IDEA

Innovations Deserving Exploratory Analysis Programs

Highway IDEA Program

Advanced Traffic Sensor for Work Zone and Incident Management Systems

Final Report for Highway IDEA Project 93

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS
MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

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1.0 Introduction

1.1 Project Summary

The project's goal was to develop an Advanced Relocatable Traffic Sensor (ARTS) System for use in construction work zone and incident management systems. A prototype smart sensor system was developed that is highly portable, easily deployable, and equipped with a wide-area wireless communications subsystem that enables real-time data acquisition, processing and communication to a Traffic Management Center (TMC) for appropriate action, or to public safety agencies for enforcement action. Alternatively, the ARTS System may be used as the input driver and communications backbone of an autonomous system for direct, automated control of widely dispersed field devices such as changeable message signs (CMS), highway advisory radio (HAR), or traffic sensors.

The ARTS System components consist of Doppler microwave radar, a digital compass, a solar portable power system, a GPS positioning subsystem, a satellite packet data terminal, a palm-size single-board computer, and an electronic interface board. The system provides accurate measures of traffic counts, speed, volume and headway. Laboratory tests using a tuning fork to simulate vehicle speeds were performed that validated the satellite communications and speed data acquisition capabilities of the system. Limited field tests were performed to test the satellite communications and speed acquisition in actual traffic. Observed data accuracy and communications transmission durations of 5-10 seconds provided encouraging indication of ARTS' potential for use in real-time applications for work zones traffic safety and incident management applications.

The software driven smart sensor technology, combined with the verified satellite communications subsystem, would appear to establish ARTS as a "place and forget" sensor that overcomes the calibration, configuration, self-diagnostics and local area line-of-sight limitations of conventional portable sensors. Additional field tests are recommended to establish the benefits, costs and limitations of the ARTS System in urban and rural work zone or incident management projects. For data acquisition needs entailing lane specific data, the Doppler microwave transceiver should be replaced by ultra-wideband radar. Hardware enhancements are recommended to reduce the size of the ARTS hardware by redesigning the electronics interface board and re-arranging the layout of the ARTS enclosure including appropriate mounting equipment. Finally, a weatherproof outdoor enclosure for the portable power system should be added.

1.2 Problem Background

There is a need for effective work zone safety and traffic management systems because of increasing safety and congestion problems near construction work zones and major traffic incidents. Work zone information systems, or "smart work zones" are being used more widely in Interstate System construction projects, and such systems are envisioned in the National ITS architecture.

Traffic sensors may be the most critical element of ITS Systems designed to control traffic or to provide real-time information to motorists. ITS system effectiveness depends on the quality of traffic data available from the sensors used, which in turn depends on sensor placement, alignment and calibration. Sensor systems are the ITS component most affected by field work zone and traffic management activities and, to be effective, must be designed for dynamic, real-world conditions.

Several non-intrusive sensors are available in the market; however, existing systems are expensive and require a high level of maintenance in mobile applications such as construction or incident management, due to issues of location, alignment, calibration, wireless communication, and power management. Therefore, the need exists for a "place and forget" sensor, envisioned by this project, that can be deployed near a work zone or incident on very short notice, and that can be easily aligned or calibrated. Such sensors would allow automatic verification of location and would configure automatically and interface wirelessly with a local or remote traffic management system. Such a system could be easily relocatable to traffic incidents or to a different work zone.

1.3 Project Objective

The project's objective was to design, develop, test and document an Advanced Relocatable Traffic Sensor (ARTS) System for application to construction work zones and roadway incidents. The ARTS System refers to a traffic sensor system consisting of microwave radar, angle sensors, GPS positioning, advanced power management, and a wireless communications system all integrated into a highly portable, real-time data acquisition system.

1.4 Project Approach

The following project tasks were identified and executed to accomplish the project's objective:

Task A.	Identify patent issues and any recent technologies or products that may impact the sensor development effort
Task B.	Perform system level tradeoffs to identify and select suitable vendors and components
Task C.	Design the various subsystems, interface cables, power and interface board, and mechanical design
Task D.	Develop embedded software for the prototype and portable traffic management system interface software
Task E.	Interface parts to configure and test an ARTS network for the portable Traffic Management System
Task F.	Design a user-interface that will be easy to operate
Task G.	Procure all components needed for the project
Task H.	Integrate all the various electronic, mechanical, and software components
Task I.	Test and debug the prototype as required to ensure that the system is functional
Task J.	Make data from the prototype available on a website
Task K.	Prepare final report to be delivered to IDEA program

The project tasks were further organized into four broad activities that comprised the project:

- System Design
- Hardware Prototype Development
- System Software Development
- System Integration

The remainder of this report documents these activities and discusses the results obtained.

1.5 Acknowledgements

The authors wish to acknowledge the contributions of Balu Subramanya, former Scientex Principal Engineer, who conceived the ARTS project and provided advice and feedback at each critical stage of the development. Also, we wish to acknowledge the encouragement, support and patience of Dr. Inam Jawed, TRB Project Manager, who kept the research on course and provided timely advice throughout the project period.

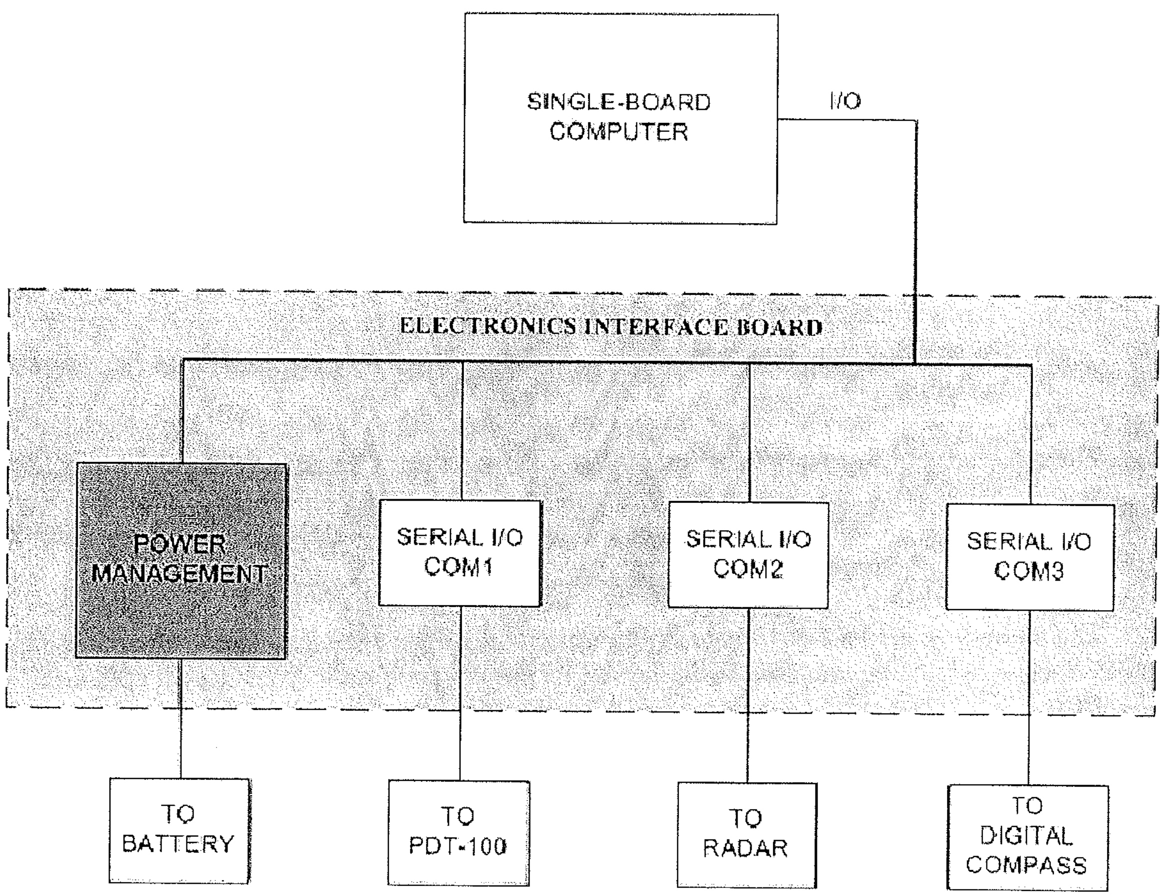
2.0 ARTS System Design

2.1 Sensor System

Figure 2.1 shows the high-level design of the ARTS Sensor System. An Electronics Interface Board integrates the major components of the system, consisting of a microwave radar system interface, a digital compass, a solar portable power system, and an interface to the wireless communication system (PDT-100). The single-board computer will house software that will control operations of the ARTS system and thereby manage operation of the intelligent sensor system.

Technology literature and product information were researched and reviewed relative to project objectives in deciding specific hardware components for the ARTS System. The final selection of system components is documented in this section.

Figure 2.1: ARTS Schematic

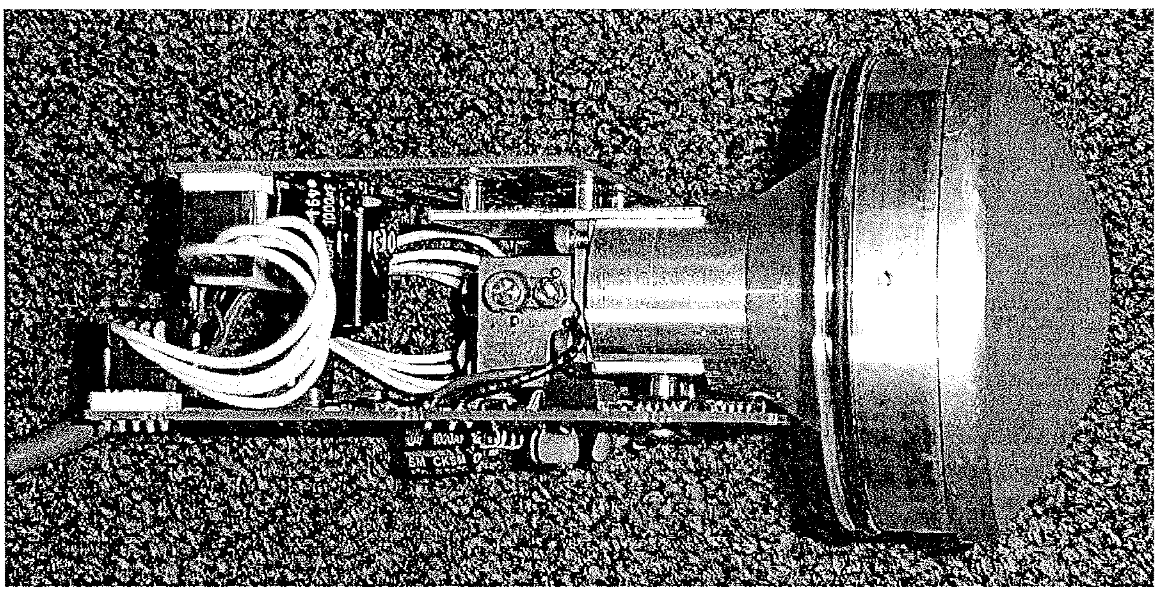


2.1.1 System Interface Special Application Radar

The System Interface (SI-2) as shown in Figure 2.2, manufactured by Decatur Electronics, Inc., is a radar sensor using a K-band antenna. The SI-2 processor board tracks target speeds from processed raw Doppler signals generated by the microwave transceiver. The SI-2 antenna is directional, meaning it can be set to track targets moving towards or away from it. The SI-2 includes an RS-232 serial port for communication with field devices such as computers, changeable radar message trailers, standard numeric display signs, and conveyer belt controls. The SI-2 antenna detects targets within the range of 2-200 mph (3-322 Km/h). Our version, the SI-2D, can detect speeds from 5-200 mph (8-320 Km/h).

Please refer to Appendix D for Technical Specifications.

Figure 2.2: System Interface Special Application Radar



Ultra-wideband radar was initially selected for use in ARTS. However, a reduction in the project's scope due to a reduction in TRB's budget led to selection of the lower cost microwave radar solution. The microwave radar also offered the advantage of ease of interface with the single-board computer using the serial port.

2.1.2 Octagon Systems' 6225 Palm-Size Single-Board Computer

It was desired to have a single-board computer that required low-power consumption, was able to withstand shock, vibration and extreme temperature, and that would allow connectivity and expandability with the most commonly used input/output (I/O) interfaces. Octagon System's 6225 Palm-Size Single-Board Computer was determined to meet these requirements.

The 6225 as shown in Figure 2.3 is an industrial computer with the most often used I/O, with component diagram shown in Figure 2.4. It integrates serial, parallel, disk, digital, and networking I/O with a low cost–per–function. The 6225 operates stand–alone with a 5V power supply, with PC/104 expansion cards, or an ISA Bus backplane.

The 6225 is an industrial product, operating from –40° to 85°C, which withstands high shock and vibration. The low power consumption allows the 6225 to be placed in sealed enclosures without the use of a fan. The card has an ambient temperature sensor that is accurate to ±3° C over –40° to 85° C and can be read remotely. The simple operator interface of a keypad and 4–line LCD display is fully supported with driver software. The card is also available depopulated for the most cost–effective OEM solutions.

Please refer to Appendix D for Technical Specifications.

Figure 2.3: Octagon Systems' 6225 Palm-Size Single-Board Computer

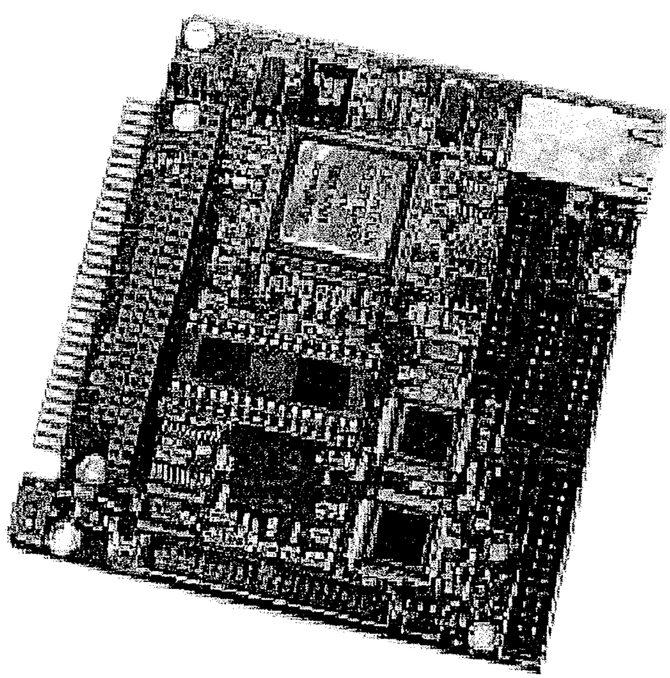
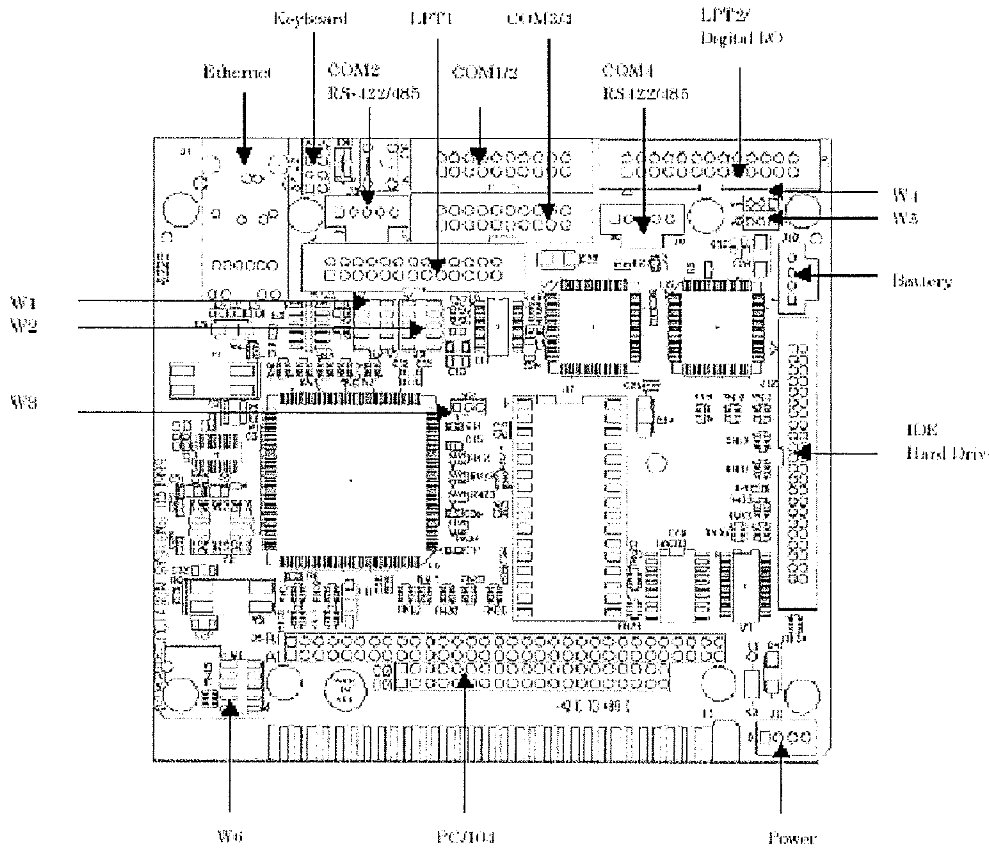


Figure 2.4: Octagon Systems' 6225 CPU Card Component Diagram



2.1.3 HMR3300 Digital Compass

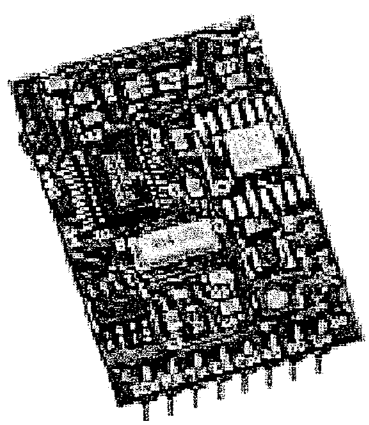
This Honeywell Digital Compass was selected for the ARTS design as it provided 3-axis support, is very compact and interfaces easily with the single-board computer.

The Honeywell HMR3300 as shown in Figure 2.5 is an electronic compassing solution for use in navigation, platform leveling, satellite antenna positioning, GPS integration, and guidance systems. Honeywell's magneto-resistive sensors are utilized to provide the reliability and accuracy of these small, solid state compass designs. This compass solution can be easily integrated into systems using a UART or SPI interface in ASCII format. The HMR3300 is a three-axis, tilt compensated compass that uses a two-axis accelerometer for enhanced performance up to a ±60° tilt range. Its dimensions are 1" x 1.45" x 0.4" for the digital compass board alone and only measures approximately 3.25"x 1.5" x 1.13" with the RS-232 interface board attached.

The Digital Compass provides the Advanced Relocatable Traffic Sensor (ARTS) the necessary information to re-calibrate itself when it shifts from its original position. A certain shift angle threshold can be set and when exceeded, due to heavy winds or drafts caused by trucks on the highway or for any other reason, a warning can be sent to the host computer / base station computer that the ARTS may not be getting accurate speeds.

Please refer to Appendix D for Technical Specifications.

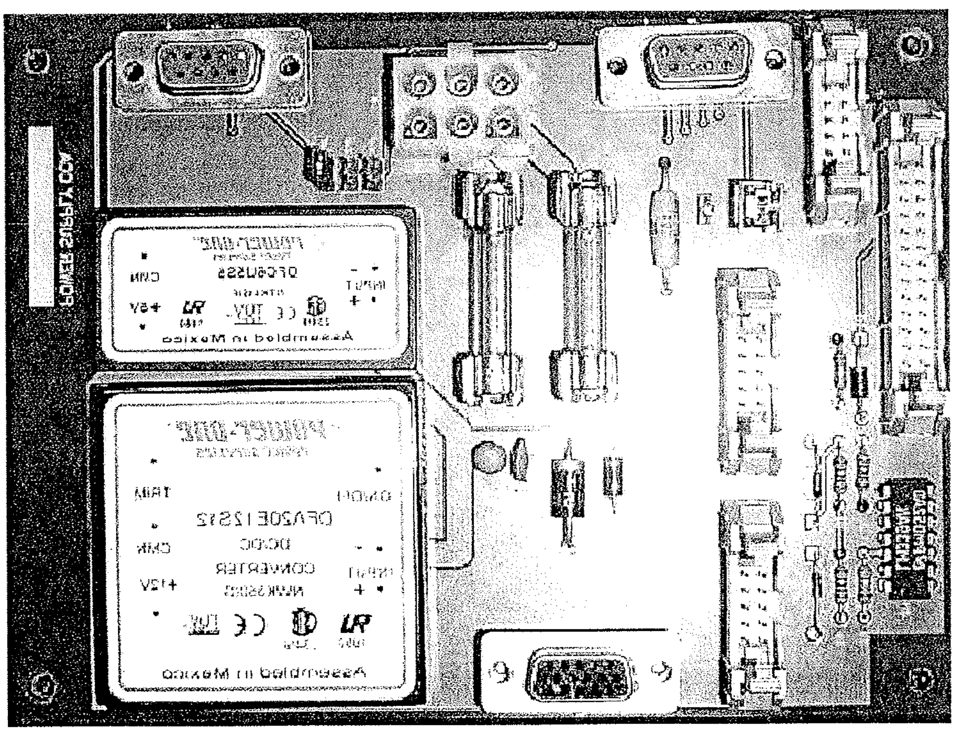
Figure 2.5: The HMR3300 Digital Compass



2.1.4 Electronics Interface Board

The Electronics Interface Board as shown in Figure 2.6 was designed and developed by The Scientex Corporation to integrate the major components of the ARTS System. It requires a 12 V DC input from which it provides a regulated 5V DC power to Octagon Systems' 6225 Single-Board Computer and a regulated 12V DC power to both the SI-2 microwave radar and the HMR3300 digital compass. The PDT-100 Satellite Packet Data Terminal comes with a 7.5A fuse which we integrated into the cables extending from the fabricated outdoor enclosure and directly draws its power from the Solar Portable Power System. The Electronics Interface Board has built-in fuses to protect system components from power surges and spikes. It was designed with 3 serial port interfaces and a Digital I/O interface. In the prototype, the 1st serial port interface (COM1) was allocated for the PDT-100 Satellite Packet Data Terminal while the 2nd serial port interface (COM2) was used for the SI-2 K-band microwave radar and the 3rd serial port interface (COM3) was used for the HMR3300 Digital Compass.

Figure 2.6: The Electronics Interface Board



2.1.5 Solar Portable Power System

Power requirements were computed and analyzed for the main components during normal operation, while in idle, suspend or low-power standby modes as shown in Table 2-1. The main power draw comes from the PDT-100 satellite packet data terminal which requires about 39.6 Watts of power during transmission of messages. When PDT-100 satellite packet data terminal receives messages it requires 3 Watts. When it is on low power, only 6 mW are needed. The 6225 Single-Board Computer typically requires 2.4 Watts of power; putting it into "suspend" mode is not practical since we need it to always be in control of the continuously operating Advanced Relocatable Traffic Sensor. The SI-2 microwave radar only requires 10 mW of power. The HMR3300 Digital Compass typically requires 270 mW.

During initial testing while a suitable solar portable power system was being finalized, the prototype was powered by a 13.8V DC regulated power supply while indoors and a 12V DC to 115V AC, 140 watt power inverter was used while outdoors (inside a car) where no AC outlets were available. The solar portable power system selected for the ARTS prototype consists of the XPower Powerpack 400 Plus and a 10W SunWize OEM Solar Panel.

Table 2-1: ARTS Power Requirement

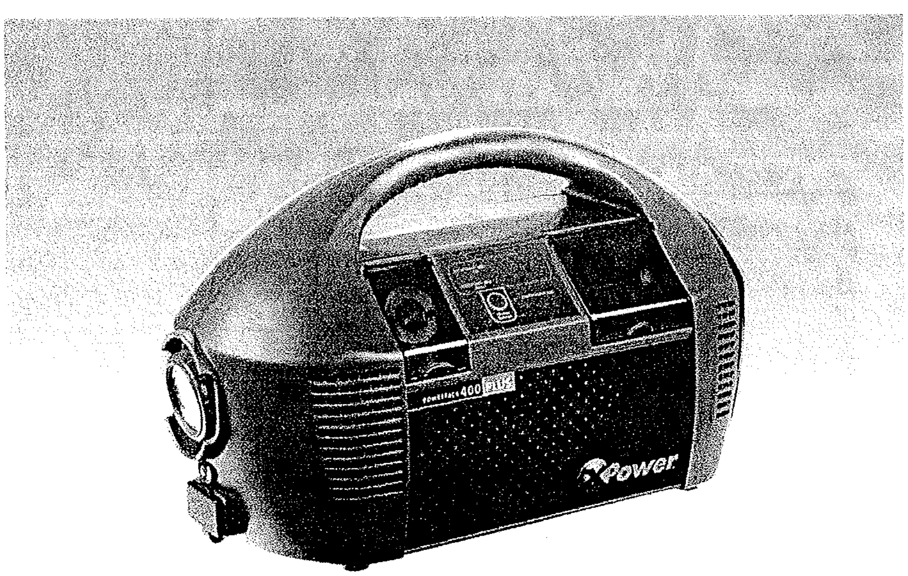
System Component	**Power Consumption**			
	Typical	Idle / Suspend	Transmit	Receive
PDT-100		6 mW	39.6 W	3 W
6225 SBC	2.4 W	835 mW		
SI-2 radar	10 mW			
HMR3300	270 mW			

2.1.5.1 XPower Powerpack 400 Plus

The XPower Powerpack 400 Plus as shown in Figure 2.7 was selected as the power source for the ARTS system. It has an internal, sealed, 12V, 20Ah, AGM (Absorbed Glass Mat) lead acid battery and a battery charging controller system for the internal battery. It can also be connected to an external battery if a certain application or deployment would require more power. Charging the batteries can be done by either plugging the AC charger to a standard AC outlet, or by plugging the DC charging cable into a vehicle's lighter socket or 12V accessory outlet or a generator's 12V DC outlet, or from a solar panel with the ARTS prototype. The XPower Powerpack 400 Plus also has a built-in inverter to power AC equipment. This inverter has built-in protection against output overload, automatically shutting power off when power drawn exceeds 320W. The inverter is also protected from overheating and automatically shuts off when it exceeds a safe temperature. The XPower Powerpack 400 Plus also has low battery protection, wherein an audible alarm sounds when the internal battery is nearly discharged (11.0 VDC) and the unit turns off at 10.5 VDC. Once the internal battery is fully charged, the charging current automatically reduces to a maintenance charge mode, and the XPower Powerpack 400 Plus may be left permanently connected to the AC charger or the solar panel. The XPower Powerpack 400 Plus is also very small (8" x 16" x 9.5"), easy to handle, and weighs only 10.5 kg, making it very portable. However, the XPower Powerpack 400 Plus was not designed for outdoor use and would require an outdoor enclosure or needs to be placed inside an outdoor cabinet.

Please refer to Appendix D for Technical Specifications.

Figure 2.7: XPower Powerpack 400 Plus



2.1.5.2 SunWize OEM10 Solar Panel

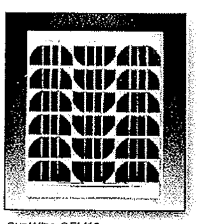
For the ARTS prototype, we selected the OEM10 which is the 10W Solar Module because of its power rating, size, dimensions, weight and cost. The PDT-100 satellite packet data terminal requires the most power during transmission and so the battery power (currently 20Ah) and charging power from the Solar Panel would depend on data transmission frequency from the Advanced Relocatable Traffic Sensor to the Base Station Computer / Traffic Management Center (TMC). In real-time applications wherein data needs to be processed quickly, satellite transmissions would be often and would require batteries and solar panels with higher ratings. In data-logging applications, wherein data is collected and sent in bunches or downloaded when the system is offline or not collecting data, wireless transmissions are few thereby requiring less power from the Solar Portable Power System.

SunWize OEM Solar Modules as shown in Figure 2.8, deliver top-quality performance for all photovoltaic applications including general battery charging. Ideal for AC and DC applications, SunWize OEM modules can be used in single-module and multiple-module systems. Each module consists of 36 solar cells connected in series providing maximum charging power. The glass surface is impact resistant and allows maximum light transmission. Single crystalline solar cells are encapsulated and bonded to the glass in multiple layers of ethylene vinyl acetate (EVA) and laminated with a white Tedlar™ backing insuring long life in severe environmental conditions.

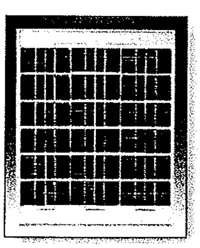
Figure 2.8: SunWize OEM Solar Modules

Rated current and voltage at Maximum Power Point (MPP)

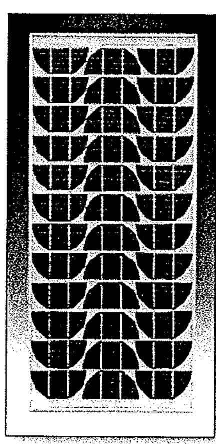
Model	Rated Power (Watts)	Rated Voltage (Vmp)	Rated Current (Imp)	Open Circuit Voltage (Voc)	Short Circuit Current (Isc)	Dimensions (inches)	Unit Weight (lbs.)	MSRP
OEM5	5	16.4	0.31	20.5	0.38	11.82" x 9.84"	3	$81.00
OEM10	10	16.4	0.61	21.0	0.70	15.15" x 14.76"	4.5	$111.00
OEM20	20	16.5	1.22	21.0	1.38	20.86" x 16.93"	6.5	$171.00
OEM40	40	16.7	2.40	21.0	2.68	38.38" x 17.13"	12.5	$271.00



SunWize OEM10

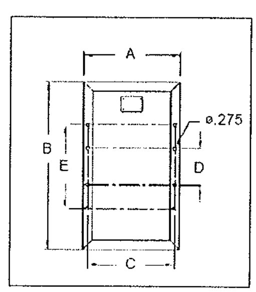


SunWize OEM20



SunWize OEM40

MODULE DIMENSIONS



OEM	A	B	C	D	E
5	9.84	11.82	8.66	7.87	–
10	14.76	15.15	13.58	9.84	–
20	16.93	20.86	15.75	9.84	–
40	17.13	38.38	15.90	9.84	23.64

2.2 Communication System

Wireless communications options for real-time work zone and incident management systems have evolved rapidly over the past decade and currently include FCC licensed UHF radio, unlicensed spread spectrum radio systems, cellular or pager based systems, satellite based systems, and third-generation (3G) wireless Internet based systems. Each communication option must be evaluated relative to its advantage for a particular project design, including consideration of cost economy, cycle or response time, topography limitation, and power management.

2.2.1 Selection of a Satellite Communication System

Existing technologies for wireless communication within the ARTS system were considered, including licensed UHF, unlicensed spread spectrum, cellular and pager systems and wireless 3G internet based systems. Following extensive investigation and analysis, a mobile site satellite communication system was selected as the ARTS communications backbone.

The satellite communications option was deemed optimum compared to the various alternatives because of its virtually unlimited and all-the-time geographic coverage for a single application (all of North America, the Caribbean and Hawaii), its capability to operate in real-time (5-10 seconds response time) and its low transmission cost for low-byte data communications involved in work zone and roadway incident data acquisition and traffic management.

2.2.2 PDT-100 Satellite Packet Data Terminal

The particular satellite communication system selected for use with ARTS is from EMS Technologies, Inc. The system operates as a Specialized Services Mobile Terminal within the Mobile Data Services (MDS) satellite communication network operated by Mobile Satellite Ventures (MSV).

One PDT unit consists of the antenna, transmitter, receiver, GPS, and RS-232 connection, all contained in a rugged 3lb enclosure (See Figure 2.9 & Figure 2.10). The PDT has a flexible open architecture that allows customized solutions. The cost of data transmission is approximately $45 per unit for 70KB per month, $60 per unit for 100KB per month with overage charges of $0.75 per KB. Translated into work zone operations, sending 8 bytes of sensor data every 5 minutes for 30 days would amount to 67.5KB.

Please refer to Appendix D for Technical Specifications.

Figure 2.9: PDT-100 Satellite Packet Data Terminal

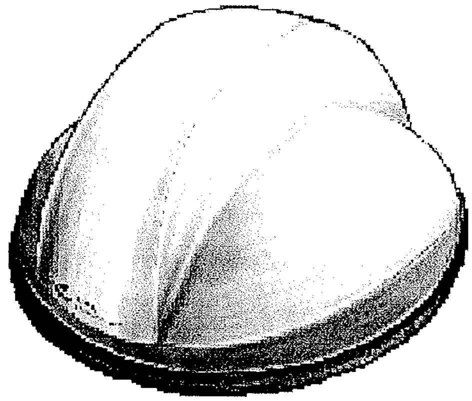
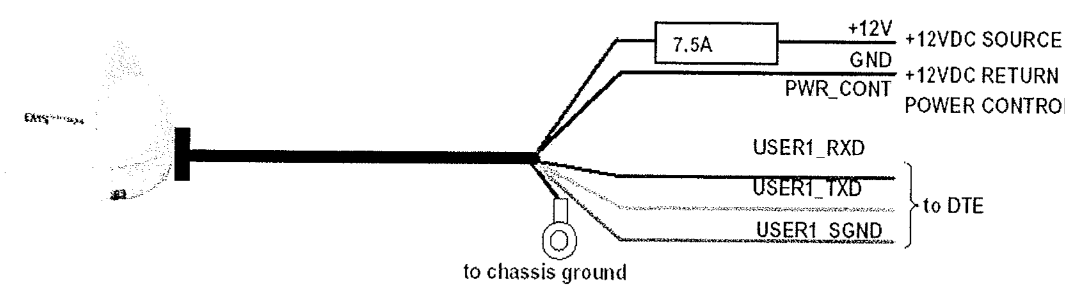


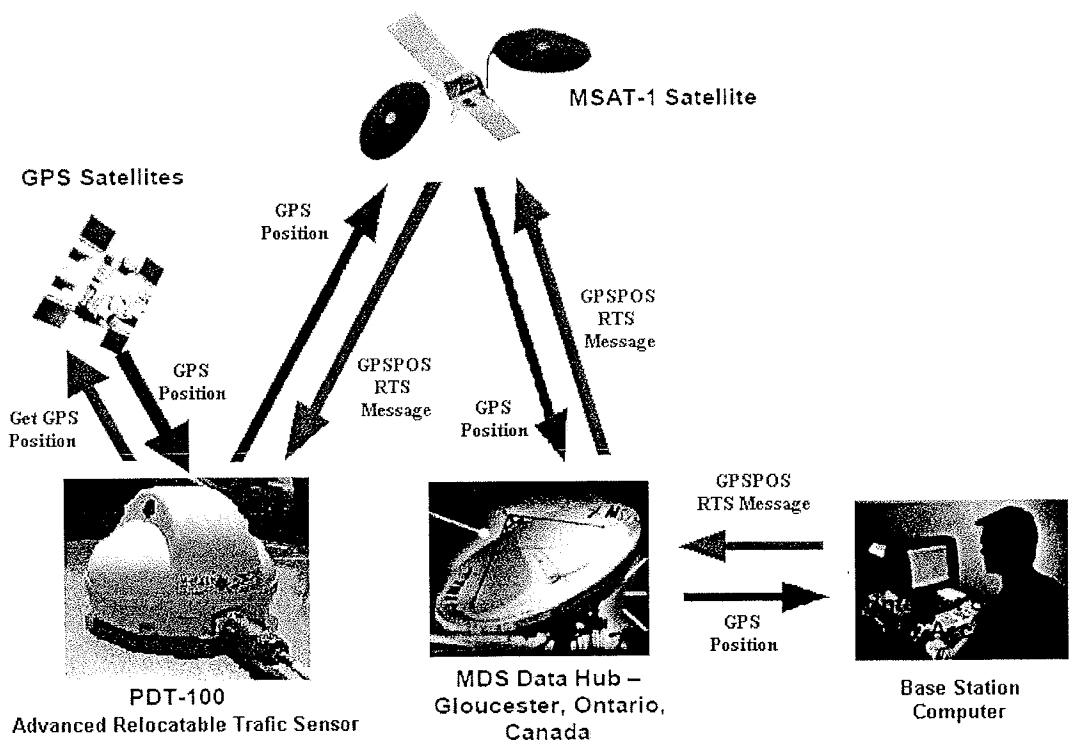
Figure 2.10: PDT-100 Cable Connections



2.2.3 Communication System Design

Figure 2.11 shows the functional design schematic of the ARTS satellite communications system. The arrowed data flow demonstrates the process of obtaining the GPS position from an Internet connected base station computer. The command is processed via Internet to the PDT data hub in Gloucester, Ontario, Canada, and then via radio communication to the MSAT-1 satellite to the PDT-100 terminal located at the ARTS site. The ARTS sensor obtains its position from the GPS satellite and the information is relayed back through a reverse communication process to the base station.

Figure 2.11: Schematic of the Satellite Communications



2.2.4 ARTS System Software

Software for the ARTS System consists of the client software that is run from a Traffic Management Center or host / base station computer and the embedded software for the single-board computer that provides first level control of the ARTS system components.

2.2.4.1 Client / Base Station Software

The client software runs on the host computer housed at the Traffic Management Center (TMC) or on a stand-alone base station computer that is Internet accessible. This software is responsible for sending commands to ARTS to monitor its status, obtain its GPS location or acquire traffic or performance data. The client software was written in Visual Basic 6.0 and runs under Windows operating system.

The Client / Base Station Software provided a means of sending commands to and receiving commands or warning messages from the ARTS prototype. These commands can be used to poll the status of the ARTS prototype, or acquire speeds and other performance information that the ARTS prototype has collected.

Five commands have been programmed to test the functionality of the Client / Base Station Software. These commands are:

a. SIGNAL – This command will query the PDT-100 satellite packet data terminal's signal strength and packet error rate. The signal strength will range from 0 to10 while the packet error rate will range from 0 to 100.

Note: A signal strength of 0 means that there is no signal (loss of service or totally blocked) and will not allow the Advanced Relocatable Traffic Sensor to receive any commands nor respond to any commands from the host computer / base station computer. When signal strength is 0, the packet error rate is 100.

b. BVOLTS – This command will query the battery voltage / power status of the Advanced Relocatable Traffic Sensor. The battery voltage reported by the PDT-100 satellite packet data terminal range from 0 to 100 and is multiplied by 16 and divided by 100 to obtain the actual battery voltage. The PDT-100 satellite packet data terminal also reports power-down thresholds and can be set to automatically power-down when voltage drops below a certain threshold (0 to 200 or 0V-20V, default is 10V) or when the satellite signal is blocked for a specified amount of time (0 to 43200 or 0 seconds – 12 hours).

c. GPSPOS - This command will query the current GPS position of the Advanced Relocatable Traffic Sensor. The GPS report can be formatted or reported as NMEA 0183 standard type reports ("RMC", "GGA", "VTG", "GSA", "GSV") or PDT-100 specific type reports ("L", "T", "S", "F4", "F5", "F6", "F7"). The default is "RMC".

d. CCLOCK - This command obtains the current MDS network date and time as broadcasted in the bulletin boards. This is the time used internally in the PDT-100 satellite packet data terminal, e.g. for time stamping messages and would also be used as the time stamp for all Advanced Relocatable Traffic Sensor logs and messages.

For example, 11 May 2004, 20:10:39 GMT would be reported as *"2004/05/11,20:10:39+00"*.

e. AVGSPD - This command obtains the current average speed recorded by the Advanced Relocatable Traffic Sensor over a preset period of time. This would later be modified on the embedded software and client software to include a parameter that would change the preset time and also report the number of samples from which the average speed was obtained.

2.2.4.2 Embedded Software

The embedded software was designed to automatically execute, initialize the hardware components, self-configure the ARTS prototype to acquire speeds and other relevant information, and send the relevant data to the base station computer. Self-diagnostics features are managed by the embedded software, including acquisition of the angle shifts (heading, pitch, and roll) from the HMR3300 Digital Compass and monitoring of battery voltage and the sending of warning messages to the Base Station computer and/or Traffic Management Center (TMC) when the sensor shifts beyond acceptable thresholds (20 degrees in our sample) or when the battery voltage drops below 11V DC.

The embedded software runs on the 6225 Single-Board Computer and is the "brain" for the Advanced Relocatable Traffic Sensor. It is responsible for acquiring speeds from the SI-2 K-Band microwave radar and computing average speeds over preset periods of time. It is also responsible for receiving, decoding and processing commands sent to the Mobile Terminal address of the PDT-100 satellite packet data terminal connected to the ARTS. Once the commands have been processed, it will then send the appropriate response or information requested to the host computer / base station computer.

The embedded software was programmed and debugged using Borland C++ 4.0. The executable was then uploaded to Octagon Systems' 6225 Single-Board Computer's flash memory and setup to automatically execute after the 6225's boot-up process.

2.3 ARTS System Cost

Table 2-2 shows the equipment cost for the ARTS prototype. The total cost of $4150 includes the cost of the application radar unit equipped with the digital compass, a rechargeable solar power supply and real-time satellite communications. To operate the system in the field, one would merely need to mount the ARTS enclosure in a desired location, attach the solar power and turn on the system.

Table 2-2: ARTS Prototype Equipment Cost

Equipment	Cost ($)
PDT-100 Packet Data Terminal	$ 1500
6225 Single-Board Computer	$ 650
SI-2 Special Application Radar	$ 650
HMR3300 Digital Compass	$ 250
Electronics Interface Board	$ 500
Enclosure	$ 350
Xpower Powerpack 400 Plus	$ 100
Sunwize OEM10 Solar Panel	$ 100
Miscellaneous (cable, connectors)	$ 50
TOTAL COST	$ 4150

To estimate monthly communications costs, we assume the average speed, volume and headway readings would be updated by satellite to the host computer on average every 5 minutes throughout the day, depending on traffic fluctuations. This would produce 8 bytes every 5 minutes or 67.5KB of data per month, resulting in a total monthly airtime cost of approximately $200 based on current air time costs as shown in Table 2-3.

Table 2-3: ARTS Monthly Operating Cost

PDT Air Time	Cost ($)
Host Access	$ 125
25 KB per month per unit	$ 23
40 KB per month per unit	$ 30
70 KB Per month per unit	$ 45
100 KB per month per unit	$ 60
Overage per KB	$ 0.75

The $4150 smart sensor unit is comparable to the cost of using UHF or spread spectrum wireless radio modems with a comparable radar unit that would not have the benefit of the digital compass nor the wide area coverage and the communications versatility of the satellite based system.

It can be expected that the cost of the PDT-100 Satellite Packet Data Terminal, the most expensive ARTS component, will reduce significantly as satellite based systems evolve and competition increases.

3.0 Hardware Prototype Development and Testing

3.1 Prototype Development

The final selection of hardware components for the ARTS is shown in Figure 3.1. Except for the custom designed Electronic Interface Board, each of the components is a commercially available hardware product. Figure 3.2 shows the main components assembled into an operational configuration for laboratory testing.

An outdoor enclosure was fabricated to encase the main components. A fiberglass material was selected for the enclosure, shown in Figure 3.3 that would allow Doppler signals from the SI-2 microwave radar to penetrate while protecting the ARTS prototype from the operating environment.

The XPower Powerpack was positioned outside the fiberglass enclosure as shown in Figure 3.4 and it will be placed in an outdoor cabinet or other appropriate enclosure during field operation. Cables and connectors were purchased or fabricated to provide connectivity among all the components.

The dimensions of the ARTS enclosure, as shown in Figure 3.3, are 11.5" x 13" x 6.25" and the total weight of the fully assembled ARTS prototype is 6 lbs.

Figure 3.1: Schematic of the ARTS Hardware Components

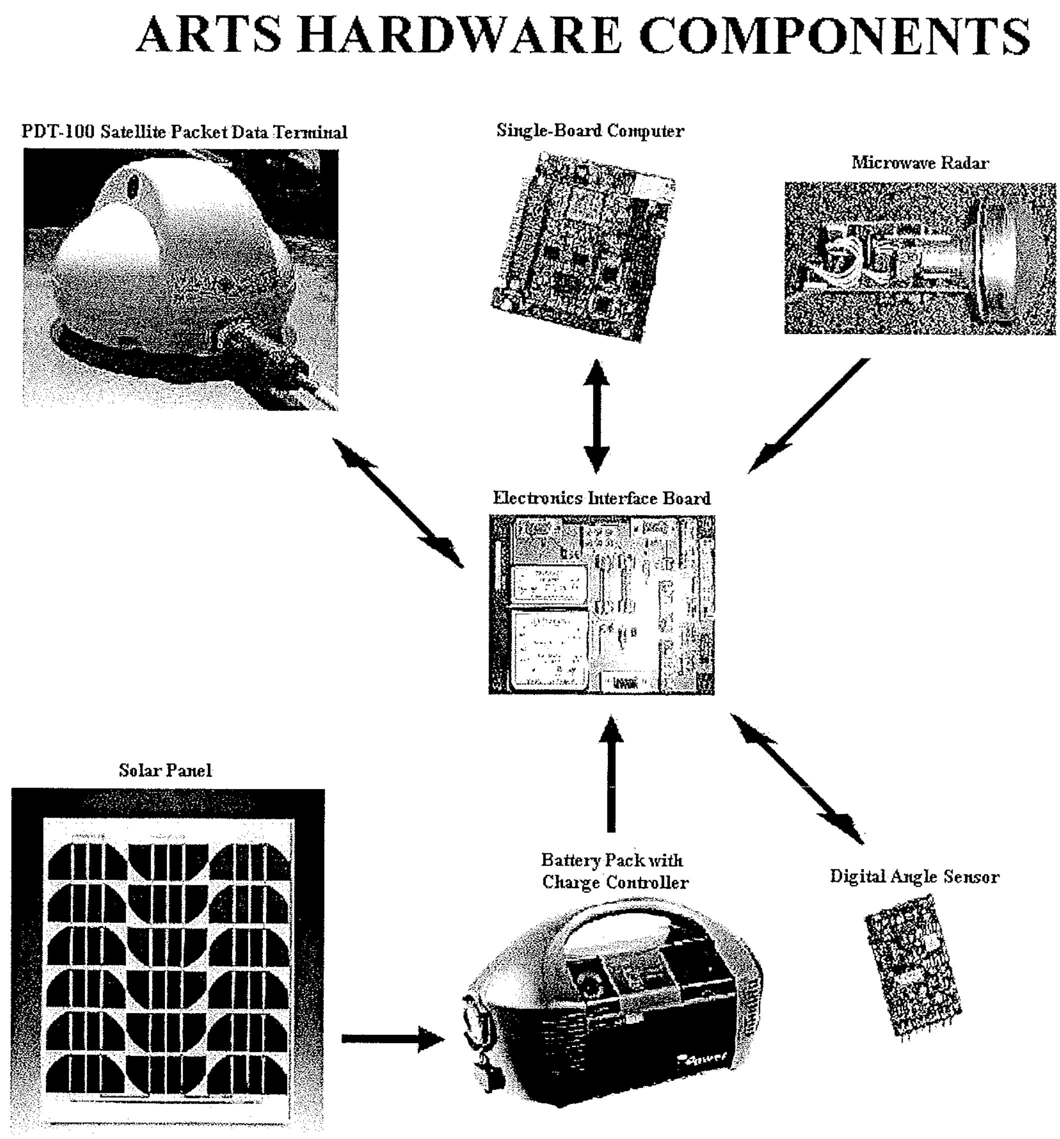


Figure 3.2: Laboratory Prototype Testing

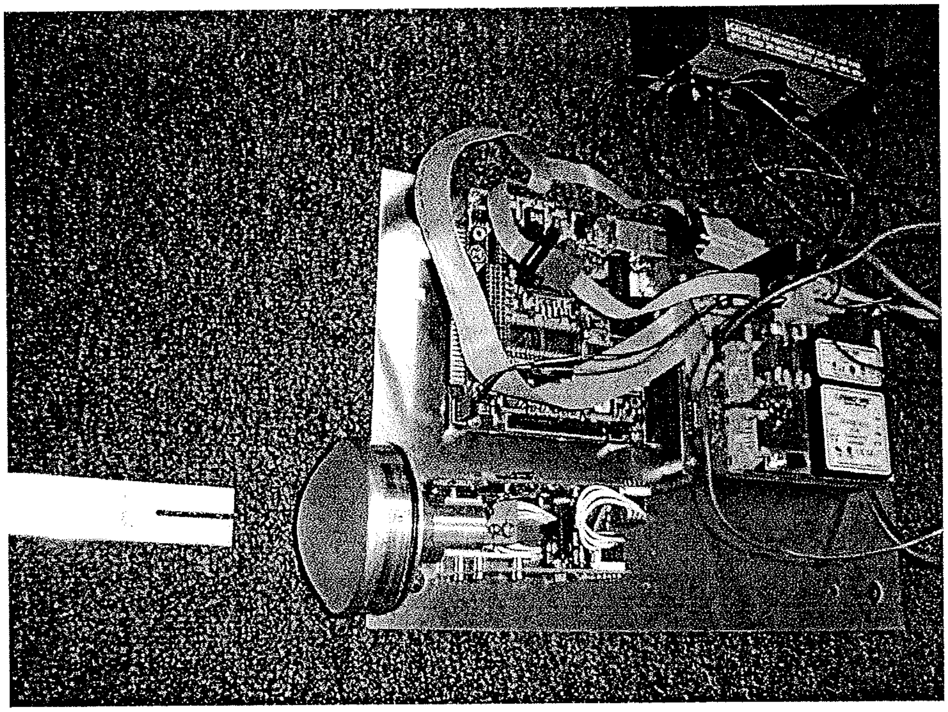


Figure 3.3: ARTS Prototype in Fiberglass Enclosure

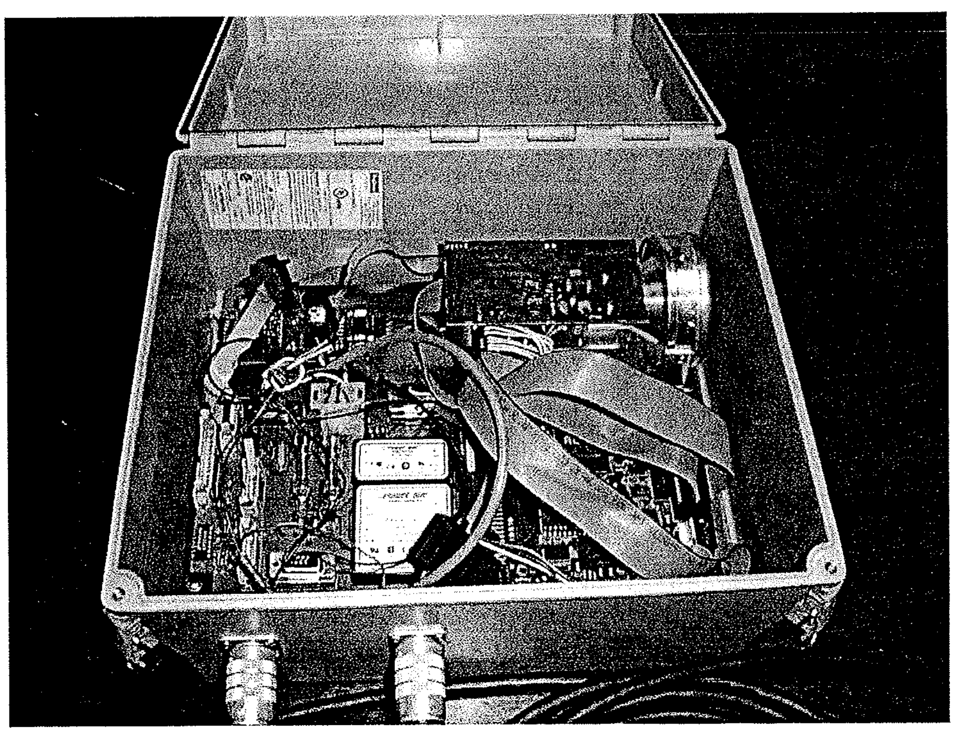
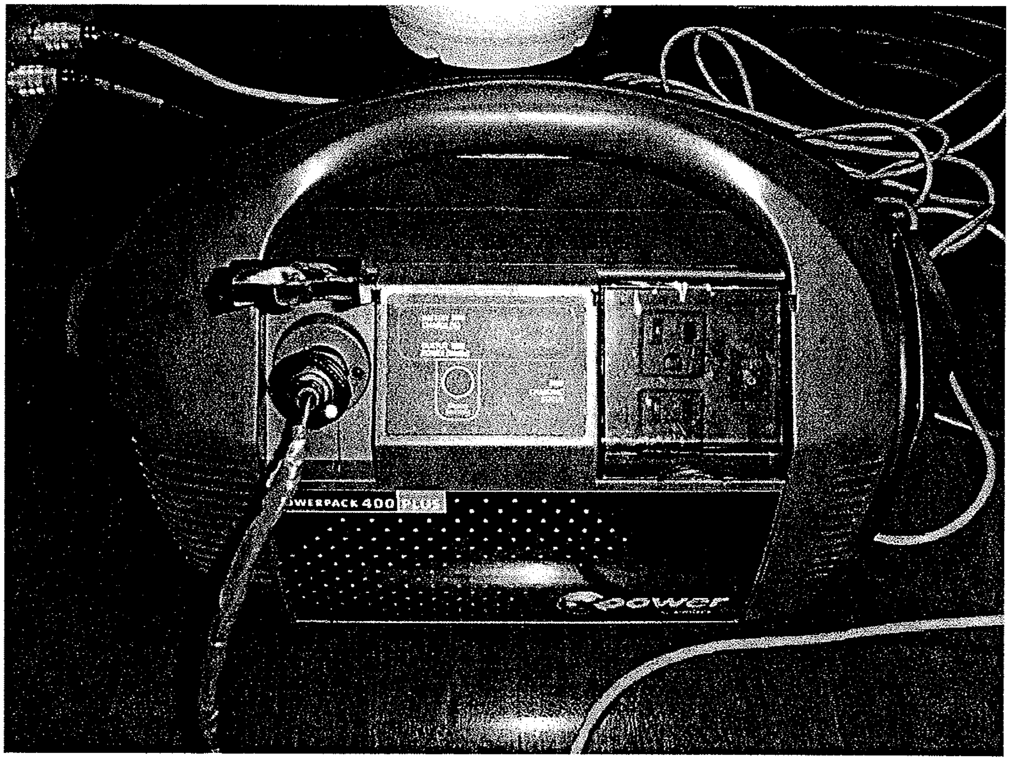


Figure 3.4: Supplying Power to the ARTS Prototype



3.2 Software Testing

3.2.1 Laboratory Testing

The embedded software in the single-board computer was programmed to echo the speeds received in COM2 out to COM4 which was used as a debugging port, to confirm that the software was receiving all the data correctly. Two certified tuning forks (33.2 mph K Band and 77 mph K Band) were used to simulate moving traffic and test the embedded software for speed acquisition. A laptop was attached to COM4 to view the speeds and proper data transmission and receipt were confirmed.

Laboratory tests were performed to confirm performance of the client / base station software. Satisfactory performance for the commands related to satellite signal strength, ARTS battery voltage, GPS position, clock and date and average speed was confirmed. See Appendix A for related software logs. See Appendix B for the corresponding embedded software logs.

3.2.2 Field Testing

The principal objective of field tests was to acquire actual traffic data from the ARTS system and to communicate appropriate data measures to an Internet accessible base station computer in real-time, and thus to confirm the data acquisition capability of ARTS. A further purpose of the field tests was to test the low battery voltage and sensor out-of-alignment self-diagnostic capability of ARTS.

Speed samples were collected from vehicles just outside the Scientex office on Eisenhower Avenue in Alexandria, VA and averaged over 3 minute intervals. That segment of the road had 5 lanes (2 in each direction with a middle lane for turning vehicles). The speeds were logged in a text file and again echoed to COM4 and monitored with a laptop. The single-board computer does not have the storage capability to continuously log and store these individual speeds over long periods of time unless a Hard Disk or high-capacity Flash Memory Card is added. Individual speeds are stored in memory over a preset period of time (in this case 3 minutes[1]) and then averaged while a new set of speeds is gathered. When the Advanced Relocatable Traffic Sensor prototype receives an AVGSPD command from the host computer / base station computer, it will then send this latest stored average speed to the host computer / base station computer.

See *Appendix C* for the speed samples obtained during prototype testing.

To make the ARTS prototype condition-responsive, instead of waiting for the TMC / base station computer to check the status of the ARTS system (e.g. battery voltage, tilt / shift condition), the embedded software on the single-board computer was updated to periodically check this status and send a WARNING message to the TMC / base station computer. Low battery voltage warning would occur when the internal battery voltage of the XPower Powerpack 400 Plus drops below 11 V DC. When the SI-2 radar sensor gets tilted / shifted substantially, its accuracy degrades along with its ability to detect whether traffic is incoming or outgoing. By adding the HMR3300 Digital Compass to the ARTS prototype, one can determine when it has tilted / shifted past the preset threshold, and a warning can be sent to the TMC / base station computer.

During initialization, the single-board computer will store the initial heading, pitch and roll of the Advanced Relocatable Traffic Sensor prototype as reported by the system digital compass. During testing, this was recorded as *85.5, 0.2, and 0.4* respectively showing heading, pitch and roll. When the ARTS prototype was tilted down, the HMR33000 Digital Compass reported *84.3, 43.3, -0.2* for the heading, pitch, and roll respectively. When the ARTS prototype was tilted up, the HMR300 Digital Compass reported *86.1, -35.9, and 1.1* for the heading, pitch, and roll respectively. Clearly, the pitch was the most affected by the ARTS vertical tilt. When the ARTS prototype was tilted to the left, the HMR33000 Digital Compass reported *56.5, 0.4, and 0.2* for the heading, pitch, and roll respectively. When the ARTS prototype was tilted to the right, the HMR300 Digital Compass reported *121.5, -0.2,*

[1] *Note: The 3-minute preset is an arbitrary interval of time. Samples of any desired period of time could be obtained since the system operates in real-time.*

and 1.0 for the heading, pitch, and roll respectively. The difference in heading and pitch of the current reading from the initial reading would indicate the extent of tilt and by comparing it to a threshold (e.g. 20 degrees), a warning can be generated when the threshold is exceeded. The roll difference can also be used in a similar manner.

A sample warning log obtained from the client software when the threshold was exceeded is shown in <u>Appendix E</u>.

An Operations Manual for deployment of ARTS is listed in <u>Appendix F</u>.

<u>4.0 Results, Conclusions and Recommendations</u>

4.1 Summary of Results and Conclusions

The results of this NCHRP-IDEA Project 93 are summarized below:

- An Advanced Relocatable Traffic Sensor (ARTS) System was developed that is highly portable, easily deployable, and equipped with a real-time satellite communications system that forms a wide area network for traffic data acquisition. An engineering prototype of the system was designed, fabricated and integrated as a working model. Initial laboratory and field tests demonstrated the system's potential for use in ITS applications involving real-time traffic data acquisition, processing and communication to a Traffic Management Center (TMC) or to law enforcement agencies without limitation of distance or line of sight.

- Software integration of the sensor with the satellite communications system achieved characteristics of a 'place and forget' sensor in comparison to wireless radio communications sensor systems. Limitations due to line-of-sight were avoided, field calibration and manual configuring of sensors were eliminated, and automated self-diagnostics of sensor performance and power management reduced the requirement for on-site maintenance.

- The satellite communications infrastructure is readily adaptable to wireless traffic management and work zone systems whereby changeable message signs (CMS) may be integrated into the system. This would provide the ability to control message boards configured into wide area networks or as part of a local project traffic control system. Because of the small byte sizes required to represent traffic sensor and CMS display messages, the cost of satellite communications is comparable to wireless radio systems on a project cost basis. A typical 8 byte sensor data acquired every 5 minutes for 30 days would total to 67.5KB of data transmission a month. Lane specific data would require more bytes, depending on the number of lanes, but could be compressed to lessen the amount of data requiring transmission.

- Ultra-wideband radar was proposed for use in the prototype but was replaced by a microwave Doppler transceiver because of cost. Although Doppler transceivers provide accurate individual speeds and related traffic measures, occlusion effects become more apparent as the number of lanes increase. Hence, application of ARTS to multi-lane urban streets or freeways may require replacement of the Doppler transceiver by ultra-wideband radar.

- The level of miniaturization anticipated for the ARTS System was not achieved. The PDT-100 Satellite Packet Data Terminal selected contained a built-in antenna that is much larger than a radio modem and could not be inserted into the ARTS enclosure. Also, the power source required was larger than intended, because of the increased cost of smaller units.

- The ARTS System achieved a high degree of modularity as envisioned for the project. Each component's connection to the single-board computer can be removed or changed without affecting the performance of any other system component. However, replacement of the SI-2D radar by ultra-wideband radar may require repackaging of components or redesign of the ARTS enclosure.

- The cost of the satellite based ARTS system is comparable to the cost of wireless radio modem based systems using microwave radars. The cost of ARTS can be expected to decrease as the market for real-time satellite based systems grows.

4.2 Recommendations

4.2.1 Field Tests

4.2.1.1 Wide Area Network of ARTS

It is recommended that several units (3-5 units) be fabricated and together be tested as a wide area network of ARTS units in the field. Traffic parameters of speed, counts, volume, occupancy, and headway can be measured and transmitted by satellite communications to a Traffic Management Center (TMC). Further, cycle time for ARTS, with its self-activated data reporting, may be compared to cycle time for data polling of the sensor system by the base station computer or TMC. This would provide a quantitative assessment of ARTS system performance versus conventional data acquisition methods.

4.2.1.2 ARTS in Smart Work Zones

It is feasible to integrate ARTS with work zone traffic management systems. One or more ARTS units can be deployed in conjunction with existing traffic management systems for work zones. Real-time traffic data from ARTS can be used by work-zone systems to provide delay predictions, speed differentials, alternate route information or travel times. The ARTS unit can also be a means to communicate with portable and permanent message boards and arrow boards through satellite communications. Ease in installation, easy adaptability to message boards, satellite communications, built-in GPS positioning, self-diagnostics, reasonable component cost, and elimination of base station polling make it an attractive choice for integration with work zone traffic control systems (See, e.g. www.i90cleveland.com or www.scientexcorp.com).

4.2.1.3 ARTS in Incident Management Systems

It is also feasible to deploy several ARTS units as part of an incident management system. Since average speeds can originate from the ARTS unit, there is no need to poll each device and more ARTS units can be deployed with each being triggered by low speeds or MDS network time. The triggering due to low speeds and low occupancy data could indicate that an incident has occurred. Additional study of the sensor data gathered during incidents could lead to improvement in incident detection algorithms. Further, satellite activated CMS could be used to warn motorists and control traffic around such incidents in real-time. The incident management system could be monitored and controlled through a TMC, or it could be implemented as a stand-alone Internet based system.

4.2.1.4 ARTS using an Ultra-wideband Radar

The ARTS was envisioned to evolve using ultra-wideband radar. The current ARTS prototype utilizing a Doppler transceiver does not have the capabilities of providing lane specific data. The Doppler transceivers would have to be mounted per lane to be able to provide lane specific data but this could be more costly than using ultra-wideband radar. Ultra-wideband radar should be integrated into ARTS.

4.2.2 Hardware Enhancements

The layout of components inside the enclosure and the design of the electronics interface board can be modified (the digital compass and possibly the circuitry of the ultra-wideband radar can be integrated with the electronics interface board and the single-board computer being on reverse sides of the same panel) which could reduce the size of the ARTS enclosure and therefore the main unit itself to at least half its current size. Fabrication of this enclosure should include a provision for mounting equipment.

The XPower Powerpack 400 Plus should be installed in an outdoor cabinet or an equivalent power source with an outdoor enclosure and charge controller. Battery overload and total discharge protection should be included whenever the ARTS unit is required to operate with an external power source.

An internal storage device should be added to provide the ARTS unit a means of storing all acquired individual speeds, lane specific information, and other raw traffic data obtained in the field.

4.2.3 Software Enhancements

The Client Software can be modified to support multiple ARTS units. Multiple ARTS units could be tested for trigger-based data transmission instead of being polled. Each one can be triggered by either low speeds during congestion or synchronized by MDS network time. Polling total turn-around times can be compared with time-triggered total turn around times to assess ARTS cycle time efficiency.

The ARTS system can also include a static map similar to that used in work zone base station software (See, e.g. www.i90cleveland.com or www.scientexcorp.com) wherein locations of the sensors are depicted on the map and the icon changes color based on the speeds obtained (e.g. red: 0-20 mph, yellow: 21-40 mph, green: 41 mph and above). The map could later become dynamic with GPS positioning and would locate or track devices on the dynamic map. The dynamic map would require less maintenance since moving devices around would not affect the system but implementing it could be more expensive.

To be able to communicate with portable and permanent signs, the ARTS unit needs to include the protocols for specific signs. Programming the protocols into the embedded software will enable the base station computer to manually or automatically (through a smart work zone system) update messages displayed on these boards remotely.

Additional algorithms can be added in the embedded software to detect traffic incidents and detect stopped traffic. Based on study of data gathered during incidents and improvement in the algorithm to identify incidents based on speeds, the ARTS can be automated to identify and report such incidents as needed.

APPENDIX A. Client Software Command Logs

SIGNAL Command Log

"4,0" → Advanced Relocatable Traffic Sensor's response

Thu May 06 15:56:40 2004 Initialize IAMS Client Thread Socket API - Mar 30, 2004
Thu May 06 15:56:40 2004 SetHeartBeatInterval 10
Thu May 06 15:56:40 2004 Set Non Blocking Mode
Thu May 06 15:56:40 2004 Connecting to SS Host: SciTexDemo Pswd: QcfG49LZTY X.121 Addr: 1299900000380
Thu May 06 15:56:40 2004 Connecting to IP Host(0) 204.138.68.129
Thu May 06 15:56:44 2004 SEND COMMAND - USER_CONNECT
UserId: SciTexDemo Pswd: QcfG49LZTY Addr: 1299900000380 SSHost: SciTexDemo HBInt: 10

Thu May 06 15:56:44 2004 Time wait for Connect ACK - 599 + 30 = 629
Thu May 06 15:56:44 2004 Starting IAMS Connection
Thu May 06 15:56:45 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:46 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:47 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:48 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:49 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:50 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:51 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:52 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:53 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:54 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:56:54 2004 Session Handle 1028441
Thu May 06 15:56:54 2004 RECV CONNECT ACK - OK
Thu May 06 15:56:54 2004 SEND DATA - RTS_DATA
MT addr: 3963 (0x00000f7b)
RTS Message Request Len 6
    num_repeats: 0 repeat_int: 0 tr_dly: 0 pri: 5
    appl_sel: 17 addr: [len 3 type 5]
    HEX: 53 49 47 4e 41 4c

Thu May 06 15:56:57 2004 RECV HEARTBEAT
Thu May 06 15:56:57 2004 SEND COMMAND - HEARTBEAT

Thu May 06 15:57:01 2004 RECV HEARTBEAT
Thu May 06 15:57:01 2004 SEND COMMAND - HEARTBEAT

Thu May 06 15:57:03 2004 RECV RTS Message Indication MT addr: 3963 (0x00000f7b)
    appl_sel: 17 pri: 4 len: 3
    HEX: 34 2c 30

Thu May 06 15:57:11 2004 SEND COMMAND - HEARTBEAT

Thu May 06 15:57:18 2004 RECV HEARTBEAT
Thu May 06 15:57:18 2004 SEND COMMAND - HEARTBEAT

Thu May 06 15:57:26 2004 RECV HEARTBEAT
Thu May 06 15:57:26 2004 SEND COMMAND - HEARTBEAT

Thu May 06 15:57:30 2004 SEND COMMAND - DISCONNECT
DISCONNECT
Thu May 06 15:57:33 2004 RECV DISCONNECT ACK
Thu May 06 15:57:33 2004 Closed session to 204.138.68.129
Thu May 06 15:57:34 2004 Stopped IAMS Connection
Thu May 06 15:57:34 2004 Disconnected OK

BVOLTS Command Log
"13.6" → Advanced Relocatable Traffic Sensor's response

Thu May 06 16:00:59 2004 Initialize IAMS Client Thread Socket API - Mar 30, 2004
Thu May 06 16:00:59 2004 SetHeartBeatInterval 10
Thu May 06 16:00:59 2004 Set Non Blocking Mode
Thu May 06 16:00:59 2004 Connecting to SS Host: SciTexDemo Pswd: QcfG49LZTY X.121 Addr: 1299900000380
Thu May 06 16:00:59 2004 Connecting to IP Host(0) 204.138.68.129
Thu May 06 16:01:01 2004 SEND COMMAND - USER_CONNECT
UserId: SciTexDemo Pswd: QcfG49LZTY Addr: 1299900000380 SSHost: SciTexDemo HBInt: 10

Thu May 06 16:01:01 2004 Time wait for Connect ACK - 599 + 30 = 629
Thu May 06 16:01:01 2004 Starting IAMS Connection
Thu May 06 16:01:02 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:03 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:04 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:04 2004 Session Handle 1028516
Thu May 06 16:01:04 2004 RECV CONNECT ACK - OK
Thu May 06 16:01:04 2004 SEND DATA - RTS_DATA
MT addr: 3963 (0x00000f7b)
RTS Message Request Len 6
  num_repeats: 0 repeat_int: 0 tr_dly: 0 pri: 5
  appl_sel: 17 addr: [len 2 type 4]
  HEX: 42 56 4f 4c 54 53

Thu May 06 16:01:12 2004 RECV HEARTBEAT
Thu May 06 16:01:12 2004 SEND COMMAND - HEARTBEAT

Thu May 06 16:01:14 2004 RECV RTS Message Indication MT addr: 3963 (0x00000f7b)
  appl_sel: 17 pri: 4 len: 4
  HEX: 31 33 2e 36

Thu May 06 16:01:15 2004 SEND COMMAND - DISCONNECT
DISCONNECT
Thu May 06 16:01:18 2004 RECV DISCONNECT ACK
Thu May 06 16:01:18 2004 Closed session to 204.138.68.129
Thu May 06 16:01:19 2004 Stopped IAMS Connection
Thu May 06 16:01:19 2004 Disconnected OK

GPSPOS Command Log
"3848.227N,07707.032W" → Advanced Relocatable Traffic Sensor's response

Thu May 06 16:05:24 2004 Initialize IAMS Client Thread Socket API - Mar 30, 2004
Thu May 06 16:05:24 2004 SetHeartBeatInterval 10
Thu May 06 16:05:24 2004 Set Non Blocking Mode
Thu May 06 16:05:24 2004 Connecting to SS Host: SciTexDemo Pswd: QcfG49LZTY X.121 Addr: 1299900000380
Thu May 06 16:05:24 2004 Connecting to IP Host(0) 204.138.68.129
Thu May 06 16:05:26 2004 SEND COMMAND - USER_CONNECT
UserId: SciTexDemo Pswd: QcfG49LZTY Addr: 1299900000380 SSHost: SciTexDemo HBInt: 10

Thu May 06 16:05:26 2004 Time wait for Connect ACK - 599 + 30 = 629
Thu May 06 16:05:26 2004 Starting IAMS Connection
Thu May 06 16:05:27 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:05:28 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:05:29 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:05:30 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:05:30 2004 Session Handle 1028581
Thu May 06 16:05:30 2004 RECV CONNECT ACK - OK
Thu May 06 16:05:30 2004 SEND DATA - RTS_DATA
MT addr: 3963 (0x00000f7b)
RTS Message Request Len 6
    num_repeats: 0 repeat_int: 0 tr_dly: 0 pri: 5
    appl_sel: 17 addr: [len 7 type 4]
    HEX: 47 50 53 50 4f 53

Thu May 06 16:05:37 2004 RECV HEARTBEAT
Thu May 06 16:05:37 2004 SEND COMMAND - HEARTBEAT

Thu May 06 16:05:40 2004 RECV RTS Message Indication MT addr: 3963 (0x00000f7b)
    appl_sel: 17 pri: 4 len: 20
    HEX: 33 38 34 38 2e 32 32 37 4e 2c 30 37 37 30 37 2e 30 33 32 57

Thu May 06 16:05:41 2004 SEND COMMAND - DISCONNECT
DISCONNECT
Thu May 06 16:05:44 2004 RECV DISCONNECT ACK
Thu May 06 16:05:44 2004 Closed session to 204.138.68.129
Thu May 06 16:05:44 2004 Stopped IAMS Connection
Thu May 06 16:05:45 2004 Disconnected OK

CCLOCK Command Log
"2004/05/06,20:58:34+00" → Advanced Relocatable Traffic Sensor's response

Thu May 06 15:58:19 2004 Initialize IAMS Client Thread Socket API - Mar 30, 2004
Thu May 06 15:58:19 2004 SetHeartBeatInterval 10
Thu May 06 15:58:19 2004 Set Non Blocking Mode
Thu May 06 15:58:19 2004 Connecting to SS Host: SciTexDemo Pswd: QcfG49LZTY X.121 Addr: 1299900000380
Thu May 06 15:58:19 2004 Connecting to IP Host(0) 204.138.68.129
Thu May 06 15:58:23 2004 SEND COMMAND - USER_CONNECT
UserId: SciTexDemo Pswd: QcfG49LZTY Addr: 1299900000380 SSHost: SciTexDemo HBInt: 10

Thu May 06 15:58:23 2004 Time wait for Connect ACK - 599 + 30 = 629
Thu May 06 15:58:23 2004 Starting IAMS Connection
Thu May 06 15:58:24 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:58:25 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:58:26 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:58:27 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:58:28 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 15:58:28 2004 Session Handle 1028473
Thu May 06 15:58:28 2004 RECV CONNECT ACK - OK
Thu May 06 15:58:28 2004 SEND DATA - RTS_DATA
MT addr: 3963 (0x00000f7b)
RTS Message Request Len 6
    num_repeats: 0 repeat_int: 0 tr_dly: 0 pri: 5
    appl_sel: 17 addr: [len 3 type 4]
    HEX: 43 43 4c 4f 43 4b

Thu May 06 15:58:36 2004 RECV HEARTBEAT
Thu May 06 15:58:36 2004 SEND COMMAND - HEARTBEAT

Thu May 06 15:58:40 2004 RECV RTS Message Indication MT addr: 3963 (0x00000f7b)
    appl_sel: 17 pri: 4 len: 22
    HEX: 32 30 30 34 2f 30 35 2f 30 36 2c 32 30 3a 35 38 3a 33 34 2b 30 30

Thu May 06 15:58:44 2004 SEND COMMAND - DISCONNECT
DISCONNECT
Thu May 06 15:58:48 2004 RECV DISCONNECT ACK
Thu May 06 15:58:48 2004 Closed session to 204.138.68.129
Thu May 06 15:58:49 2004 Stopped IAMS Connection
Thu May 06 15:58:49 2004 Disconnected OK

AVGSPD Command Log
"33" → Advanced Relocatable Traffic Sensor's response

Thu May 06 16:01:44 2004 Initialize IAMS Client Thread Socket API - Mar 30, 2004
Thu May 06 16:01:44 2004 SetHeartBeatInterval 10
Thu May 06 16:01:44 2004 Set Non Blocking Mode
Thu May 06 16:01:44 2004 Connecting to SS Host: SciTexDemo Pswd: QcfG49LZTY X.121 Addr: 1299900000380
Thu May 06 16:01:44 2004 Connecting to IP Host(0) 204.138.68.129
Thu May 06 16:01:48 2004 SEND COMMAND - USER_CONNECT
UserId: SciTexDemo Pswd: QcfG49LZTY Addr: 1299900000380 SSHost: SciTexDemo HBInt: 10

Thu May 06 16:01:48 2004 Time wait for Connect ACK - 599 + 30 = 629
Thu May 06 16:01:48 2004 Starting IAMS Connection
Thu May 06 16:01:49 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:50 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:51 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:52 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:53 2004 Wait for Conn ACK - 1 more sec. passed
Thu May 06 16:01:53 2004 Session Handle 1028534
Thu May 06 16:01:53 2004 RECV CONNECT ACK - OK
Thu May 06 16:01:53 2004 SEND DATA - RTS_DATA
MT addr: 3963 (0x00000f7b)
RTS Message Request Len 6
num_repeats: 0 repeat_int: 0 tr_dly: 0 pri: 5
appl_sel: 17 addr: [len 1 type 4]
HEX: 41 56 47 53 50 44

Thu May 06 16:01:57 2004 RECV HEARTBEAT
Thu May 06 16:01:57 2004 SEND COMMAND - HEARTBEAT

Thu May 06 16:02:02 2004 RECV RTS Message Indication MT addr: 3963 (0x00000f7b)
appl_sel: 17 pri: 4 len: 2
HEX: 33 33

Thu May 06 16:02:04 2004 SEND COMMAND - DISCONNECT
DISCONNECT
Thu May 06 16:02:07 2004 RECV DISCONNECT ACK
Thu May 06 16:02:07 2004 Closed session to 204.138.68.129
Thu May 06 16:02:07 2004 Stopped IAMS Connection
Thu May 06 16:02:08 2004 Disconnected OK

APPENDIX B. Embedded Software Command Logs

SIGNAL Command received

```
...

+CMTI: "ME",1
AT+CMGR=1

+CMGR: "REC UNREAD","17",,"2004/05/06,20:56:58+00"
3963,5,SIGNAL
OK

AT+CSQ
+CSQ: 4,0
OK

AT+CMGS=17

> 2,0,4,1,4,0
+CMGS: 0
OK
```

BVOLTS Command received

```
...

+CMTI: "ME",3
AT+CMGR=3

+CMGR: "REC UNREAD","17",,"2004/05/06,21:01:09+00"
3963,5,BVOLTS
OK

AT+CBC?
+CBC: 0,85,0,0,0,100
OK

... (conversion → 85 * 16 / 100 = 13.6)

AT+CMGS=17

> 2,0,4,1,13.6
+CMGS: 0
OK
```

GPSPOS Command received

```
...

+CMTI: "ME",7
AT+CMGR=7

+CMGR: "REC UNREAD","17",,"2004/05/06,21:05:34+00"
3963,5,GPSPOS
OK

AT+CMGS=3000

> G
+CMGS: 0
OK

+CMTI: "ME",8
AT+CMGR=8

+CMGR: "REC UNREAD","3000",,"2004/05/06,21:05:35+00"
3963,0,A,3848.227N,07707.032W

AT+CMGS=17

> 2,0,4,1,3848.227N,07707.032W
+CMGS: 0
OK
```

CCLOCK Command received

...

+CMTI: "ME",2
AT+CMGR=2

+CMGR: "REC UNREAD","17",,"2004/05/06,20:58:33+00"
3963,5,CCLOCK
OK

AT+CCLK?

+CCLK: 2004/05/06,20:58:34+00
OK

AT+CMGS=17

> 2,0,4,1, 2004/05/06,20:58:34+00
+CMGS: 0
OK

AVGSPD Command received

...

+CMTI: "ME",4
AT+CMGR=4

+CMGR: "REC UNREAD","17",,"2004/05/06,21:01:57+00"
3963,5,AVGSPD
OK

... (get stored average speed)

AT+CMGS=17

> 2,0,4,1,33
+CMGS: 0
OK

APPENDIX C. Speed Log from Field Test

The following were the speeds obtained over a 3 minute period from 12:35:30 up to 12:38:30 on Oct. 8, 2004 at Eisenhower Avenue just in front of the Scientex office. The street is an arterial roadway with two lanes on each direction plus a fifth lane that is used as a shared turning lane. Sampling rate was set at 10 samples per second. Same speeds occurring 2-4 consecutive times were counted as one or assumed to be one vehicle but since there are 2 lanes some vehicles might have been omitted if both vehicles on those two lanes were running at the same speed and passing the Advanced Relocatable Traffic Sensor at the same time. Some vehicles in the outermost lanes can also be omitted if they are bunched up with vehicles on the innermost lanes or covered by larger vehicles on the innermost lanes. Some vehicles would be counted more than once as they accelerate or decelerate while passing the Advanced Relocatable Traffic Sensor. Slow speeds obtained were from vehicles making either a left or a right turn. The SI-2 radar sensor used for the ARTS prototype was pre-programmed to only record speeds from a minimum of 5 mph to a maximum of 99 mph. The first character on each line of the speed log represents the direction of the vehicle followed by the recorded speeds. A [+] would indicate approaching vehicles; a [-] would indicate vehicles going away from the Sensor; while the [?] would indicate an unknown direction. All the recorded speeds are in miles per hour. 97 speed samples were recorded, 28 from approaching vehicles, 63 from outgoing vehicles, and 6 speeds had unknown directions. The approaching vehicles had an average speed of 17.75 mph while the outgoing vehicles had an average speed of 22.9683 mph.

SPEED LOG

```
+005
+006
+008
-028
+007
+006
+005
-026
-012
-009
-007
-006
-005
-024
-026
-025
-026
-029
+012
+029
-014
-015
-015
-014
-009
-008
-006
-005
-022
+027
-011
-012
-012
-011
?011
-021
-024
-024
-028
-029
-021
-022
+020
-017
-021
+028
+030
-014
+009
-034
-031
+012
+011
?011
+010
+035
-034
-036
-037
-036
?036
-035
?034
-026
-027
-030
-033
-034
?013
+021
+020
+019
-028
-029
+015
-031
+025
-024
-033
-034
+031
+029
-041
?043
-029
-030
-031
-033
-029
-028
-018
-020
-018
+031
+015
+016
+015
```

APPENDIX D. Hardware Technical Specifications

SI-2 System Interface Special Application Radar

SI-2 ANTENNA TECHNICAL SPECIFICATIONS

General

Antenna	K-band
Frequency	24.150GHz ± 50 MHz
Nominal Power Out	10mW nominal
Output Power Density	0.5 mW/cm2
Beam Width	12 degrees
Detection Range	1500 feet
Supply voltage	10.8VDC – 24VDC
Nominal current draw	+12V (.250mA) +24V (.120mA)
Surge current requirements	1 Amp
Operating temperature	–22°F to +158°F (–30°C to +70°C)
Maximum Humidity	100% (Unit is weatherproof, not waterproof)
Polarization	Linear
Input voltage	10.8 – 24VDC

Processor

Serial communications	RS232C
Data rate	Baud rates 1200, 2400, 9600, 19200
Data format	(Various, see selectable RS232 output protocols below.)
Target acquisition time	0.021ms

Mechanical

Weight	1.60 lbs. (0.73 kg)
Length	8 in (20.3 cm)
Width	3 in (7.6 cm)

Accuracy

Speed range	2 - 200 mph (3 - 322 Km/h)
Accuracy	±0.1 mph (±0.1 Km/h)

DB-9 Connector Pinout

Signal	DB-9 Connector
+12VDC power	1 (red)
RS232 TX	2 (black)
RS232 RX	3 (green)
Ground (shield)	5 (brown)
Ground	9 (black)

Output Rate (Programmable)

Selectable output rate when target speed changes	1-10 times per second
When polled Data hold time:	1-10 seconds
Low/high speed cutoff	

Angle and Direction (Programmable)

Horizontal and vertical cosine corrections from 0° – 45°
Direction (D) report switch ON/OFF
D = + (approaching target)
D = – (receding target)
D = ? (target from unknown direction)

Octagon Systems' 6225 Palm-Size Single-Board Computer

CPU	ALi M6117 386SX Embedded Microprocessor
Bus clock	25 MHz, 40 MHz
BIOS	AT compatible with industrial extensions
DRAM	4 MB DRAM soldered on–card, 8MB OEM option
Floppy drive	Floppy drive support via the LPT1 parallel port or external adapter. The 6225 has an on–board floppy drive interface at J4.
Hard drive	Hard drive BIOS supported using external hard drive controller which allows extended IDE drives larger than 528 MB. The 6225 has an on-board hard drive interface at J12.
Solid–state disk 0	Supports an M–Systems DOC, 5V flash, 512 KB SRAM or EPROM
Solid–state disk 1	Supports a 2048 KB flash
ROM–DOS	ROM–DOS 7.1 compatible
Serial I/O	COM1 through COM4 are 16C550 compatible
Digital I/O	The digital I/O port provides 17 lines of digital I/O: eight lines are configurable as a group for input or output, five lines are input only, and four lines are output only.
Parallel port	LPT1 is PC compatible with multifunctional capability
Watchdog timer	Time–out is from 0.5 seconds to 64 seconds, software enabled and strobed. Disabled on power-up and reset. Controls are through built–in, enhanced INT 17h function calls.
Bus mastering	Bus mastering is not supported
Power requirements	5V ±0.25V @ 1.0 Amp. maximum Full 40MHz operation: 480 mA typical Suspend: 167 mA typical
Environmental specifications	–40° to 85° C when operating at 25 MHz 0° to 60° C when operating at 40 MHz –55° to 90° C, non-operating RH 5% to 95%, non-condensing
Size	4.5 in. x 4.9 in.

HMR3200/HMR3300

Honeywell
SENSOR PRODUCTS

SPECIFICATIONS

Characteristics	Conditions	Min	Typ	Max	Units
Heading					
Accuracy	Level 0° to ±30° (HMR3300 only) ±30° to ±60° (HMR3300 only)		1.0 3.0 4.0		deg RMS
Resolution			0.1		deg
Hysteresis	HMR3200 HMR3300		0.1 0.2	0.2 0.4	deg
Repeatability	HMR3200 HMR3300		0.1 0.2	0.2 0.4	deg
Pitch and Roll	(HMR3300 only)				
Range	Roll and Pitch Range		± 60		deg
Accuracy	0° to ± 30° ± 30° to ± 60°		0.4 1.0	0.5 1.2	deg
Null Accuracy*	Level -20° to +70°C Thermal Hysteresis -40° to +85°C Thermal Hysteresis		0.4 1.0 5.0		deg
Resolution			0.1		deg
Hysteresis			0.2		deg
Repeatability			0.2		deg
Magnetic Field					
Range	Maximum Magnetic Flux Density		± 2		gauss
Resolution			0.1	0.5	milli-gauss
Electrical					
Input Voltage	Unregulated	6	-	15	volts DC
Current	HMR3200 HMR3300		18 22	20 24	mA mA
Digital Interface					
UART	ASCII (1 Start, 8 Data, 1 Stop, 0 Parity) User Selectable Baud Rate	2400	-	19200	Baud
SPI	CKE = 0, CKP = 0 Pseudo Master				
Update	Continuous/Strobed/Averaged HMR3200 HMR3300		15 8		Hz
Connector	In-Line 8-Pin Block (0.1" spacing)				

* Null zeroing prior to use of the HMR3300 and upon exposure to temperature excursions beyond the Operating Temperature limits is required to achieve highest performance.

Characteristics	Conditions	Min	Typ	Max	Units
Physical					
Dimensions	Circuit Board Assembly		25.4 x 36.8 x 11		mm
Weight	HMR3200 HMR3300		7.25 7.5		grams
Environment					
Temperature	Operating (HMR3200) Operating (HMR3300) Storage	-40 -20 -55	- -	+65 +70 +125	°C °C °C

Pin Configuration

Pin Number	Pin Name	Description
1	SCK	Serial Clock Output for SPI Mode
2	RX/SDI	UART Receive Data/SPI Data Input
3	TX/SDO	UART Transmit Data/SPI Data Output
4	CS	Chip Select for SPI Mode (active falling edge)
5	CAL	Calibration ON/OFF input (active falling edge)
6	+5VDC*	+5 VDC Regulated Power Input
7	GND	Power and Signal Ground
8	+V*	Unregulated Power Input (+6 to +15 VDC)

*Note: Use either pin 6 (+5VDC) or pin 8 (+V) to power the circuit board. Hold the board with pin header edge close to you and pins pointing DOWN. Then PIN 1 is the left most pin.

XPower Powerpack 400 Plus

XPower Powerpack 400 Plus

400 Watts Portable AC with 250 PSI Air Compressor

Electrical Specifications

115 volt AC section		12 volt DC section	
AC output power (max. continuous)	320 W	Internal battery type	Sealed lead acid, AGM
AC output power (5 minutes)	400 W	Internal battery capacity	20 amp-hours, 200 CCA
AC surge power (peak)	600 W	Internal battery voltage	12 VDC (nominal)
AC output voltage (nominal)	115 V	DC power socket (circuit breaker)	12 amps (automatic reset)
AC output frequency	60 Hz +/-4 Hz		
AC output waveform	Modified sine wave		
Inverter no-load current	< 0.20 amps (battery drain with no load on inverter)		

Charging system		Charging time	
AC charger bulk charging current	750 mA (maximum)	From AC outlet	max. 35 hours*
Peak charging voltage	14.2V (nominal)	From DC outlet	max. 4 hours*
Charge restart voltage	12.6V (nominal)	*Maximum charging time occurs when battery is completely discharged.	
Float charge current	1 mA (nominal)		
Charger input socket current	2.5 amps (maximum)		

General Specifications

Air compressor	250 psi (lbs. per square inch)
Jump-start cables	24" (61 cm), 4 AWG
Built-in incandescent light	5 watt (replaceable)
Operating/storage temperature	32°F - 104°F (0°C - 40°C) / 32°F - 86°F (0°C - 30°C)
Inverter low battery alarm	11.0 volts (nominal)
Inverter low battery shutdown	10.5 volts (nominal)
Dimensions (H x W x L)	9.5 x 8.1 x 15.8" (24.2 x 20.6 x 40.2 cm)
Weight	20 lb (9.0 kg)
Warranty	6 months

Note: Specifications subject to change without notice.

How Long Will It Provide Power?

	Watts (1)	Hours (2)		Watts (1)	Hours (2)
AC Powered Products:			DC Powered Products:		
Cordless Telephone (used by time)	5	40	Cellular Telephone (3)	6	30
Home Security System	5	40	Incandescent Light (built-in to unit)	5	30
Clock Radio	8	22	Portable Cooler	30	4
Portable Stereo	10	17	Portable Vacuum Cleaner	100	1
Fluorescent Work Light	14	10			
Fireplace Fan	20	8			
Laptop Computer	25	6			
Table Lamp	40	3			
Color TV (13")	60	2.5			

(1) Represents actual power consumption as measured on sample products

(2) Operating times assume a fully charged 20 Ah battery and may vary based on model/brand used

(3) Represents talk time available from 10 recharge cycles

PDT-100 Satellite Packet Data Terminal

Parameter	Min	Typical	Max	Units
Physical				
Weight		3		lbs
Height		5.8		inches
Diameter		7.8		inches
Mounting		3 ¼-20 equally spaced 5.8" PCD-mount		
Input Power				
Voltage (per SAE J1455)	9.0		16.0	Vdc
Current - Receive Mode		250		mA
Current - Transmit Mode		3300[1]		mA
Current – Low Power		0.5		mA
Environmental				
Operating Temperature	-40		+50	?C
Storage Temperature	-55		+85	?C
Humidity	0		98	%RH
Vibration (Operational)		$1.05G_{rms}$; 5 to 20 Hz @ 0.019 g^2/Hz 20 to 150 Hz @ -3 dB/octave		
User Data Port Interface[2]				
Electrical Levels		EIA RS-232C		
Baud Rate		1200 to 38400 (9600 default)		bps
Parity		No		
Stop Bit		1		
Data Bit Format		8		
Flow Control		None		
Discretes				
V_{in}			16	Vdc
I_{in}			7 (@16V)	mA
High Input Threshold	2.4			V
Low Input Threshold			1.4	V
$I_{overcurrent}$		2		A
Active Overvoltage Clamps		Yes		
Data Communications Performance				
RTS Transport Time		2.5, 95% of the time		s
Effective UDS Throughput		2000		bps
GPS				
Accuracy		? 30		m
Channels		12		
Data Format		NMEA 0183		

APPENDIX E. Sample Warning Log when ARTS was Tilted

Fri Oct 08 14:35:45 2004 Initialize IAMS Client Thread Socket API - Mar 30, 2004
Fri Oct 08 14:35:45 2004 SetHeartBeatInterval 10
Fri Oct 08 14:35:45 2004 Set Non Blocking Mode
Fri Oct 08 14:35:45 2004 Connecting to SS Host: SciTexDemo Pswd: QcfG49LZTY X.121 Addr: 1299900000380
Fri Oct 08 14:35:45 2004 Connecting to IP Host(0) 204.138.68.129
Fri Oct 08 14:35:49 2004 SEND COMMAND - USER_CONNECT
UserId: SciTexDemo Pswd: QcfG49LZTY Addr: 1299900000380 SSHost: SciTexDemo HBInt: 10

Fri Oct 08 14:35:49 2004 Time wait for Connect ACK - 599 + 30 = 629
Fri Oct 08 14:35:49 2004 Starting IAMS Connection
Fri Oct 08 14:35:50 2004 Wait for Conn ACK - 1 more sec. passed
Fri Oct 08 14:35:51 2004 Wait for Conn ACK - 1 more sec. passed
Fri Oct 08 14:35:52 2004 Wait for Conn ACK - 1 more sec. passed
Fri Oct 08 14:35:53 2004 Wait for Conn ACK - 1 more sec. passed
Fri Oct 08 14:35:53 2004 Session Handle 1028441
Fri Oct 08 14:35:53 2004 RECV CONNECT ACK - OK

Fri Oct 08 14:35:57 2004 RECV HEARTBEAT
Fri Oct 08 14:35:57 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:01 2004 RECV HEARTBEAT
Fri Oct 08 14:36:01 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:05 2004 RECV HEARTBEAT
Fri Oct 08 14:36:05 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:09 2004 RECV HEARTBEAT
Fri Oct 08 14:36:09 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:12 2004 RECV HEARTBEAT
Fri Oct 08 14:36:12 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:16 2004 RECV HEARTBEAT
Fri Oct 08 14:36:16 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:20 2004 RECV HEARTBEAT
Fri Oct 08 14:36:20 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:24 2004 RECV HEARTBEAT
Fri Oct 08 14:36:24 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:28 2004 RECV HEARTBEAT
Fri Oct 08 14:36:28 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:31 2004 RECV HEARTBEAT

Fri Oct 08 14:36:31 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:32 2004 RECV RTS Message Indication MT addr: 3963 (0x00000f7b)
appl_sel: 17 pri: 4 len: 8
HEX: 57 41 52 4E 49 4E 47 32

Fri Oct 08 14:36:36 2004 RECV HEARTBEAT
Fri Oct 08 14:36:36 2004 SEND COMMAND - HEARTBEAT

Fri Oct 08 14:36:38 2004 SEND COMMAND - DISCONNECT
DISCONNECT
Fri Oct 08 14:36:41 2004 RECV DISCONNECT ACK
Fri Oct 08 14:36:41 2004 Closed session to 204.138.68.129
Fri Oct 08 14:36:41 2004 Stopped IAMS Connection
Fri Oct 08 14:36:42 2004 Disconnected OK

APPENDIX F. Operations Manual

F.1 Deploying the ARTS Prototype

The ARTS prototype is composed mainly of three subsystems:

1. The Advanced Relocatable Traffic Sensor (composed of the SI-2D Radar, Octagon Systems' 6225 Single-Board Computer, the Electronics Interface Board, and the HMR3300 Digital Compass which are all bundled up in the outdoor enclosure).
2. The PDT-100 Satellite Packet Data Terminal (the wireless communications link to the base station computer / Traffic Management Center)
3. The Solar Portable Power System (composed of the XPower Powerpack 400 Plus with its internal, sealed, 12V, 20Ah, AGM lead acid battery and a battery charging controller system and the SunWize OEM10 Solar Panel)

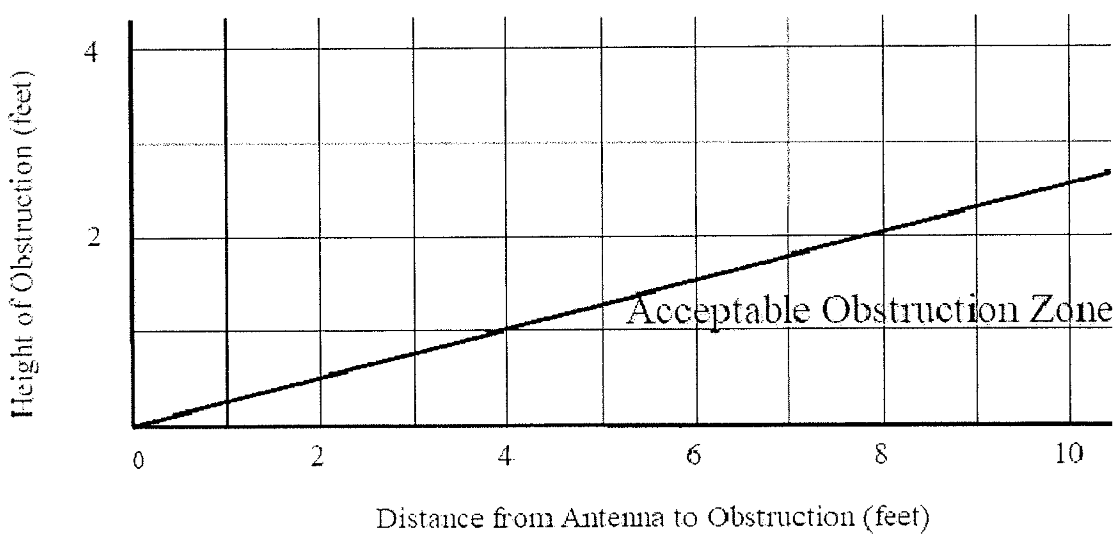
There are two cables that connect the Advanced Relocatable Traffic Sensor to the PDT-100 Satellite Packet Data Terminal and the Solar Portable Power System. The cables are easily distinguishable as the enclosure was so designed so that one end connector is male and the other end connector female. The PDT-100 Satellite Packet Data Terminal cable has a 5-pin male connector that plugs into the 5-pin female enclosure. The Power Cable has a 5-pin female connector on one end and a vehicle lighter adapter on the other end. The power cable can be plugged into the XPower Powerpack 400 Plus or other power sources (vehicle, CMS, etc.) providing 12V DC power preferably regulated power sources. The SunWize OEM10 Solar Panel has a built in cable that connects to the AC charging port in the XPower Powerpack 400 Plus.

Mounting the Advanced Relocatable Traffic Sensor is very important as the accuracy and relevance of the data it collects will depend on how it was initially mounted. Since it is radar, relying on Doppler signals to measure speeds, it needs to be mounted at vehicle level and pointing towards traffic. Due to cost restrictions, the design of the enclosure did not minimize its size but it can be redesigned and re-organized to be at least half of its size now. Depending on the application, (e.g. mount on portable CMS, mount on wooden poles, etc.) the appropriate mounting brackets can be included in the design of the enclosure. Stability and security should also be considered when mounting the Advanced Relocatable Traffic Sensor. The ability to detect when the Advanced Relocatable Traffic Sensor tilts / shifts past the preset threshold can only serve as a warning that speeds obtained may not be that accurate but manual intervention will be needed to correct the problem.

Once the Advanced Relocatable Traffic Sensor is deployed, we can now power it on by switching our power source, the XPower Powerpack 400 Plus to ON. The Advanced Relocatable Traffic Sensor will now enter its initialization process, storing the initial heading, pitch and roll parameters as recorded by the HMR3300 Digital Compass. As the ARTS prototype gathers average speeds, it will also check on the changes in heading and pitch. If these changes exceed 20 degrees, a WARNING2 message will then be sent to the base station computer to inform the user of the problem. If we need to re-align the Advanced Relocatable Traffic Sensor without switching the power OFF, we can just open the ARTS enclosure and press on the RESET button on the Octagon Systems' 6225 Single-Board Computer.

The proper placement of the PDT-100 Satellite Packet Data Terminal should also be considered. Glass, fiberglass and plastic have negligible affect on the satellite signal used by the PDT-100. However, there are materials which will interfere with the satellite signal and which will degrade the performance of the satellite link. These materials include metallic objects or objects painted with metallic/lead-based paints. The PDT-100's view of the sky must not be blocked by any of these objects. For optimum performance a minimum "look angle" should also be observed. See Figure 5.1 below for more information. If the Advanced Relocatable Traffic Sensor is to be mounted on Changeable Message Signs, it is therefore suggested to mount the PDT-100 Satellite Packet Data Terminal on top of the Changeable Message Sign.

Figure F.1: PDT-100 Acceptable Obstruction Zone



The XPower Powerpack 400 Plus needs to be placed inside an outdoor cabinet. Although there were other solar portable power systems that were designed with outdoor enclosures, their cost were more than double of the XPower Powerpack 400 Plus and due to cost restrictions they were therefore not selected for the prototype of the Advanced Relocatable Traffic Sensor. They could definitely replace the XPower Powerpack 400 Plus for Work Zone and Incident Management Systems wherein the Advanced Relocatable Traffic Sensor would not be mounted on Changeable Message Signs.

The Solar Module should be mounted / oriented properly to ensure maximum charging capabilities. A tilted solar module will allow for about 50% more daily power output than modules mounted horizontally. The manufacturer recommends a location with good solar exposure and to orient the module so that the tilted surface will receive maximum sunlight. Adjust the solar array to face true South (in northern latitudes), or true North (in southern latitudes). To optimize a fixed tilt angle for annual performance and to eliminate seasonal adjustment, use the table below:

Site Latitude	Horizontal Tilt Angle
0 – 10	= 10 degrees
11 – 20	= latitude
21 – 30	= latitude + 5 degrees
31 – 40	= latitude + 10 degrees
41 – 50	= latitude + 15 degrees

To increase performance during summer hours; if the tilt angle can be adjusted, use a lesser tilt angle from the table. Select site latitude and choose negative values.

F.2 Using the Client Software

The Advanced Relocatable Traffic Sensor will gather speeds and average it over a period of time (e.g. 3 minutes). Since storing all the individual speeds and all the average speeds and time stamps will not be possible given the current setup since we do not have any storage device within the Advanced Relocatable Traffic Sensor prototype, we would need to receive a request from the base station / Traffic Management Center for the average speeds. From there, the base station computer through the client software can then store the average speeds and all other information it wishes to get from the ARTS prototype. These average speeds could be analyzed or processed to provide delay information, speed differentials, and other information that could be very useful to the public. As an option, a storage device compatible with the ARTS prototype can also be added if the application only needs data logging or for other applications that might require the data to be stored within the Advanced Relocatable Traffic Sensor.

Before the hardware is setup out on the roads, there are other things that need to be considered regarding the PDT-100 Satellite Packet Data Terminal. The PDT-100 needs to be registered with the service provider, in our case EMS Technologies. It also needs to be commissioned, if needed. They are usually commissioned before they are shipped to the user. During the registration process, the service provider will provide all the necessary information that will be needed to log-in to their network and be able to send messages to and receive messages from the PDT-100 Satellite Packet Data Terminal and host computer / base station computer connected to the Internet.

Once the registration process and commissioning process are completed, the client software can be run. Run the *vbclient2.exe* by double clicking it. It should now open up a window similar to what we have on Figure F.2 on the next page. From here, the user needs to click on the *Connect* Button to connect our client software to the service provider's network which will allow us to communicate to the Advanced Relocatable Traffic Sensors. Another window will open up. This will be where the user would need to input the log-in information provided to us by the service provider. In this prototype version, we have already hard-coded those information and would just need to click on the *OK* Button to proceed, as shown on Figure F.3. It is necessary for the base station computer running the client software to be connected to the Internet for us to be able to log-in to the service provider's network. The Status Window located at the upper right hand corner just below the Connect and Disconnect Buttons will show the status of our connection process.

Figure F.2: Client Software Initial Screen

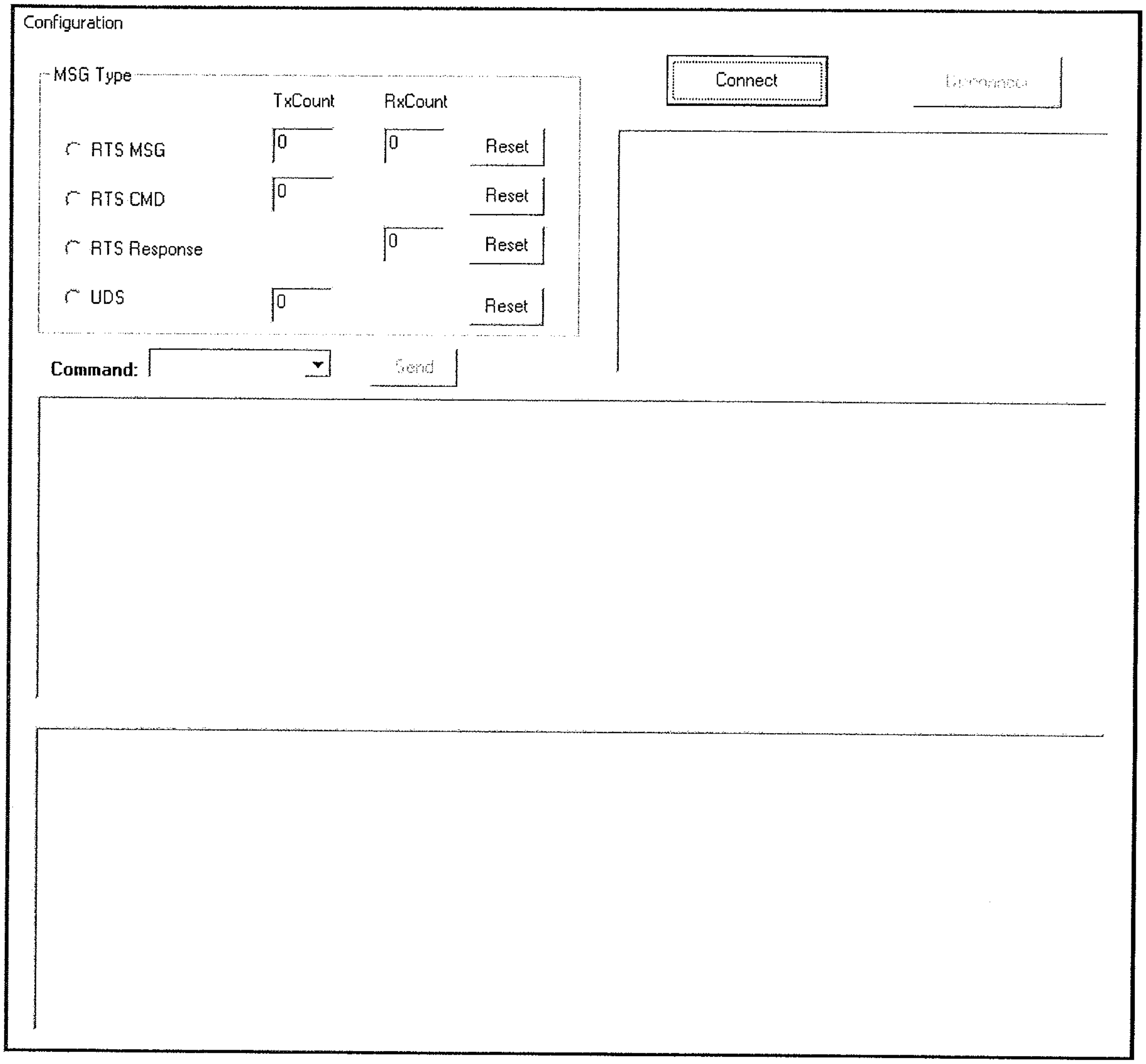
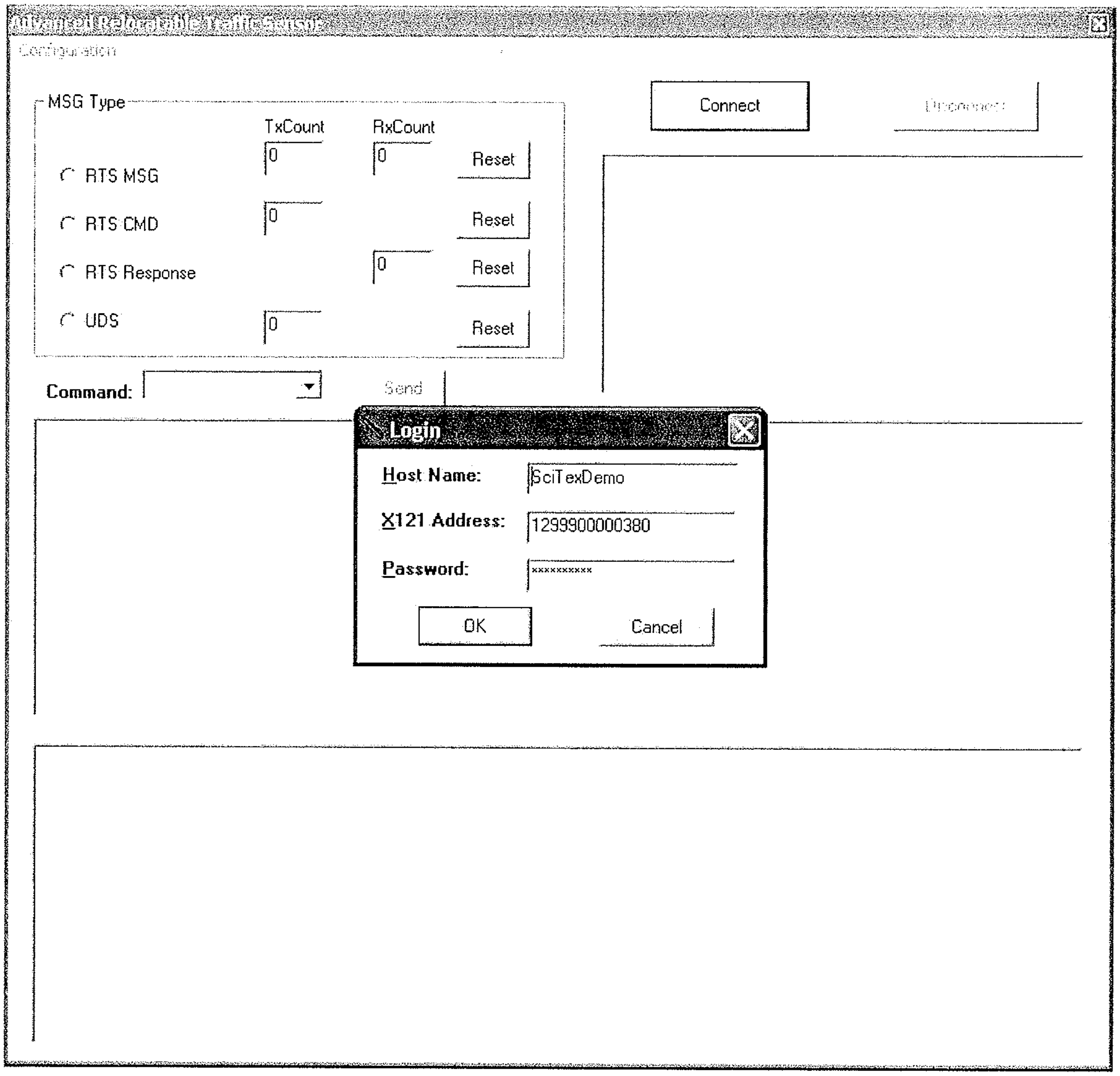


Figure F.3: Client Software Log-in Screen



Once we are connected, we can now send commands to any Advanced Relocatable Traffic Sensor we have deployed. We can now select a *Command* from the preset commands by clicking on the dropdown arrow just beside the Command: label. Clicking on any of the preset commands will select that particular command. Then click on the *RTS MSG* radio button, which will open up another window as shown on Figure F.4. This is important because the Embedded Software on the Advanced Relocatable Traffic Sensors would only accept RTS (Response-oriented Transaction Service) messages and would ignore all other types of messages. Each PDT-100 Satellite Packet Data Terminal is identified by its Mobile Terminal Address or MDS Address. So to send commands to a specific ARTS system sensor, we need to know its Mobile Terminal Address or MDS Address. For our example, we used the PDT-100 with MDS Address 3962. All of our preset commands were designed so that all of them would have a datalength of 6 characters, so that we won't need to change any other values from this window except for the MDS Address. After we input the *MDS Address*, click on the *OK* button. Then click on the *Send* button just beside the Command dropdown list to send the selected command to the ARTS system sensor with the MDS Address we specified in the RTS MSG. All messages coming from the client software will be shown on the middle text box while all other messages received by the client software including errors, warnings, and responses from the ARTS will be shown on the text box below it as shown on Figure F.5. The TxCount just beside each Message Type represents the number of messages sent by the client software while the RxCount represents the number of messages received by the client software. Clicking on the Reset button beside any Message Type would reset the counters of that Message type to 0. In that example, the client software sent a BVOLTS command to ARTS with MDS Address 3962. The error response was because we did not deploy the ARTS with MDS Address 3962. The TxCount and RxCount were both updated to 1 as we sent 1 RTS message and received 1 RTS error response.

For our "LIVE" Demo we have prepared another version of the client software which will periodically (every 2 minutes) send AVGSPD commands to the Advanced Relocatable Traffic Sensor with MDS Address 3962 and store those average speeds in a log file.

Figure F.4: Sending a Command from the Client Software

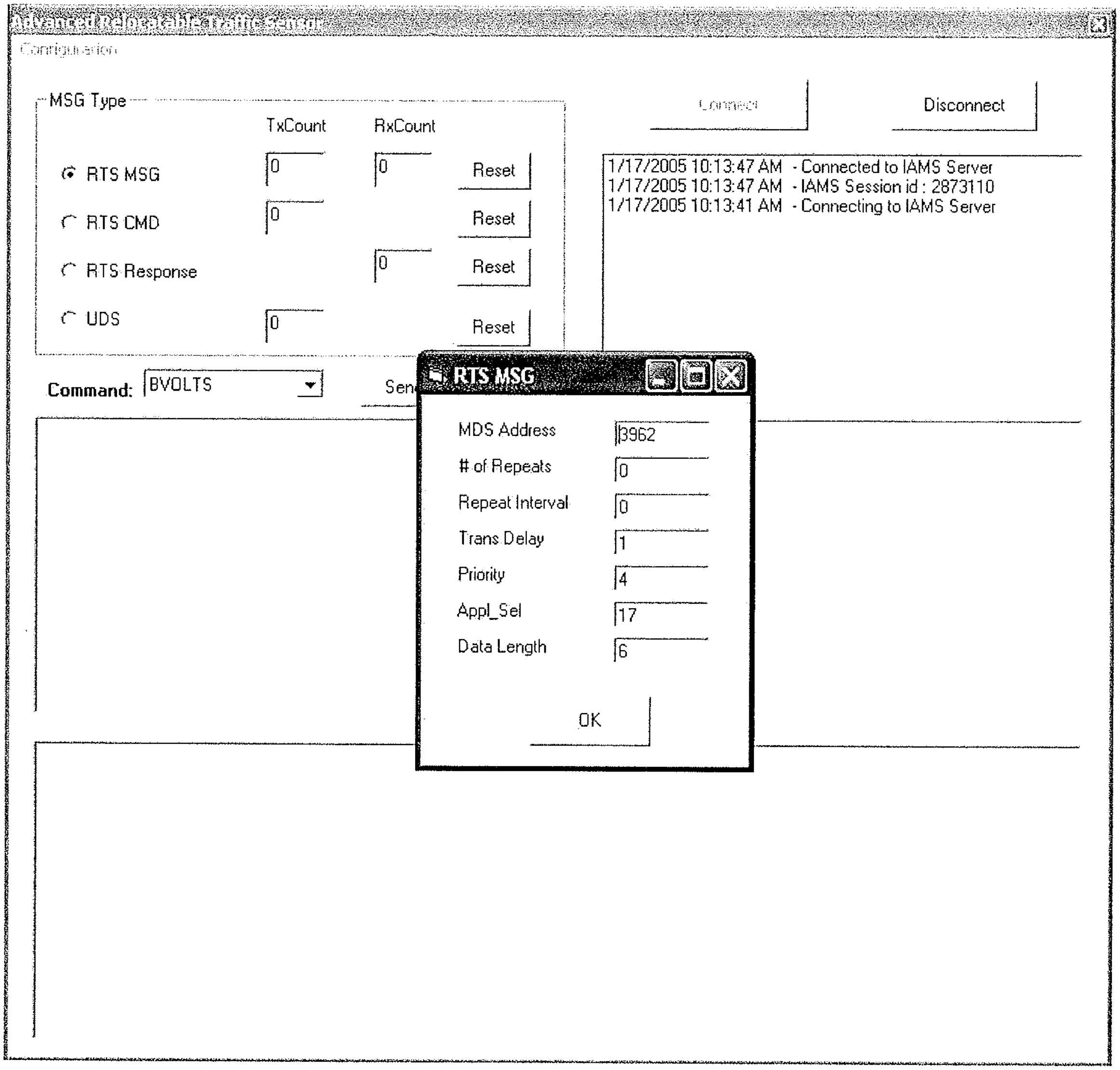


Figure F.5: Message Windows showing BVOLTS Command Status