems. This means that the high voltage bus is not referenced (connected) to the vehicle chassis. The voltage is a relative measurement between the positive and negative terminals of the battery pack, and it remains isolated from the chassis. An isolation resistance for the APU output leads is specified to allow integration into such a system. However, it does not prevent APUs that meet this specification from being used in a system with high voltage grounded to the chassis.

F. Case Ground

Typically on electric and hybrid electric vehicles, high voltage components are mounted in some type of enclosure to prevent people, especially service and maintenance personnel, from being exposed to potentially dangerous voltages. If these enclosures are conductive, it is possible, though unlikely, that an enclosure could become electrified with high voltage as the result of some failure. In order to prevent this from occurring, thus preserving system safety, all such cases should be grounded to the vehicle chassis.

V. ELECTROMAGNETIC COMPATIBILITY

The APU shall meet a modified electromagnetic compatibility MIL-STD-461C, Part 10 specification. These modifications are detailed in the specification (Appendix A).

VI. ELECTROMAGNETIC SUSCEPTIBILITY

The APU shall also meet electromagnetic susceptibility specifications from a modified SAE J1113, as well as a modified MIL-STD-461C. These modifications are detailed in the specification (Appendix A).

VII. PHYSICAL INTERFACE

A. Communications Network

The digital communications network is based on the SAE draft recommended practice J1939. The physical layer of the network shall comply with J1939/11, and application layer shall conform to the J1939/71 portion of the specification. The message set is specified by the APU specification.

The configuration commands provide methods for allowing better matching of the APU and the electric drive system. Each of the commands in this specification is designed to enable the electric drive controller to dynamically modify the characteristics of the APU. The commands provided for in the specification are:

- APU upper voltage limit
- APU upper current limit
- Requested APU electrical power level
- APU electrical power produced
- APU engine start/stop

Informational messages are used to report general information such as present output current, engine speed, etc. Messages not provided for in this specification are permitted in miscellaneous message provisions. Informational messages provided for in this specification are:

- APU fault warning
- APU fault shutdown
- APU scheduled maintenance required
- APU unscheduled maintenance required
- APU limiting conditions
- current output
- voltage output
- starting battery voltage
- hardware maximum current
- maximum no-load voltage
- engine speed
- engine oil pressure
- engine oil filter delta pressure
- fuel delivery pressure
- turbocharger boost pressure
- engine oil temperature
- coolant temperature
- exhaust temperature
- intake manifold temperature
- generator temperature
- running time
- cumulative energy produced
- number of engine starts
- APU identification
- time until next maintenance
- time until next oil change
- coolant level
- fuel level
- throttle position

The data content definitions for use in the communication network should use existing J1939 definitions where possible. Data contents unique to the hybrid electric vehicle have been assigned proprietary data content numbers starting at zero. All implementations of these specifications should consider the APU as the engine and the electric motor drive system as the transmission. This allows the J1939 defined addresses for the engine and transmissions to be applied. All unsupported messages contained in a data content message should have all bits set to 1 to indicate an invalid value.

B. Analog Physical Interface

12-volt DC power in

The 12-volt DC power was divided into two inputs to the APU. The first was intended to be the power source for electronic devices. Therefore, it should be a very stable voltage source to prevent resetting or disrupting the operation of those devices powered with this supply. The second 12-volt DC supply was intended to be used primarily for the engine starter and should be able to handle the high transient currents associated with engine cranking. Due to the range of possible engines, the transient current limit must be defined on an application-by-application basis. For each 12-volt DC supply, the nominal voltage, operational voltage range, allowable voltage spikes, and maximum current draw are also defined.

C. Maintenance Done Signal

If an APU developer/manufacturer implements the capability to track and notify the vehicle and/or service personnel of required maintenance, there must be provisions for resetting these flags once the service has been performed. The preferred method is via the communication link reset message. However, it is desired to provide the means for a manual reset method, which did not require access to the communication link. Implementation of this manual method is optional and the responsibility of the APU supplier.

D. Electrical Connections

A connector and pin-out are specified for the low voltage/current lines in an attempt to standardize. From a reliability and robustness standpoint, the military style connector is preferred over lower cost connectors. Lug connectors are specified for the high current lines in order to have application flexibility to handle the range of APU power levels. In other words, this allows the lug connector to be appropriately sized for the APU output power/current level. With safety in mind, it is also specified that these lug connectors be fully enclosed, with access protected by the interlock circuit.

E. Mechanical Physical Interface

Due to the application-specific packaging of APUs and the current maturity level of commercial hybrid electric vehicles, a common mechanical interface is not practical. At this time, this interfacing is to be coordinated by the vehicle manufacturer, the electric drive system supplier, and the APU supplier.

VIII. CONCLUSION

The development of an APU specification for series hybrid electric vehicles has been a successful cooperative effort involving all aspects of hybrid vehicle design. The specification is updated regularly based on feedback from persons and companies that have reviewed and/or implemented the specification. There are currently seven APUs in operation under the DARPA program to develop hybrid and electric vehicles, which utilizes the specification in their development programs. Copies of the specification have been sent to over 80 companies, both inside and outside the DARPA program. It is the desire of the specification developers to submit the specification to SAE for approval as a recommended practice.

APPENDIX A

Auxiliary Power Unit/Range Exender Interface Reqirements Specification

DARPA PROGRAM

RA93-23

Auxiliary Power Unit/Range Extender Interface Requirements Specification

Prepared by:

Southwest Research Institute
and
Allison Transmission Division of GMC

Version: 3.0

March 20, 1996

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO
DETROIT
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WASHINGTON, DC

DARPA Program

RA93-23

Auxiliary Power Unit / Range Extender Interface Requirements Specification

Version: 3.0

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1. Scope

The scope of this document shall be to define the interface requirements of an auxiliary power unit (APU) or range extender for use in series hybrid electric vehicles. Intended applications shall include medium duty commercial vehicles and small transit buses. An APU shall be defined as a device that converts a stored source of potential energy to electrical power.

2. General

2.1. Referenced Documents

The following is a list of the documents referenced in this specification. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

ANSI/UL 1012-1981, Standard for Power Supplies
SAE Recommended Practice No. J726, Jun87, Air Cleaner Test Code, Society of Automotive Engineers.
SAE Recommended Practice No. J1096, Feb87, Measurement of Exterior Sound Levels for Heavy Trucks Under Stationary Conditions, Society of Automotive Engineers.
SAE Recommended Practice No. J1113, Aug87, Electromagnetic Susceptibility Measurement Procedures for Vehicle Components (Except Aircraft), August, Society of Automotive Engineers.
SAE Recommended Practice No. J1455, Jan88, Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks), Society of Automotive Engineers.
SAE Recommended Practice No. J1939, draft of Recommended Practice for a Serial Control and Communications Vehicle Network, Class C, Society of Automotive Engineers.

Military Standard MIL-STD-461C, 4 August 1986, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, Department of Defense.
Military Specification MIL-C-5015G,9 May 1980, Connectors, Electrical, Circular Threaded, AN Type, General Specification for, Department of Defense.

2.2. Included Components

2.2.1. APU Compartment Mounted Components

APU systems meeting this specification shall include at least the following components to be mounted within the space claim defined as the APU compartment:

air filter
engine of choice
gearbox (if used)
generator
engine and generator cooling system
catalytic converter (if used).

The vehicle manufacturer or systems integrator shall be responsible for any necessary ducting up to the entrance of the air filter and any necessary exhaust routing away from the exit flange of the catalytic converter. Mufflers may be provided with the APU, but are not covered in this document.

2.2.2. Power Electronic Components

The power electronics components may be located outside of the APU compartment. This is to facilitate development by requiring that these components withstand the ambient temperature range rather than the elevated temperature range of the APU compartment.

2.2.3. APU System Controller Components

The APU system controller components may be located outside of the APU compartment. This is to facilitate development by requiring that these components withstand the ambient temperature range rather than the elevated temperature range of the APU compartment.

2.3. Auxiliary Drives

APU systems meeting this specification shall not be required to have auxiliary mechanical drives. However, such drives shall be allowable. In support of these drives, communication network messages shall be reserved for future usage.

2.4. Fuel Type

The following fuel types shall be supported by this specification:

compressed natural gas
diesel fuel
gasoline
liquid propane gas.

3. Safety

Upon detection of the loss of the interlock signal (Ref. section 6.1.2.3) or any exposure of high voltage, the output voltage of the APU shall be discharged to 42.4 volts, or below, within 250 milliseconds. (42.4 volt level is from ANSI/UL 1012-1981 Standard for Power Supplies)

4. Environmental

4.1. Ambient Temperature

Ambient air shall range in temperature from -40 to 85 °C (-40 to 185 °F). (from SAE J1455)

4.2. APU Compartment Temperature

The APU shall be capable of operating with no degradation in performance at all compartment temperatures between -40 and 123 °C (-40 and 253 °F). (from SAE J1455)

4.3. Storage Temperature

The APU shall be capable of operating with no degradation in performance after exposure to ambient temperatures between -50 and 85 °C (-58 and 185 °F) for a maximum 24 hour period. (from SAE J1455)

4.4. Vibration

The APU shall be subjected to both sinusoidal and random vibrations and shall remain operational, with no degradation in performance before, during and after the vibration.

4.4.1. Sinusoidal Vibration

The APU shall be subjected to an initial sweep with vibration in each of three mutually perpendicular axes. The frequency of vibration shall be varied between 10 and 1500 Hz, at levels defined by Figure 1, with a sweep rate defined in Figure 2. During the initial sweep, all major resonant frequencies shall be identified. The APU shall then be vibrated for 30 minutes in each of the three axes at the four lowest resonant frequencies. The APU shall be running and monitored for performance during the test. Spectrum was derived by Allison Transmission Division of General Motors Corporation (ATD) from test data and experience with chassis mounted equipment.

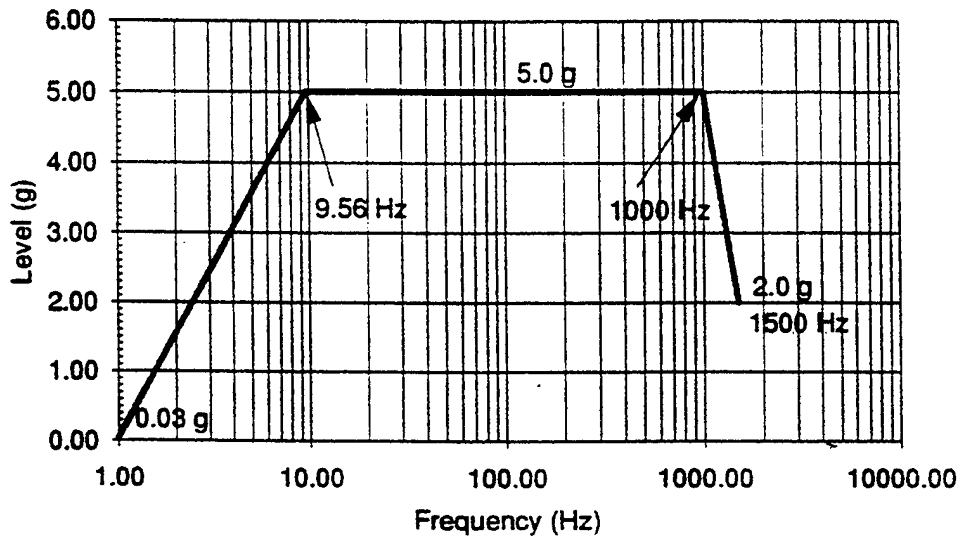

Figure 1 Sinusoidal Vibration Spectrum

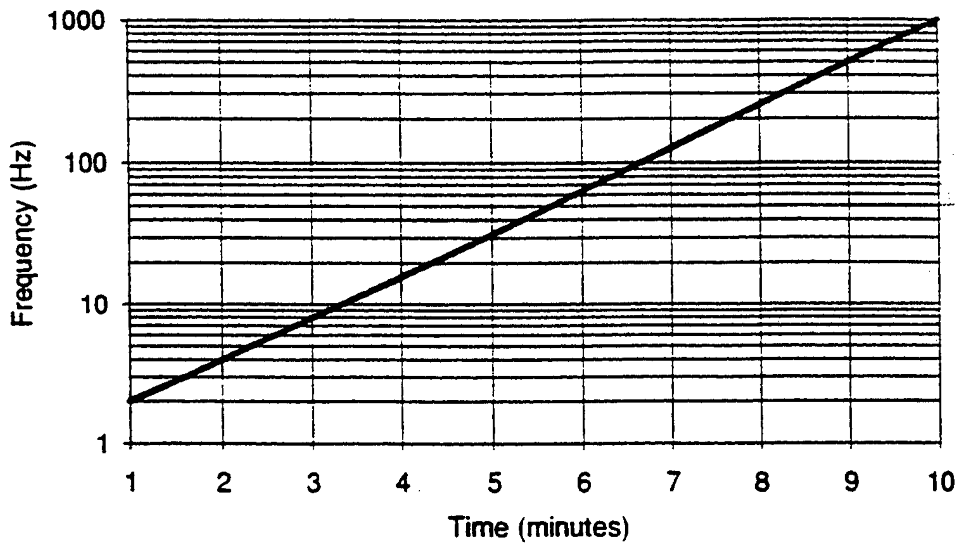

Figure 2 Sweep Rate For Sinusoidal Vibration Test

4.4.2. Random Vibration

The APU shall be subjected to 100 hours of random vibration testing in each of three mutually perpendicular axes. The power spectral density is shown in Figure 3. This spectrum ranges from 10 to 2000 Hz and has a total content of 5 g rms. The APU shall be running and monitored for performance during the test. Spectrum was derived by ATD from test data and experience with chassis mounted equipment.

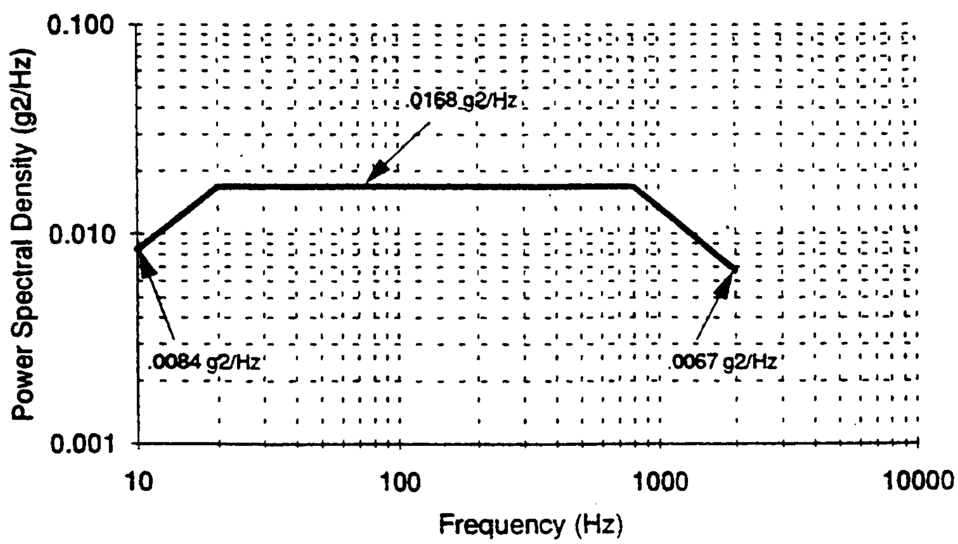

Figure 3 Random Vibration Spectrum, 5.05 g rms Total (ATD Chart 90-027)

4.5. Shock

The APU shall be capable of withstanding 3 shocks, in each direction, along 3 mutually perpendicular axes, for a total of 18 shocks. The shock pulse shall be a half-sine, with an amplitude of 20 g and a duration of 18 ms. The duration shall be measured from a reference line of zero g. The APU shall operate, with no degradation in performance, before, during and after the shocks. (Derived by ATD)

4.6. Humidity

The APU shall be capable of withstanding up to 100% relative humidity with no degradation in performance. (from SAE J1455)

4.7. Sand and Dust

The APU shall be capable of operating with no degradation in performance during and after exposure to sand and dust per Section 4.7 of SAE J1455. Briefly, the test consists of a 24 hour exposure to a concentration of 0.88 g/m^3 (0.025 g/ft^3) of coarse grade dust as defined in SAE J726. See the referenced SAE Recommended Practices for more details.

4.8. Salt Spray

The APU shall be capable of operating with no degradation in performance during and after exposure to a solution of 5 parts salt and 95 parts water at 35 °C (95°F) for a period of at least 24 hours and not to exceed 96 hours. Actual exposure time shall be determined by the specific location. (from SAE J1455)

4.9. Noise Signature

The noise signature should be 62 dBA maximum measured at 10 feet. Test shall be conducted per SAE J1096 under the following conditions or exceptions:

- APU installed in the vehicle
- APU operating at rated power
- noise levels to be measured at a minimum of 3 locations around vehicle to determine the overall maximum.

Note: This is a goal, not a requirement. At this time, with limited vehicle experience, actual noise requirements are unknown. However, it is anticipated that the requirements will eventually involve both an idle requirement and a rated power requirement.

5. Electrical

5.1. DC Output Voltage Range

The APU shall be capable of delivering full DC power at voltages ranging from 240 to 360 volts. (Derived by Southwest Research Institute)

5.2. Output Voltage Ripple

The steady state output voltage ripple shall be less than 5% (peak to peak) of the maximum full power voltage (as specified in Section 5.1) for a purely resistive load at rated power.

5.3. Maximum DC Output Voltage Limits

Two maximum voltage limits shall be available with the APU. A hardware limit shall be the absolute maximum voltage; whereas, the software limit shall allow dynamic changes to optimize operation.

5.3.1. Hardware Limit

The APU shall have the capability of limiting the maximum DC output voltage. This shall be based on APU hardware limitations. This limit shall be set by the APU manufacturer and the actual value shall be coordinated with the vehicle manufacturer or systems integrator

5.3.2. Software Limit

The APU shall also have the capability of limiting the maximum DC output voltage to a value below the above hardware limit by means of a command on the communication network. This adjustment can occur at any time during vehicle operation.

5.4. Output Power Envelope

The maximum output power envelope shall be as shown in Figure 4, with voltages defined as below:

V1 = 240 VDC
V2 = 360 VDC
V3 = 420 VDC

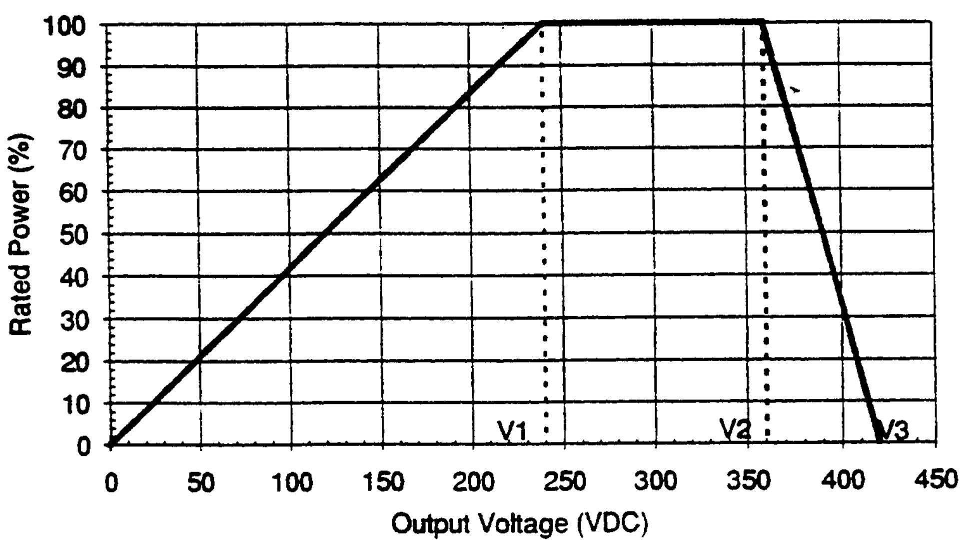

Figure 4 Maximum Output Power Envelope

5.5. Transient Operation

During transient conditions due to sudden load variations, the APU shall be capable of operating with no degradation in performance up to the maximum output voltage as defined in Sections 5.3 and 5.4. Load variations shall include sudden load increases which create high current draws, and sudden load drops which create momentary voltage transients. These load drops can occur during regenerative braking or in the event the APU is disconnected from the high voltage DC bus.

5.6. Charging Voltages

During battery charging, the APU shall withstand voltages up to 450 VDC, but not operate. After charging, the APU shall operate with no degradation in performance.

5.7. High Voltage DC Bus Equalization

Initialization of the APU to the high voltage DC bus shall be accomplished in such a manner that no large currents (more than 50 Amps) flow out of the vehicle and into the APU. Acceptable methods of meeting this requirement shall include hardware that blocks the in-rush current or a "pre-charge" process. If a "pre-charge" process is utilized, it can be internal (APU supplied and controlled) or external (vehicle supplied and controlled). In either case, the process shall be coordinated with the vehicle manufacturer or systems integrator.

5.8. High Voltage Isolation

The minimum DC isolation resistance of any major component which interfaces with the high voltage DC bus shall be no less than 5 megaohms. This resistance shall be maintained over the life of the APU. This resistance will be measured at nominal high voltage DC bus voltage from either positive or negative terminal relative to vehicle metal (conductive structure).

5.9. Case Ground

All components that are connected to the high voltage DC bus shall be grounded to the vehicle chassis.

5.10. Electromagnetic Compatibility

The APU shall meet a modified MIL-STD-461C, Part 10 specification. The modifications are specified in the following sections.

5.10.1. Conducted Emissions, 50 kHz to 50 MHz

The MIL-STD-461C UM05 50 kHz limit and point shall be relaxed by a factor or 20*log(load current / 10) and a straight line shall be drawn from the adjusted endpoint to the 2 MHz, 50 dBµA/MHz point.

5.10.2. Radiated Emissions, Electric Field, 14 kHz to 1 GHz

The UM04 limits shall be used as shown in Figure 9-2 of MIL-STD-461C.

5.11. Electromagnetic Susceptibility

The APU shall meet specifications from a modified SAE J1113, as well as a modified MIL-STD-461C. The modifications shall be detailed in the follow sections.

5.11.1. Conducted Susceptibility, 30 Hz to 50 kHz

1.5 V_{rms} or 50 W, whichever comes first (modified from SAE J1113).
50 W with output impedance equal to, or less than, 2.0 Ω (capable of delivering 50 W into a 0.5 Ω resistive load connected across an isolation transformer secondary) (modified from SAE J1113).
Use MIL-STD-461C CS01 limits in the 30 Hz to 15 kHz range.
Use MIL-STD-461C CS02 limits in the 15 kHz to 50 MHz range.

5.11.2. Conducted Susceptibility, 50 kHz to 100 MHz

A 50 Ω output impedance source with an output of 100 V or greater into a matched load shall be used. (modified from SAE J1113)
MIL-STD-461C CS02 limits shall be used in the 50 kHz to 100 MHz range.

5.11.3. Conducted Susceptibility, Transients

Testing shall be done per SAE J1113, using a pulse generator capable of producing the following test pulses:

5.11.3.1. Test Pulse 1 (Disconnection from Inductive Loads)

V_s = -100 V
R_i = 10 Ω
T = 2 ms
T_r = 1 µs
t_2 = earliest possible time
V_r = 13.5 VDC, typical

5.11.3.2. Test Pulse 2 (Sudden Interruption of a Series Current)

V_s = 100 V
R_i = 10 Ω
T = 0.05 ms
T_r = 1 µs
t_1 = 2 s
V_r = 13.5 VDC, typical

5.11.3.3. Test Pulse 3A (Switching Spikes, Type "A")

V_s = -150 V
R_i = 50 Ω
T = 0.1 µs
T_r = 0.005 µs
t_1 = 100 µs
t_2 = 10 ms
t_3 = 80 ms
V_r = 13.5 VDC, typical

5.11.3.4. Test Pulse 3B (Switching Spikes, Type "B")

V_s = 100 V
R_i = 50 Ω
T = 0.1 µs
T_r = 0.005 µs
t_1 = 100 µs
t_2 = 10 ms
t_3 = 90 ms
V_r = 13.5 VDC, typical

5.11.3.5. Test Pulse 4 (Single Pulse)

Not Applicable

5.11.3.6. Test Pulse 5 (Load Dump, Single Pulse)

V_s = 80 V
R_i = 2 Ω
T = 400 ms
T_r = 10 ms
V_r = 13.5 VDC, typical

5.11.3.7. Test Pulse 6 (Ignition Coil Current Interruption)

V_s = -300 V
R_i = 4 Ω
T = 300 µs
T_r = 60 µs
t_1 = 15 µs
t_2 = 1 s
t_3 = typical 5 pulses at 10 s intervals
V_r = 13.5 VDC, typical

5.11.3.8. Test Pulse 7 (Load Dump)

V_s = -80 V
R_i = 4 Ω
T = 200 ms
T_r = 10 ms
t_r = typical 5 pulses at 10 s intervals
V_r = 13.5 VDC, typical

5.11.4. Radiated Susceptibility, Power Line Magnetic Field 60 Hz to 30 kHz

Magnetic flux density shall be 160 decibels per picoTesla (dBpT) at 60 Hz and falling off at a rate of 12 dB/octave to 30 kHz, with testing done per SAE J1113.

5.11.5. Radiated Susceptibility, 14 kHz to 18 GHz

E-field shall be at a field intensity of 100 V/m, with testing done per SAE J1113

6. Physical Interface

6.1. Electrical Interface

6.1.1. Digital Communication Network

The communications network will be founded on the SAE draft recommended practice J1939. The physical layer of the network shall comply with J1939/11. The application layer shall conform to the J1939/71 portion of the specification. Refer to the entire J1939 specification for details. The message set is detailed in the following sections.

6.1.1.1. Control Messages

Configuration commands provide methods for allowing better matching of the APU and Electric Drive System. Each of these commands enables the *Electric Drive Controller* (EDC) to dynamically modify the characteristics of the APU.

6.1.1.1.1. APU Upper Voltage Limit

This command is used to limit the maximum voltage that the APU will produce. A typical application of this command is to set a voltage limit that prevents gassing of the battery pack. This limit can be lower but not higher than the limits inherent to the APU design.

The cutoff is defined as the line described by the line ***V2-V3*** in Figure 4. Point ***V2*** represents the APU's maximum voltage produced at full power. Point ***V3*** represents the maximum voltage output without any power (upper voltage limit). In order to support variations in battery pack design and/or power management schemes, the upper voltage limit will be adjustable up to fixed maximum value set in the APU. Throughout the adjustments, the cutoff slope will remain constant.

Data Length:	2 bytes
Resolution:	0.05 V/bit gain, 0 V offset
Data Range:	0 to +3212.75 V
Type:	Measured

6.1.1.1.2. APU Upper Current Limit

This command limits the amount of current the APU can produce. The current limit can be changed dynamically to handle conditions such as battery pack recharge. This limit can be lower but not higher than the limits inherent to the APU design.

Data Length:	2 byte

Resolution:	0.05 A/bit gain, 0 A offset
Data Range:	0 to +3212.75 A
Type:	Measured

6.1.1.1.4. Requested APU Electrical Power Level

The electrical power level packet is originated by the Electric drive controller. The command serves two purposes. The first provides the mechanism whereby the electric drive controller requests the APU to make more or less power. The second purpose provides a *heartbeat* link between the APU and Electric drive controller.

The Electric drive controller must make a request every 50 milliseconds. The Electric drive controller will be considered off-line if 150 milliseconds elapse without a power request. When the Electric drive controller is considered off-line, the APU shall declare that it is shutting down due to a fault and then shut its engine off.

The transmission of a Requested Electrical Power Level packet is not dependent on other events or data packets. It is an asynchronous transmission that commences as soon as the communications network comes on-line.

Data Length:	2 bytes
Resolution:	.05 kW/bit gain, 0 kW offset
Data Range:	0 to +3212.75 kW
Type:	Measured

6.1.1.1.5. APU Electrical Power Produced

This packet originates at the APU and is transmitted to the Electric drive controller every 50 milliseconds. The data packet may contain zero (0) or any positive value less than or equal to 3212.75 kilowatts (kW). A data packet containing a value with all bits set ($0xFFFF_{16}$) is reserved to indicate the APU is operational but not running.

The APU controller must report the amount of power produced every 50 milliseconds. The APU will be considered off-line if 150 milliseconds elapse without transmission of an Electric Power Produced packet. When the APU controller is considered off-line, the vehicle controller shall command zero power and command the engine to stop.

The transmission of an Electrical Power Produced packet is not dependent on other events or data packets. It is an asynchronous transmission that commences as soon as the communications network comes on-line.

Data Length:	2 bytes
Resolution:	.05 kW/bit gain, 0 kW offset
Data Range:	0 to +3212.75 kW , $0xFFFF_{16}$ indicates APU on-line but not running
Type:	Measured

6.1.1.1.6. APU Engine Start/Stop

The APU Start/Stop command provides a mechanism for allowing the Electric Drive Controller to start and stop the APU engine.

Data Length:	1 byte

Resolution:	N/A
Data Range:	a value of 1 signals a request for the APU to start it's engine a value of 0 signals a request for the APU to stop it's engine
Type:	Measured

6.1.1.2. Informational Messages

Informational messages are used to report general information such as present current being output, APU engine speed, APU oil pressure, etc.

6.1.1.2.1. APU Fault Warning

Fault warning messages inform the driver of conditions that can cause the APU to go into a **Fault Shutdown**. The warning is intended to give the driver time to check the problem before a shutdown occurs. Ignoring the fault may cause the APU to go into a fault shutdown condition. Individual fault warnings shall be cleared automatically by the APU controller when the condition is no longer present. Message shall be retransmitted at each condition change.

Data Length:	2 bytes
Resolution:	N/A - Bit mapped fields
Data Range:	1 to 63

Bit Position	Description
0	Oil Temperature High
1	Oil Pressure High
2	Oil Pressure Low
3	Coolant Temperature High
4	Exhaust Temperature High
5	Low APU Battery
6-15	Unused

0 = condition not present
1 = condition present

Table 1 APU Fault Warning Bit Map

6.1.1.2.2. APU Fault Shutdown

The fault shutdown condition is transmitted to indicate the APU is immediately going off-line due to a fault in the APU. Examples of these fault conditions include over temperature, low oil pressure, failure to start APU, etc. Individual fault shutdowns shall be latched by the APU controller and shall be cleared only by the appropriate reset message from the vehicle controller.

Data Length:	2 bytes
Data Range:	N/A - Bit mapped fields
Data Range:	1 to 16383

Bit Position	Description
0	Oil Temperature High
1	Oil Pressure High
2	Oil Pressure Low
3	Coolant Temperature High
4	Exhaust Temperature High
5	Over Voltage
6	Under Voltage
7	Over Current
8	APU Overspeed
9	APU Underspeed
10	Loss of Heartbeat
11	APU Overcranking
12	APU Failed to Crank
13	Loss of APU Speed Sensor
14	Loss of Interlock
15	Unused

0 = condition not present
1 = condition present

Table 2 APU Fault Shutdown Bit Map

6.1.1.2.3. APU Scheduled Maintenance Required

A scheduled maintenance required message is issued to inform the driver of required periodic maintenance. Periodic oil changes, filter changes, etc. can be handled with messages of this class. Individual scheduled maintenance requests shall be latched by the APU controller and shall be cleared only by the appropriate reset message from the vehicle controller.

Data Length: 2 bytes
Resolution: N/A - Bit mapped fields
Data Range: 1 to 127

Bit Position	Description
0	Oil Change
1	Oil Filter Change
2	Air Filter Change
3	Fuel Filter Change
4	Belt Replacement
5	Spark Plug change
6	Tune-up
7-15	Unused

0 = condition not present
1 = condition present

Table 3 APU Scheduled Maintenance Required Bit Map

6.1.1.2.4. APU Unscheduled Maintenance Required

Specifies unscheduled maintenance of the APU is required. This is a bitmapped message where each bit position signals a unique item requiring maintenance. Individual unscheduled maintenance requests shall be latched by the APU controller and shall be cleared only by the appropriate reset message from the vehicle controller.

Data Length: 2 bytes
Resolution: N/A - bitmapped field
Range: 0 to 1023

Bit Position	Description
0	Low oil level
1	High oil level
2	Oil pressure sender out of range
3	Oil temperature sender out of range
4	Coolant temperature sender out of range
5	Exhaust temperature sensor fault
6	Coolant level low
7	Oxygen sensor fault
8	Oil filter service required
9	Air filter service required
10-15	Unused

0 = condition not present
1 = condition present

Table 4 APU Unscheduled Maintenance Required Bit Map

6.1.1.2.5. APU Limiting Conditions

Indicates a request not completed due to a limit set within the APU. Individual limits shall be cleared automatically by the APU controller when the condition is no longer present.

Data Length: 1 byte
Resolution: N/A - bitmapped field
Data Range: 0 to 7

Bit Position	Description
0	Current limited
1	Voltage limited
2	Power request out of range
3-7	Unused

0 = condition not present
1 = condition present

Table 5 APU Limiting Conditions Bit Map

6.1.1.2.6. APU Current Out

Indicates current being output by the APU.

Data Length: 2 bytes
Resolution: 0.05 A/bit gain, 0 A offset

Data Range:	0 to +3212.75 A
Type:	Measured

6.1.1.2.7. APU Voltage Out

Indicates the voltage being output from the APU.

Data Length:	2 bytes
Resolution:	0.05 V/bit gain, 0 V offset
Data Range:	0 to +3212.75 V
Type:	Measured

6.1.1.2.8. APU Starting Battery Voltage

Indicates the potential, in volts, of the APU starter battery.

Data Length:	2 bytes
Resolution:	0.05 V/bit gain, 0 V offset
Data Range:	0 to +3212.75 V
Type:	Measured

6.1.1.2.9. APU Hardware Maximum Current

Maximum current that the APU is able to produce. This value is a function of the APU hardware and cannot be changed via the communication link; it can only be reported.

Data Length:	2 bytes
Resolution:	0.05 A/bit gain, 0 A offset
Data Range:	0 to +3212.75 A
Type:	Measured

6.1.1.2.10. APU Maximum No-Load Voltage

Maximum voltage, without a load, the APU is able to produce. This value is a function of the APU hardware and cannot be changed via the communication link; it can only be reported.

Data Length:	2 bytes
Resolution:	0.05 V/bit gain, 0 V offset
Data Range:	0 to +3212.75 V
Type:	Measured

6.1.1.2.11. APU Engine Speed

APU engine speed in revolutions per minute.

Data Length:	2 bytes
Resolution:	4 RPM/bit, 0 RPM offset
Data Range:	0 to 257,020 RPM
Type:	Measured

6.1.1.2.12. APU Oil Pressure

Gage pressure of the oil in the APU lubrication system as provided by the oil pump.

Data Length:	1 byte
Resolution:	4 kPa/bit (0.58 psi/bit) gain, 0 kPa (0 psi) offset
Data Range:	0 kPa to 1000 kPa (0-145 psi)
Type:	Measured

6.1.1.2.13. APU Oil Filter Delta Pressure

Change in engine oil pressure, measured across the filter, due to the filter and any accumulation of solid material on the filter.

Data Length:	1 byte
Resolution:	0.5 kPa/bit (0.073 psi/bit) gain, 0 kPa (0 psi) offset
Data Range:	0 to +125 kPa (0 to 18.1 psi)
Type:	measured

6.1.1.2.14. APU Fuel Delivery Pressure

Gage pressure of the fuel system as delivered from the supply pump.

Data Length:	1 byte
Resolution:	4 kPa/bit (0.58 psi/bit) gain, 0 kPa (0 psi) offset
Data Range:	0 to +1000 kPa (0 to 145 psi)
Type:	measured

6.1.1.2.15. APU Turbocharger Boost Pressure

Gage pressure of air measured downstream on the compressor discharge side of the turbocharger.

Data Length:	1 byte
Resolution:	2 kPa/bit (0.29 psi/bit) gain, 0 kPa (0 psi) offset
Data Range:	0 to +500 kPa (0 to 72.5 psi)
Type:	measured

6.1.1.2.16. APU Oil Temperature

The temperature of the APU engine lubricant.

Data Length:	2 bytes
Resolution:	0.0625 °C/bit (0.11 °F/bit) gain, -400 °C (-688 °F) offset
Data Range:	-400 to +3615 °C (-688 - 6539 °F)
Type:	measured

6.1.1.2.17. APU Coolant Temperature

The temperature of the APU engine coolant.

Data Length:	1 byte

Resolution:	1 °C/bit (1.8 °F/bit) gain, -40 °C (-40 °F) offset
Data Range:	-40 to 210 °C (-40 - 410 °F)
Type:	measured

6.1.1.2.18. APU Exhaust Temperature

The temperature of the APU engine exhaust gas.

Data Length:	2 bytes
Resolution:	0.0625 °C/bit (0.11 °F/bit) gain, -400 °C (-688 °F) offset
Data Range:	-400 to +3615.0 °C (-688 - 6539 °F)
Type:	measured

6.1.1.2.19. APU Intake Manifold Temperature

The temperature of the APU intake gas.

Data Length:	2 bytes
Resolution:	0.0625 °C/bit (0.11 °F/bit) gain, -400 °C (-688 °F) offset
Data Range:	-400 to +3615.0 °C (-688 - 6539 °F)
Type:	measured

6.1.1.2.20. APU Generator Temperature

Temperature of the electrical power generator.

Data Length:	2 bytes
Resolution:	0.0625 °C/bit (0.11 °F/bit) gain, -400 °C (-688 °F) offset
Data Range:	-400 to +3615.0 °C (-688 - 6539 °F)
Type:	measured

6.1.1.2.21. APU Running Time

The accumulated operational time of the APU.

Data Length:	4 bytes
Resolution:	0.05 hrs/bit gain, 0 hrs offset
Data Range:	0 to 210,554,060.8 hrs
Type:	measured

6.1.1.2.22. APU Cumulative Energy Produced

Cumulative energy produced by the APU, measured in kilowatt hours.

Data Length:	4 bytes
Resolution:	0.05 kW*hrs/bit gain, 0 kW*hrs offset
Data Range:	0 to 210,554,060.8 hrs
Type:	measured

6.1.1.2.23. Number of APU Starts

Accumulated number of times the APU engine was started.

Data Length:	2 bytes
Resolution:	1 start/bit gain, 0 offset
Data Range:	0 to 32767 starts
Type:	Measured

6.1.1.2.24. APU Identification

Serial/Identification number of the APU.

Data Length:	Variable
Resolution:	ASCII
Data Range:	ASCII
Type:	Measured

6.1.1.2.25. APU Time Until Next Maintenance

Number of hours until the next scheduled maintenance for the APU.

Data Length:	2 bytes
Resolution:	1 hour/bit resolution gain, 0 hours offset
Data Range:	0 to 32767 hours
Type:	Measured

6.1.1.2.26. APU Time Until Next Oil Change

Number of hours until the next scheduled oil change for the APU.

Data Length:	2 bytes
Resolution:	1 hour/bit resolution gain, 0 hours offset
Data Range:	0 to 32767 hours
Type:	Measured

6.1.1.2.27. APU Coolant Level

Ratio of volume of liquid found in the APU cooling system to the total cooling system volume.

Data Length:	1 byte
Resolution:	0.4 %/bit gain, 0 % offset
Data Range:	0 to +100 %
Type:	measured

6.1.1.2.28. APU Fuel Level

Ratio of the volume of fuel to the total volume in the fuel storage container.

Data Length:	1 byte
Resolution:	0.4 %/bit gain, 0 % offset

Data Range:	0 to +100 %
Type:	measured

6.1.1.2.29. APU Throttle Position

The ratio of actual acceleration pedal position to the maximum pedal position.

Data Length:	1 byte
Resolution:	0.4 %/bit gain, 0 % offset
Data Range:	0 to +100 %
Type:	measured

6.1.1.3. Miscellaneous Messages

6.1.1.3.1. APU Mechanical Speed

Data Length:	undefined
Resolution:	undefined
Data Range:	undefined
Type:	undefined

6.1.1.3.2. APU Mechanical Power

Data Length:	undefined
Resolution:	undefined
Data Range:	undefined
Type:	undefined

6.1.1.4. Minimum Command Set

The following list constitutes the minimum required set of commands. These commands have all been previously defined. One difference in the definition is the *Cutoff Slope*. In the minimum set, the *Cutoff Slope* is set by either a switch or by a jumper block as opposed to requesting the data via the network.

Control Messages	Informational Messages
Electrical Power Produced	APU Fault Shutdown
Requested Electrical Power Level	
Upper Voltage Limit	
Upper Current Limit	
APU Engine Start/Stop	

Table 6 Minimum Command Set

6.1.1.5. Data Content Definitions

This section defines the data content messages for use in the communication network. Where possible, existing J1939 data content definitions are used. Data contents unique to the hybrid-electric vehicle have been assigned proprietary data content numbers starting at zero (0). All implementations of this specification should consider the APU to be the vehicle *engine* and the electric motor drive system as the vehicle *transmission*. This will allow the J1939 defined addresses for the engine and transmission to be applied.

All unsupported messages contained in a data content message shall have all bits set to 1 to indicate an invalid value.

6.1.1.5.1. APU Output Control: APU1

Transmission repetition rate:	50 ms
Data length:	8 bytes
Data page:	0
Data content identifier:	255
Data content number:	0
PDU specific field:	APU address
Priority:	3

Byte	Description
1,2	requested APU electrical power level
3,4	APU upper voltage limit
5,6	APU upper current limit
7	APU operational mode
8	APU engine start/stop

Table 7 APU Output Control Data Content Description

6.1.1.5.2. APU Maintenance and Fault Shutdown Flag Resets: APU2

Transmission repetition rate:	command transmitted as required
Data length:	8 bytes
Data page:	0
Data content identifier:	255
Data content number:	1
PDU specific field:	APU address
Priority:	6

Byte	Description
1,2	reset mask for scheduled maintenance
3,4	reset mask for unscheduled maintenance
5,6	Fault Shutdown
7-8	Unused

Table 8 APU Maintenance Flag Resets Data Content Description

6.1.1.5.3. APU Warning/Shutdown/Maintenance

Transmission repetition rate:	command transmitted as required
Data length:	8 bytes
Data page:	0
Data content identifier:	255
Data content number:	2
PDU specific field:	Electric Drive controller address
Priority:	6

Byte	Description
1,2	fault warning bit fields
3,4	fault shutdown bit fields
5,6	scheduled maintenance bit fields
7,8	unscheduled maintenance bit fields

Table 9 APU Warning/Shutdown/Maintenance Data Content Description

6.1.1.5.4. APU Limiting Conditions

Transmission repetition rate: command transmitted as required
Data length: 8 bytes
Data page: 0
Data content identifier: 255
Data content number: 3
PDU specific field: Electric Drive controller address
Priority: 6

Byte	Description
1	APU limiting conditions bit fields
2,3	APU hardware maximum current
4,5	APU hardware maximum no-load voltage
6-8	Unused

Table 10 APU Limiting Conditions Data Content Description

6.1.1.5.5. APU Outputs

Transmission repetition rate: every 50 ms
Data length: 9 bytes
Data page: 0
Data content identifier: 255
Data content number: 4
PDU specific field: Electric Drive controller address
Priority: 3

Byte	Description
1,2	APU electrical power produced
3,4	APU current output
5,6	APU voltage output
7,8	APU engine speed in RPM

Table 11 APU Outputs Data Content Description

6.1.1.5.6. APU Pressures

Transmission repetition rate: as requested
Data length: 8 bytes
Data page: 0
Data content identifier: 255

Data content number: 5
DU specific field: Electric Drive controller address
Priority: 6

Byte	Description
1	APU oil pressure
2	APU oil filter delta pressure
3	~~APU fuel delivery pressure~~
4	APU turbocharger boost pressure
5-8	Unused

Table 12 APU Pressures Data Content Description

6.1.1.5.7. APU Temperatures

Transmission repetition rate: as requested
Data length: 9 bytes
Data page: 0
Data content identifier: 255
Data content number: 6
PDU specific field: Electric Drive controller address
Priority: 6

Byte	Description
1,2	APU oil temperature
3,4	APU exhaust temperature
5,6	APU intake manifold temperature
7,8	APU generator temperature
9	APU coolant temperature

Table 13 APU Temperatures Data Content Description

6.1.1.5.8. Component Identification

Transmission repetition rate: as requested
Data length: variable
Data page: 0
Data content identifier: 254
Data content number: 16107
PDU specific field: 235
Priority: 6

Field	Description
a	make including 3 trailing asterisks (ASCII "*") as a delimiter
b	model including 3 trailing asterisks (ASCII "*") as a delimiter
c	serial number

Table 14 Component Identification Data Content Description

Note: The make, model, and serial number fields in this message are optional and separated by the delimiter. It is not necessary to include all fields, however, the delimiter is always required.

6.1.1.5.9. APU Operational Hours

Transmission repetition rate:	as requested
Data length:	8 bytes
Data page:	0
Data content identifier:	255
Data content number:	7
PDU specific field:	Electric Drive controller address
Priority:	6

Byte	Description
1-4	APU running time
5-8	APU running kW hours

Table 15 APU Operational Hours Data Content Description

6.1.1.5.10. APU Maintenance Scheduling

Transmission repetition rate:	as requested
Data length:	8 bytes
Data page:	0
Data content identifier:	255
Data content number:	8
PDU specific field:	Electric Drive controller address
Priority:	6

Byte	Description
1,2	Number of APU starts
3,4	APU time until next maintenance
5,6	APU time until next oil change
7,8	Unused

Table 16 APU Maintenance Scheduling Data Content Description

6.1.1.5.11. APU Levels/Starter Battery Voltage

Transmission repetition rate:	as requested
Data length:	8 bytes
Data page:	0
Data content identifier:	255
Data content number:	9
DU specific field:	Electric Drive controller address
Priority:	6

Byte	Description
1	APU coolant level
2	APU fuel level
3-4	APU Starting Battery Voltage
5-8	Unused

Table 17 APU Levels/Starter Battery Voltage Data Content Description

6.1.2. Analog Interface

6.1.2.1. 12 volt Power In

A "switched" 12 VDC supply shall be supplied to the APU from the vehicle as a source of "clean" power for electronic equipment. This supply shall be switched with the vehicle ignition. Continuous current draw shall not exceed 5 A. Nominal voltage shall be 13.6 - 13.8 VDC; however, the APU shall function without degradation in performance when this voltage is between 9 and 18 VDC. Voltage spikes shall not exceed 20 VDC.

6.1.2.2. 12 volt Starter Power In

An "unswitched" 12 VDC supply shall be supplied to the APU from the vehicle as a source of power for APU engine starting. This supply shall not be switched. Continuous current draw shall not exceed 10 A. Transient cranking current limits shall be coordinated with the vehicle manufacturer or systems integrator. Nominal voltage shall be 13.6 - 13.8 VDC; however, the APU shall function without degradation in performance when this voltage is between 9 and 18 VDC. Voltage spikes shall not exceed 20 VDC.

6.1.2.3. Interlock Circuit

The interlock circuit shall enable safety shutdowns in the event of any exposure of a high voltage source. The circuit shall be a current loop with a nominal current of 8 - 12 mA. Upon loss of current, a positive hardware shutdown shall occur. This shutdown shall consist of at least the APU dropping the high voltage output as described in Section 3.

6.1.2.4. Maintenance Done Signal

The APU shall have at least one method of resetting internal maintenance flags. This function shall be implemented via the communication network message *Maintenance completed* or via a manual input on the APU itself. If the manual input is implemented, it shall be done in a rugged manner so as to prevent damage or accidental triggering. Additionally, it shall be accessible from the service side of the unit.

6.1.3. Electrical Connections

6.1.3.1. Low Current Lines

Two types of connectors are needed to implement the network. The connector to be used to connect an Electronic Control Unit (ECU) to the backbone is called the *Stub Connector*. The connector used to extend the connector is called the *Through Connector*. These connectors must meet the electrical performance requirements outlined in section 3.3.1 of specification SAE J1939/11.

The communications wire bundle will consist of 10 conductors. The connector to join segments will be a standard MIL-C-5015 connector. Specifically identified for this task is an ITT-CANNON plug connector with shell size 18-1 (10 pins, all of size 16). Table 18 contains the pin assignments that will be used.

Pin Number	Description
1	12 volt clean power (positive terminal)
2	12 volt clean power (negative terminal)
3	Communication link (high line)
4	Communication link (low line)
5	Communication link (shield)
6	Interlock circuit (out)
7	Interlock circuit (return)
8	Spare
9	Spare
10	Spare

Table 18 Network Connector Pin Assignments

6.1.3.2. High Current Lines

Connection of the APU to the high voltage DC bus will be via an inexpensive lug connector terminal strip. In addition to the high voltage DC bus connectors, the terminal strip will also have connectors for providing APU starter power.

For safety purposes, the terminal strip will be fully enclosed. Access to the terminal lugs will be provided by a removable panel or housing cover. Planned or accidental removal of the housing/cover will cause the safety interlock circuit to open. This action will quickly remove all power from the grid, and either prevent the APU from starting, or shut it down if it is running.

Every APU must have a lug strip and housing to allow connection to the high voltage DC bus and to provide start power. The specific size of the lugs will be left up to the APU manufacturer.

Lug connectors shall be provided on the APU for the following:

High voltage high voltage DC bus (+ terminal)
High voltage high voltage DC bus (- terminal)
12 volt Starter Power In (+ terminal)
12 volt Starter Power In (- terminal).

Access to these terminals shall be protected by the high voltage interlock, so that the terminals shall not be live when exposed (Ref. Section 6.1.2.3.) Lug sizing is a function of the power rating of the APU and shall be coordinated with the vehicle manufacturer or systems integrator.

6.2. Mechanical Interface

6.2.1. Air Intake

Air intake interface shall be coordinated with the vehicle manufacturer or systems integrator.

6.2.2. Fuel Connection

Due to wide range of APU power levels, fuel states (gaseous, liquid), and specific requirements of the vehicle manufacturer or systems integrator, the fuel connection shall be coordinated with the vehicle manufacturer or systems integrator.

6.2.3. Exhaust

Exhaust interface shall be coordinated with the vehicle manufacturer or systems integrator.

6.2.4. Mechanical Mounting

Mechanical mounting shall be coordinated with the vehicle manufacturer or systems integrator.

APPENDIX B

LIST OF DOCUMENTS REFERENCED IN SPECIFICATION

The following is a list of the documents referenced in this specification. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

SAE Recommended Practice No. J726, Jun87, Air Cleaner Test Code, Society of Automotive Engineers.

SAE Recommended Practice No. J1096, Feb87, Measurement of Exterior Sound Levels for Heavy Trucks Under Stationary Conditions, Society of Automotive Engineers.

SAE Recommended Practice No. J1113, Aug87, Electromagnetic Susceptibility Measurement Procedures for Vehicle Components (Except Aircraft), August, Society of Automotive Engineers.

SAE Recommended Practice No. J1455, Jan88, Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks), Society of Automotive Engineers.

SAE Recommended Practice No. J1939, draft of Recommended Practice for a Serial Control and Communications Vehicle Network, Class C, Society of Automotive Engineers.

Military Standard MIL-STD-461C, 4 August 1986, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, Department of Defense.

Military Specification MIL-C-5015G, 9 May 1980, Connectors, Electrical, Circular Threaded, AN Type, General Specification for, Department of Defense.

Fuels Distribution List

Department of Defense

DEFENSE TECH INFO CTR ATTN: DTIC OCC 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218	12
ODUSD ATTN: (L) MRM PETROLEUM STAFF ANALYST PENTAGON WASHINGTON DC 20301-8000	1
ODUSD ATTN: (ES) CI 400 ARMY NAVY DR STE 206 ARLINGTON VA 22202	1
HQ USEUCOM ATTN: ECJU L1J UNIT 30400 BOX 1000 APO AE 09128-4209	1
US CINCPAC ATTN: J422 BOX 64020 CAMP H M SMITH HI 96861-4020	1
JOAP TSC BLDG 780 NAVAL AIR STA PENSACOLA FL 32508-5300	1
DIR DLA ATTN: DLA MMSLP 8725 JOHN J KINGMAN RD STE 2533 FT BELVOIR VA 22060-6221	1
CDR DEFENSE FUEL SUPPLY CTR ATTN: DFSC I (C MARTIN) DFSC IT (R GRAY) DFSC IQ (L OPPENHEIM) 8725 JOHN J KINGMAN RD STE 2941 FT BELVOIR VA 22060-6222	 1 1 1
DIR DEFENSE ADV RSCH PROJ AGENCY ATTN: ARPA/ASTO 3701 N FAIRFAX DR ARLINGTON VA 22203-1714	 1

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HQDA ATTN: DALO TSE DALO SM 500 PENTAGON WASHINGTON DC 20310-0500	 1 1
SARDA ATTN: SARD TT PENTAGON WASHINGTON DC 20310-0103	 1
CDR AMC ATTN: AMCRD S AMCRD E AMCRD IT AMCEN A AMCLG M AMXLS H 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001	 1 1 1 1 1 1
U.S. ARMY TACOM TARDEC PETR. & WTR. BUS. AREA ATTN AMSTA TR-D/210 (L. VILLHAHERMOSA) AMSTA TR-D/210 (T. BAGWELL) WARREN, MI 48397-5000	 10 1
CDR ARMY TACOM ATTN: AMSTA IM LMM AMSTA IM LMB AMSTA IM LMT AMSTA TR NAC MS 002 AMSTA TR R MS 202 AMSTA TR D MS 201A AMSTA TR M AMSTA TR R MS 121 (C RAFFA) AMSTA TR R MS 158 (D HERRERA) AMSTA TR R MS 121 (R MUNT) AMCPM ATP MS 271 AMSTA TR E MS 203 AMSTA TR K AMSTA IM KP AMSTA IM MM AMSTA IM MT AMSTA IM MC AMSTA IM GTL AMSTA CL NG USMC LNO AMCPM LAV AMCPM M113 AMCPM CCE WARREN MI 48397-5000	 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

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SFAE FAS PAL 1
PICATINNY ARSENAL
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TACTICAL WHEELED VEHICLES
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UNMANNED GROUND VEH
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REDSTONE ARSENAL
AL 35898-8060

DIR
ARMY RSCH LAB
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2800 POWDER MILL RD
ADELPHIA MD 20783-1145

VEHICLE PROPULSION DIR
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21000 BROOKPARK RD
CLEVELAND OH 44135

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ATTN: AMXSY CM 1
AMXSY L 1
APG MD 21005-5071

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RSCH TRIANGLE PK
NC 27709-2211

CDR AEC
ATTN: SFIM AEC ECC (T ECCLES) 1
APG MD 21010-5401

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CDR ARMY ARDEC
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WATERVLIET NY 12189

CDR APC
ATTN: SATPC L 1
SATPC Q 1
NEW CUMBERLAND PA 17070-5005

CDR ARMY LEA
ATTN: LOEA PL 1
NEW CUMBERLAND PA 17070-5007

CDR ARMY TECOM
ATTN: AMSTE TA R 1
AMSTE TC D 1
AMSTE EQ 1
APG MD 21005-5006

PROJ MGR MOBILE ELEC PWR
ATTN: AMCPM MEP T 1
AMCPM MEP L 1
7798 CISSNA RD STE 200
SPRINGFIELD VA 22150-3199

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ARMY COLD REGION TEST CTR
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STECR LG 1
APO AP 96508-7850

CDR ARMY ORDN CTR
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CDR ARMY INF SCHOOL
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CDR ARMY AVIA CTR
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FT LEONARD WOOD
MO 65473-5000

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FT WAINWRIGHT AK 99703

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YUMA AZ 85365-9130

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FT BELVOIR VA 22060-5818

CDR I CORPS AND FT LEWIS
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RED RIVER ARMY DEPOT
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TEXARKANA TX 75501-5000

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CDR
NAVAL SEA SYSTEMS CMD
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2531 JEFFERSON DAVIS HWY
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CDR
NAVAL SURFACE WARFARE CTR
ATTN: CODE 63 1
CODE 632 1
CODE 859 1
3A LEGGETT CIRCLE
ANNAPOLIS MD 21402-5067

CDR
NAVAL RSCH LABORATORY
ATTN: CODE 6181 1
WASHINGTON DC 20375-5342

CDR 1
NAVAL PETROLEUM OFFICE
8725 JOHN J KINGMAN RD
STE 3719
FT BELVOIR VA 22060-6224

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NAVAL AIR SYSTEMS CMD
ATTN: AIR 4.4.5 (D MEARNS) 1
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QUANTICO VA 22134-5080

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MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080
PROG MGR ENGR SYS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

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814 RADFORD BLVD
ALBANY GA 31704-1128

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CAMP H M SMITH
HI 96861-4118

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GA 31098-1647

Other Federal Agencies

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CLEVELAND OH 44135

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