

June 1, 2004

# Embedded Diagnostics & Prognostics Wireless Sensing Platforms

**Mark Ousachi**

American Systems Technology, Inc.

**Andrew Scott**

U.S. Army RDECOM/TARDEC

**David Yee**

U.S. Army RDECOM/TARDEC

**Thomas Hosmer**

U.S. Army RDECOM/TARDEC

**Dave Daniszewski**

U.S. Army RDECOM/TARDEC

## ABSTRACT

An embedded diagnostics and prognostics architecture affects several aspects associated with military ground vehicles such as improved safety, reduction in maintenance times, weapon system readiness, and awareness of mission capabilities. These capabilities can be enhanced further by implementing wireless technologies on vehicles and utilizing wireless communication in the theater of operations. A wireless architecture on the vehicle provides the foundation for additional significant attributes such as improved theater awareness and more efficient distribution of supplies and if implemented on legacy systems would allow for incremental addition of sensors and technology. Additionally, directly integrating RF circuitry with a sensing device allows a systems integrator to minimize the typical integration hassles of adding wiring harnesses, weight increase, packaging limitations, and cost increases inherent in installing new systems onto legacy systems.

Promising applications which could benefit from this embedded diagnostic & prognostic wireless sensing architecture may include battery monitoring in 42-volt systems, automotive fluid quality monitoring systems, and tire pressure monitoring systems.

## INTRODUCTION

The vision for the future Army in the 21<sup>st</sup> Century will consist of a highly rapidly deployable and highly mobile force to be sent anywhere in the world within 72 hours. This future Army will have to be lethal and be able to survive in any conditions and have the capability to achieve a decisive victory against any adversary. To

support this vision the Army's logistics system must be versatile, agile, sustainable and affordable. The goal of Army transformation is to bring about fundamental changes in the Army's structure and to allow for faster insertion of advanced technology to the field. This includes the effort to reduce cost, reduce the logistics footprint and improve weapon system readiness. Use of open system architectures will allow for the incorporation of the greatest variety of commercial hardware and will speed adoption of these goals.

## BACKGROUND

One of the Army's main objectives is to reduce the logistics footprint while in any situation; whether in combat or in support. This will require the Army to be agile and ready; thus the need for wireless technology, embedded diagnostics and prognostics systems. The Army currently does not possess any automated failure prediction capabilities to date. There is some ability to access and acquire data on some vehicles. However, due to the large number of customized vehicle platforms, building a common embedded diagnostics and prognostics framework to suit all platforms has not been accomplished. Developing the infrastructure to implement an embedded diagnostics and prognostics system is a major challenge. On the vehicle side, this infrastructure will need to continuously collect diagnostics/prognostics data and provide appropriate alerts to the vehicle operator. Following command from the vehicle operator or initiation from a remote location, this data would be relayed to a back-end server, where it will be stored for and analyzed further using more advanced diagnostic and prognostic algorithms.

# Report Documentation Page

*Form Approved*  
*OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>JUN 2004</b>	2. REPORT TYPE <b>N/A</b>	3. DATES COVERED	
4. TITLE AND SUBTITLE <b>Embedded Diagnostics &amp; Prognostics Wireless Sensing Platforms</b>		5a. CONTRACT NUMBER <b>DAAE07_03_C_L008</b>	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) <b>; ; ; Ousachi /MarkScott /AndrewYee /DavidHosmer /ThomasDaniszewski /Dave</b>		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>US Army RDECOM, TARDEC, Vetronics 6501 E 11 Mile Warren, MI 48397-5000 American Systems Technology, Inc. 888 West Big Beaver Rd, Suite 420 Troy, MI 48084</b>		8. PERFORMING ORGANIZATION REPORT NUMBER <b>14064</b>	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited.</b>			
13. SUPPLEMENTARY NOTES <b>The original document contains color images.</b>			
14. ABSTRACT <b>An embedded diagnostics and prognostics architecture affects several aspects associated with military ground vehicles such as improved safety, reduction in maintenance times, weapon system readiness, and awareness of mission capabilities. These capabilities can be enhanced further by implementing wireless technologies on vehicles and utilizing wireless communication in the theater of operations. A wireless architecture on the vehicle provides the foundation for additional significant attributes such as improved theater awareness and more efficient distribution of supplies and if implemented on legacy systems would allow for incremental addition of sensors and technology. Additionally, directly integrating RF circuitry with a sensing device allows a systems integrator to minimize the typical integration hassles of adding wiring harnesses, weight increase, packaging limitations, and cost increases inherent in installing new systems onto legacy systems. Promising applications which could benefit from this embedded diagnostic &amp; prognostic wireless sensing architecture may include battery monitoring in 42-volt systems, automotive fluid quality monitoring systems, and tire pressure monitoring systems.</b>			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>	
			18. NUMBER OF PAGES <b>9</b>
			19a. NAME OF RESPONSIBLE PERSON

## APPLICATIONS

An on vehicle wireless architecture will permit relatively quick and cost-effective additions to vehicle hardware and replacement of wireless modules. One specific application envisioned is an oil analysis sensor which monitors the quality of engine oil with the desire of eliminating the need to collect oil samples from each crankcase and send to an outside lab for analysis.

Monitoring and control of components in advanced/hybrid power systems is another likely candidate.

Adding wireless sensors and communications to legacy systems will enable Telematics capabilities to be added relatively easily to legacy systems and permit health and usage monitoring of systems which no Telematics capability designed in. This could permit development of diagnostics and prognostics procedures for legacy systems, which are a substantial fraction of Army systems, and could result in significant cost savings and improvements in operational readiness.

A wireless architecture coupled with a wireless sensor network could improve tracking of logistic assets and permit more efficient distribution of these assets.

Wi-Fi	1Mb - 54Mb	see below	facing each other. For simple data exchange. Uses very little power.
802.11a	1 - 54Mb	50ft - 150ft	Wi-Fi refers to any of the three 802.11 types of wireless service below, and to future new subcategories yet to be released. Acts like a regular wired network in most respects. Either built in or available as add-on cards or adapters for desktop computers.
802.11b	1 - 11Mb	100ft - 300ft	Not commonly used, uses different frequency than 802.11b/g.
802.11g	1 - 54Mb	120ft - 350ft	Most common version at present.
			The latest version, backwardly compatible with 802.11b.

802.11i*	.11 a or b or g	.11 a or b or g	Draft to improve security. Problems in WEP (Wired Equivalent Privacy) render it easily circumvented
802.16*	up to 70M bit/sec	up to 50 kilometers	Wireless Personal Area Network (WPAN)

## OPEN ARCHITECTURE FRAMEWORK

As improvements to software and hardware are implemented, and as requirements change, the need for an open architecture becomes apparent. An open architecture allows for flexibility and scalability, and provides the ability to support the incremental insertion of additional capabilities.

In contrast to an open architecture framework, proprietary "closed" system architecture would not offer the flexibility in adapting commercially-off-the-shelf (COTS) components and subsystems into the existing system. Furthermore, these types of architectures are not designed with the future in mind and are difficult and expensive to upgrade/update as requirements change.

Bluetooth	120kb - 723kb	30ft - 300ft	Primarily viewed as a cable replacement
			Class 3 devices (eg in most personal computing type devices) have a short 30ft range, high powered Class 1 devices have the longer range. Either built in or available as add-on cards.
GPRS	< 115kb	wherever suitable cell phone coverage	Data service used by GSM cell phones and by some add-on cards for laptops and pda's. Speed typically about 30kb depending on how many users are sharing the service on each cell at any given time. A 2.5G service.

## TYPES OF WIRED/WIRELESS COMMUNICATION PROTOCOLS

The following chart depicts various parameters of wireless communication protocols: The security enhancements to 802.11 (802.11i) and the Wireless Personal Area Network (802.16) remain in draft.

Type	Speed	Range	Comment
IRDa	9.6kb - 115kb (- 4Mb)	< 6ft	Infra-red. The two devices must have their IR ports facing each other.
2.5G Cellular	variously up to about 128kb	wherever suitable cell phone coverage	Various compromise new types of 'always on' data service for cell phones that are better than nothing but not nearly as good as the 3G service that all cell phone companies are hoping to introduce when funding and technology allows.
3G Cellular	2Mb stationary, 384kb moving with good signal, 144kb	wherever suitable cell phone coverage	A largely futuristic technology not much deployed (yet) in the US which promises amazingly fast data transfer. Sprint PCS Vision and AT&T EDGE

	moving fast/poor signal		(100-130kb) are the closest things to 3G in the US at present.
Dial Up ISP	< 56kb	<i>not wireless</i>	The 'old fashioned' way to dial up from a computer to the internet.
DSL/Cable ISP	100kb - 1.5Mb	<i>not wireless</i>	Not wireless. 'Broadband' connections to the internet.
Wired LAN	10Mb - 100Mb	<i>not wireless</i>	Common type of cabled network in most offices.

\* 802.11i and 802.16 are pending.

## TECHNICAL CONCERNS

Wireless transmission of data immediately leads to concerns for interception of the signal by third parties and therefore to the necessity of securing the data via encryption; the military has required the encryption of data transmitted wirelessly. This concern resulted in adoption of the Wired Equivalent Privacy standard currently implemented on 802.11 hardware. This standard has several known flaws and can be readily circumvented, i.e. "cracked", using easily obtained software. A newer standard, 802.11i, addresses this issue and has the name of Wi-Fi Protected Access (WPA) and applies to all the 802.11 technologies (802.11a, b, and g). Once finalized the 802.11i standard might satisfy the Army's encryption requirements, but the Army has not yet officially ruled on the use of the 802.11i standard.

Proliferation of wireless devices raises the prospect of interference issues both with other electronic devices carried on vehicle and with other nearby vehicles using similar wireless technology. This matter must be addressed to permit reliable wireless communication as the RF environment becomes increasingly crowded. Utilization of coding schemes, frequency management, management of transmitted power, and directional antennas may factor into controlling and adapting to changing RF conditions. Wireless channels can be greatly affected by atmospheric conditions and these techniques play a role in adapting to dynamic changes in the properties of wireless channels.

Power considerations factor into the use of battery operated wireless sensors. Both the power needs of the sensor and the power consumption implications of the protocol used determine the longevity of the battery supplying the wireless sensor. Low power, low duty cycle sensors coupled with a protocol designed to minimize current draw are essential when using battery powered wireless sensors.

## AMERICAN SYSTEMS TECHNOLOGY, INC.

American Systems Technology, Inc. (ASTI) is a full-service electronics systems integrator. Through creativity and technology, ASTI creates win-win opportunities for its clients by leveraging U.S. innovations to produce quality products and integrated systems ( see Appendix A ).

The architecture that ASTI has designed and developed is a microcontroller-based sensor platform capable of hosting multiple automotive sensors, conducting sensor signal conditioning and processing, and transmitting data to and receiving messages from a host system via wireless and traditional vehicle data bus methods.

The embedded diagnostics and wireless communication system requires two types of electronics devices: an RF-based sensor hub, we call **Almont**, and an RF sensor node, we refer to as **Zeeland**.

The Almont is intended to be capable of hosting multiple types of sensors (both wired and wireless via RF communication,) interfacing with a vehicle communication bus (such as SAE J1939,) and interfacing with a host computer system (such as a Windows-based desktop PC.) Additionally, the Almont simultaneously provides on-board signal processing and analysis for diagnostic and prognostic algorithms. The Almont's capability of communicating with a PC allows for more options not only for connecting to a host system, but also for increased convenience for system debugging and testing. In addition, an Almont can also function as a sensor node when multiple Almonts are deployed as a wireless sensor network. In this case, an Almont may also relay data received from a peer Almont board.

The Zeeland is intended as a means to provide wireless communications from small sensor components to the Almont. Powered by a coin cell battery, the Zeeland provides for integration flexibility for integrating new systems and sensors in legacy vehicles.

## REQUIREMENTS AND SYSTEM CONFIGURATION

SYSTEM REQUIREMENTS – The wireless sensing prototype was designed with particular attention to the following two principal requirements:

### Data Acquisition Requirements

- **Data acquisition from multiple sensors.** The Almont is able to conduct data acquisition from the multiple wired sensors of different types, as well as from RF adapted sensors.
- **Support for different types of sensors.** The different types of sensors that are supported, but not limited to, include (1) sensors with various types of

differential voltage outputs, (2) 4-20 mA current outputs, (3) PWM sensor signals, and (4) PWM variant types.

- **Certain cases of sensor failures detectable.** The Almont is able to detect certain categories of sensor failures such as “short to ground,” “short to battery,” and open signal lines.
- **Programmable sensor interface signal I/Os.** There exist at least 20 software re-configurable signal lines that are used to interface with the multiple sensors. The sensor signal can be configured into different combinations of analog/digital inputs and/or outputs.
- **Sensor signal conditioning and preprocessing.** The Almont is equipped with proper signal pre-processing hardware to enable sensor raw signal conditioning and processing including signal amplification and attenuation.
- **Analytical computation capability.** The acquired measurements for the purposes of providing diagnostic and/or prognostic information.
- **Stored measurements.** Uses acquired data to compute diagnostic and/or prognostic information for later retrieval.
- **Visual Display.** Visual display of diagnostic and/or prognostic results to the vehicle operator.
- **Information Transmittal.** Relay information to maintenance technicians or support logisticians to help them visualize the current vehicle situation and anticipate maintenance needs.

#### Power Consumption Requirements

- **Wired External Device.** Power to the wired external devices (such as sensors) is strategically limited. The supplied power to each wired sensor is monitored and bounded to an upper limit of 25 mA.
- **RF Circuitry.** The RF circuitry is controlled to reduce power consumption. The RF transceiver circuitry can be also turned off when the Zeeland works in the self-event-triggered mode. In other working modes, the RF transmitter can be always shut down and enter a “sleep” state when there is no RF communication.
- **Wireless Protocol.** Choosing the right wireless communication protocol for low power consumption. It is important to realize that the RF protocol can affect the power requirements as much or more than the optimization of the hardware.

SYSTEM CONFIGURATION - To illustrate the overall system configuration of the wireless automotive diagnostic system, Appendix B shows three Almonts and two Zeelands. As illustrated in Appendix A, an Almont can not only be connected to the host system (such as a desktop PC) via a wired communication link (like USB), but may also communicate with a host system (such as a laptop) via certain wireless methods (i.e. using a built-in wireless PCMCIA card). By using these three Almonts, two Zeelands, procured sensor devices, and some commercial products (desktop and laptop PCs, wireless adaptation cards, etc.), we are able to demonstrate various cases of sensor data collection and data relay.

In applications where the number of the sensors is limited and these sensors are deployed in a limited space with no significant obstacles to sensor data transmission, the RF diagnostics platform also can be used as a smart data acquisition platform with multiple external communication links.

## MULTIPLE SENSOR INTERFACING CONCEPTS

The sensor signals interfacing with the Almont and Zeeland can be either raw signals (e.g. from thermocouples,) or signals that have been already conditioned and preprocessed (e.g., signals of 1~5V or 4~20 mA.) Some sensor devices have electronics circuitry physically integrated with the sensor for sensor raw signal conditioning.

The primary requirements for sensor interfacing were:

- Physically generic connections for simplifying installation and configuration.
- Software re-configurable sensor interfaces. This ensures the flexibility to accommodate multiple types of sensors.

Besides the raw signals (which can be both analog and digital) from sensor devices, some sensing devices may need active control signals. The active controls signals could be digital control signals, or analog signals, such as controlled power supply, some high-frequency signals with adjustable frequency (for capacitance measurements), or some programmable waveforms. To interface with multiple types of sensors, the interface signals include an ensemble of signal lines such as: (a) Analog signals from the sensor end; (b) Digital signals from the sensor end; (c) Analog active controls to the sensor end; and (d) Digital active controls to the sensor end.

## MOVING TOWARDS MEMS

Applying MEMS technologies and other forms of miniaturization as part of a wireless embedded diagnostics architecture for automotive applications is also feasible. This allows for the implementation of multiple miniature sensing devices, which can communicate data wirelessly via RF to a microcontroller-based sensor platform. This sensor platform is capable of hosting multiple automotive sensors, conducting sensor signal conditioning, and transmitting data to and receiving messages from a host system via wireless (Bluetooth) and traditional vehicle data bus methods (CAN, J1850, etc.)

The path to MEMS-based applications includes a technology roadmap moving from “Multi-Chip” modules to more advanced modular approaches such as “Micro-Stacks.”

Multi-Chip modules are comprised of bare silicon chips that are wired together with other components. These modules are typically embedded in a ceramic matrix and

possess moderate density. Multi-Chip modules offer a high degree of compatibility and have reasonable thermal management. However, these types of components are associated with higher costs due to lack of modularity.

individual vehicles (e.g. legacy systems) provides a necessary foundation towards network centric warfare.

Taking technology a step further introduces the concept of micro-motherboards. These are modules comprised of bare silicon chips, but unlike Multi-Chip modules, they are flip-chip mounted on a larger silicon chip. Flip-Chip Mount Technology (FCMT) is useful for minimizing electronics components and IC packaging. In addition to high density, micro-motherboards offer good thermal management options and relatively lower cost than Multi-Chip modules. Nevertheless, FCMT is only used in a limited number of applications due to complexity. A significant obstacle is the lack of infrastructure and the difficulty in handling flip-chip components.

A more advanced modular approach is the concept of the "Micro-Stack." In this scheme, bare silicon chips are flip-chip mounted onto each other in a three-dimensional stack. This provides for all the benefits associated with micro-motherboards such as high density, lower cost, and low surface area in a more compact design. However, thermal management becomes more of an issue in this type of arrangement. Appendix C illustrates the three concepts described above.

## CONCLUSION

The coordination and synchronization of embedded diagnostics and prognostics for military ground vehicles is critical to the Army transformation because this technology impacts logistics operations at all levels. Utilization of wireless technologies, both on vehicle and within the theater of operations, provides a core foundation for the Army's transformational goals of improving vehicle readiness, reducing logistic footprint, improving maintenance capabilities, while reducing associated costs and facilitating rapid insertion of advanced technologies into theater of operation. A wide range of Army organizations responsible for the doctrine, policy, equipment, training, funding, business processes, information systems, and communications systems will be affected by this technology. It will take many years and substantial investment to fully implement the Army's vision for a self-reporting weapons platform and support vehicles with embedded diagnostics and prognostics capabilities. Incorporation of embedded diagnostics and prognostics capabilities on vehicle, coupled with wireless technologies, will provide the vehicle specific information which can later be aggregated and analyzed at the back end of a logistics system. This will enable a more comprehensive view of readiness and logistic requirements at the theater level and will permit more efficient and timely distribution of supplies.

While significant work remains to accomplish this vision of a comprehensive operational architecture, inclusion of embedded sensors and wireless communications onto

## CONTACTS

Mark Ousachi  
Director, Engineering Development  
American Systems Technology, Inc.  
888 West Big beaver Road  
Troy, MI 48084  
Ph. 248-362-4100 Ext. 23  
Email: [mousachi@amsystech.com](mailto:mousachi@amsystech.com)

Andrew Scott  
Research Engineer  
AMSRD-TAR-R (MS 263)  
6501 E. 11 Mile Rd.  
Warren, MI 48397  
Ph. 586-764-6558  
Email: [scottA@tacom.army.mil](mailto:scottA@tacom.army.mil)

David Yee  
Project Engineer  
AMSRD-TAR-N (MS 289)  
6501 E. 11 Mile Rd.  
Warren, MI 48397  
Ph. 586-574-8579  
Email: [yeed@tacom.army.mil](mailto:yeed@tacom.army.mil)

Thomas Hosmer  
Electrical Engineer  
AMSRD-TAR-R (MS 264)  
6501 E. 11 Mile Rd.  
Warren, MI 48397  
Ph. 586-574-4436  
Email: [hosmert@tacom.army.mil](mailto:hosmert@tacom.army.mil)

David Daniszewski  
Electrical Engineer  
AMSRD-TAR-R (MS 264)  
6501 E. 11 Mile Rd.  
Warren, MI 48397  
Ph. 586-753-2582  
Email: [daniszed@tacom.army.mil](mailto:daniszed@tacom.army.mil)

## DEFINITIONS, ACRONYMS, ABBREVIATIONS

Almont: The electronics platform devices equipped with ColdFire CPU having Bluetooth and RF915 capability

Zeeland: The small RF sensor adaptors equipped with MSP430F123 CPU having RF915 capability

BLUETOOTH: One of the main wireless communication protocols. It is used between the Almont and an external user interface device.

RF915: The shorter range, lower frequency wireless link between the Almont and Zeeland.

## REVIEWER CONTACTS

Greg Hudas  
Research Scientist  
AMSRD-TAR-N (MS 157)  
6501 E. 11 Mile Rd.  
Warren, MI 48397  
Ph. 586-574-0318  
Email: [Hudash@tacom.army.mil](mailto:Hudash@tacom.army.mil)

Robbie Thomas  
Project Engineer  
AMSRD-TAR-N (MS 272)  
6501 E. 11 Mile Rd.  
Warren, MI 48397  
Ph. 586-574-8743  
Email: [ThomasR@tacom.army.mil](mailto:ThomasR@tacom.army.mil)

COTS: Commercial Off The Shelf

Wi-Fi: One of the 802.11 standards  
(802.11a, 802.11b, or 802.11g)


MEMS: Micro-Electro-Mechanical Systems

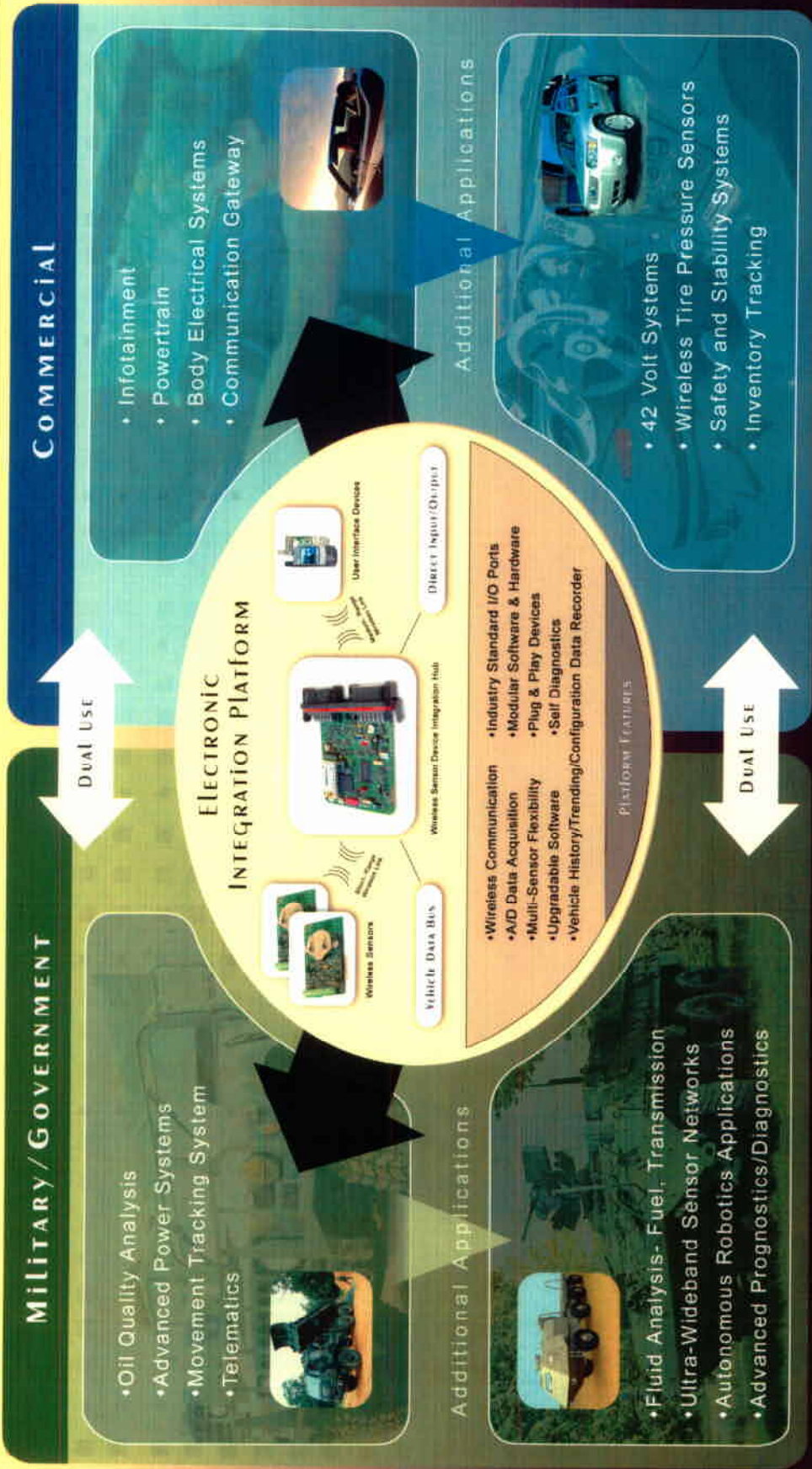
GSM: Global System for Mobile communications

GPRS: General Packet Radio Service

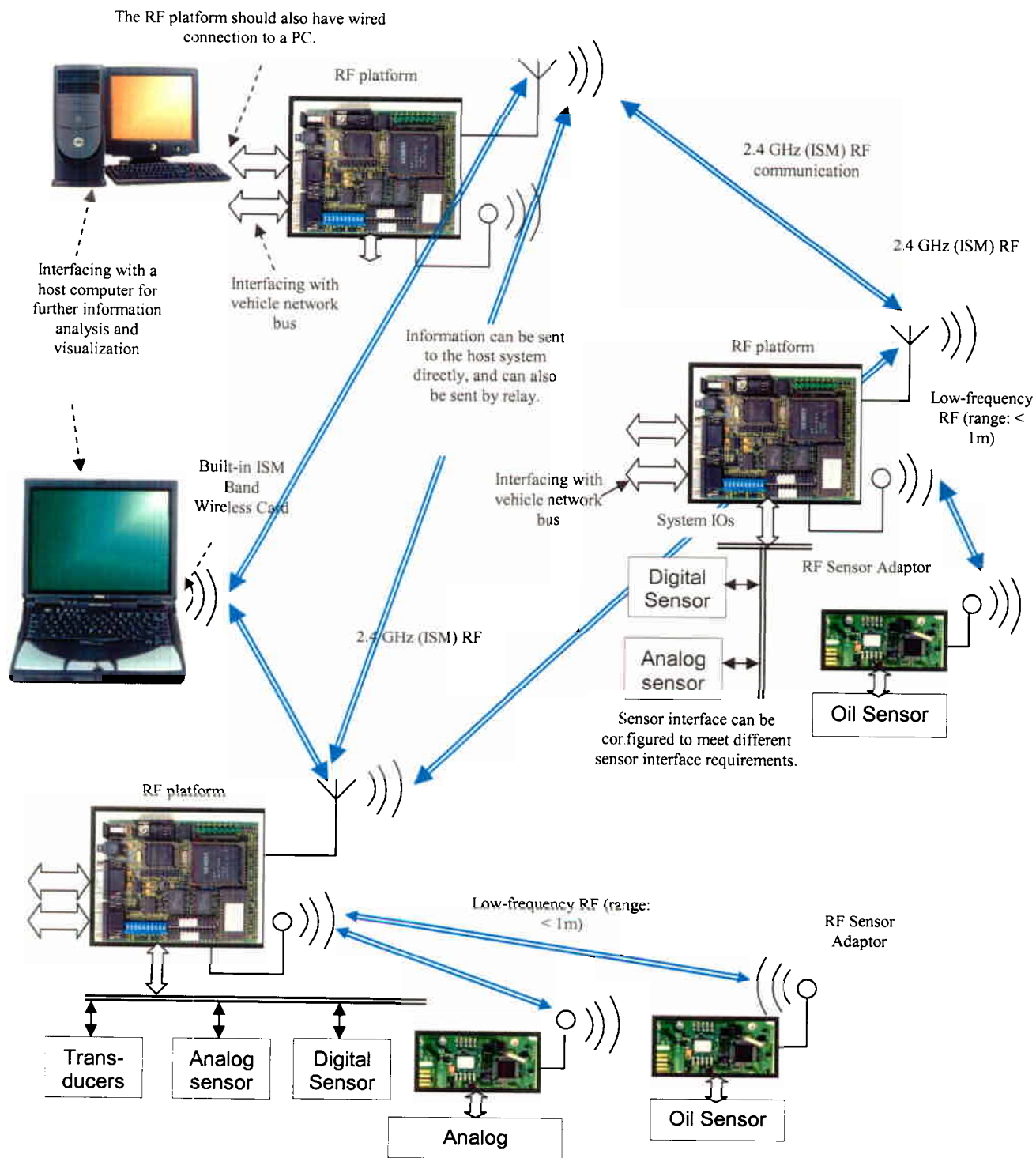
PWM: Pulse Width Modulation

APPENDIX A – VEHICLE ELECTRONIC INTEGRATION PLATFORM

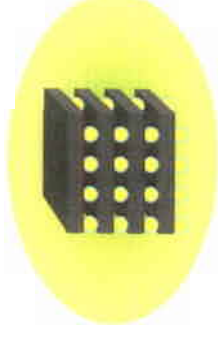
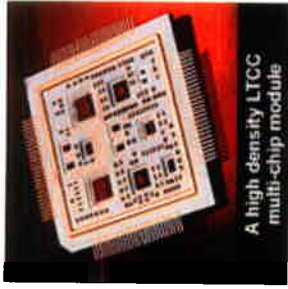
VEHICLE ELECTRONIC INTEGRATION PLATFORM 



# APPENDIX B – WIRELESS SYSTEM CONFIGURATION



**APPENDIX C – ADVANCED MODULAR APPROACHES**



**Multi-Chip Module**

- ❖ Bare Silicon Chips
- ❖ Wired Together With Other Components
- ❖ Usually Embedded in a Ceramic Matrix
- ❖ Moderate Density
- ❖ Some Thermal Issues Avoided
- ❖ Compatible With Diverse Components
- ❖ Higher Cost

**Micro-Motherboard**

- ❖ Bare Silicon Chips
- ❖ Flip-Chip Mounted On a Bigger Silicon Chip
- ❖ Good Density
- ❖ High Surface Area
- ❖ Good Thermal Management Options
- ❖ Lower Cost

**Micro-Stack**

- ❖ Bare Silicon Chips
- ❖ Flip-Chip Mounted Onto Each Other in a 3D Stack
- ❖ High Density
- ❖ Low surface area
- ❖ More Challenging Thermal Management
- ❖ Lower Cost