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## **Advanced Exterior Sensor Project Final Report September 2004**

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# **Advanced Exterior Sensor Project Final Report September 2004**

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*Multi-Band Sensor Project  
Final Report for FY04 Activities*

## **Abstract**

This report 1) summarizes the overall design of the Advanced Exterior Sensor (*AES*) system to include detailed descriptions of system components, 2) describes the work accomplished throughout FY04 to evaluate the current health of the original prototype and to return it to operation, 3) describes the status of the *AES* and the *AES* project as of September 2004, and 4) details activities planned to complete modernization of the system to include development and testing of the second-generation *AES* prototype.

## **Acknowledgements**

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## Executive Summary

An original *AES* prototype, developed using Defense Threat Reduction Agency (DTRA) and U.S. Air Force funding, was last demonstrated in 2000 before work was suspended. The Department of Energy (DOE) Office of Security (SO) resumed project funding for FY04 with the objective of demonstrating the *AES* prototype to potential manufacturers who may then make commercial units available to the DOE.

This report includes a brief history of the *AES* project, and details work accomplished under Sandia's Multi-Band Sensor Project during fiscal year 2004 to evaluate the current health of the original prototype in order to return it to operation. This report also provides a detailed description of the *AES* system and its three main components, and discusses work accomplished to evaluate, upgrade, and improve each component. Finally, this report discusses activities planned to complete modernization of the system, to include development and testing of the second-generation *AES* prototype.

The Bibliography section of this report lists important reports with valuable content. Additionally, the Bibliography provides additional overview material, as well as the two papers presented this year to update *AES* project progress.

For additional information on the *AES* system, the author highly recommends a conference paper presented in October 2004 at the 38<sup>th</sup> Annual IEEE Proceedings of the International Carnahan Conference on Security Technology. Entitled *Seeing Beyond the Perimeter: The Advanced Exterior Sensor AES* (see Bibliography), this paper provides an in-depth discussion of the overall philosophy of the *AES* system.

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## Nomenclature

The following acronyms are provided to assist the reader when reviewing material contained in this and other reports:

|        |  |
|--------|--|
| ADC    | Analog-to-Digital Converter                    |
| AES    | Advanced Exterior Sensor                       |
| ASIC   | Application Specific Integrated Circuit        |
| ALTAS  | Adversary Time-line Analysis System            |
| ATR    | Automatic (or aided) Target Recognition        |
| CCD    | Charge-coupled Device                          |
| COTS   | Commercial off-the-shelf                       |
| CRADA  | Cooperative Research and Development Agreement |
| DAC    | Digital-to-analog Converter                    |
| DCM    | Display Control Module                         |
| DOE    | Department of Energy                           |
| DPM    | Data Processor Module                          |
| DRAM   | Dynamic Random Access Memory (volatile)        |
| DSP    | Digital Signal Processor                       |
| DTRA   | Defense Threat Reduction Agency                |
| EC     | Executive Controller                           |
| EPROM  | Erasable Programmable Read-Only Memory         |
| FAR    | False Alarm Rate                               |
| FIFO   | First In, First Out                            |
| FIR    | Finite Impulse Response                        |
| FLIR   | Forward Looking Infrared                       |
| FMCW   | Frequency-modulated, Continuous-wave           |
| FPA    | Focal Plane Array                              |
| FPDP   | Front Panel Data Port                          |
| FPGA   | Field Programmable Gate Array                  |
| FOA    | Focus of Attention                             |
| FOV    | Field of View                                  |
| GFLOPS | Trillion Floating Point Operations Per Second  |
| GPS    | Global Positioning System                      |
| HF     | High Frequency                                 |
| HgCdTe | Mercury, Cadmium, Telluride                    |
| IC     | Integrated Circuit                             |
| IFOV   | Instantaneous Field-of-view                    |
| InSb   | Indium Antimonide                              |

|        |  |
|--------|--|
| IR     | Infrared   |
| IRST   | Infrared Search and Track                                  |
| IVAL   | IR Valve   |
| KBT    | Knowledge-Based Tracker                                    |
| Ladar  | laser detection and ranging                                |
| LISA   | Linear Infrared Scanning Array                             |
| LWIR   | Long-Wave Infrared (approximately 8-12 microns wavelength) |
| LUT    | Look Up Table  |
| MCT    | Mercury, Cadmium, Telluride                                |
| Mbyte  | Mega byte  |
| MFLOPS | Million Floating Point Operations Per Second               |
| MHz    | Mega Hertz   |
| MIDAS  | Mobile Intrusion Detection and Assessment System           |
| MIPS   | Million Instructions Per Second                            |
| MLP    | Multi-Layer Perception                                     |
| MRTD   | Minimum Resolvable Temperature Difference                  |
| MTBF   | Mean Time Between Failure                                  |
| MTI    | Moving Target Indicator                                    |
| MTTR   | Mean Time to Repair  |
| MWIR   | Mid-Wave Infrared (approximately 3-5 microns wavelength)   |
| MUX    | Multiplexer  |
| NAR    | Nuisance Alarm Rate  |
| NRE    | Non-Recurring Engineering                                  |
| OS     | Operating System   |
| PbSe   | Lead Selenide  |
| Pd     | Probability of Detection                                   |
| PC     | Personal Computer  |
| PCI    | Peripheral Component Interconnect                          |
| PLD    | Programmable Logic Device                                  |
| POT    | Pixels On Target   |
| POVAL  | Positive Valve Indicator (block for good data)             |
| PtSi   | Platinum Silicide  |
| Radar  | Radio frequency detection and ranging                      |
| RAM    | Random Access (read/write) Memory                          |
| RBF    | Radial Basis Function                                      |
| RF     | Radio Frequency  |
| RFI    | Request for Information (formal memo)                      |
| ROM    | Read-only Memory   |

|       |                                       |
|-------|---------------------------------------|
| RSM   | Remote Sensor Module                  |
| RVAL  | Radar Value                           |
| SAM   | Serial Access Memory                  |
| SAR   | Synthetic Aperture Radar              |
| SCR   | Signal-to-clutter Ratio               |
| SNL   | Sandia National Laboratories          |
| SNR   | Signal-to-noise Ratio                 |
| SO    | Office of Security                    |
| SRAM  | Static or Shared Random Access Memory |
| TBD   | Track-before-detect                   |
| TCATS | Target Cueing and Tracking System     |
| TDI   | Time Delay and Integration            |
| TE    | Thermo-Electric (Peltier effect)      |
| UML   | Universal Modeling Language           |
| USAF  | United States Air Force               |
| VCR   | Videocassette Recorder                |
| VHF   | Very High Frequency                   |
| VIS   | Visible                               |
| VMD   | Video Motion Detection                |
| VME   | Versa-module, European                |
| VRAM  | Video Random Access Memory            |

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# 1. Advanced Exterior Sensor Project Overview

## 1.1 Project Background

The original Advanced Exterior Sensor (*AES*) prototype was developed using approximately \$4 million dollars of U.S. Government (Defense Threat Reduction Agency and U.S. Air Force) funding before work was suspended due to a lack of funding for technology-transfer support. The system was last demonstrated in 2000. The Department of Energy (DOE) Office of Security (SO) resumed project funding for FY04 with the objective of demonstrating the *AES* prototype to potential manufacturers who may then make commercial units available to the DOE. There is great potential for DOE site security enhancement using the *AES*, which was designed for low-cost, easy use, and rapid deployment to cover wide areas beyond typical perimeters (possibly in place of typical perimeter sensors), and for tactical applications around fixed or temporary high-value assets.

This moderate-resolution, panoramic-imaging sensor is intended for exterior use at ranges from 50 to 1500 meters and beyond. The *AES* integrates three sensor technologies (thermal infrared waveband, visible waveband, and microwave radar) with three motion-detection target trackers and a sensor fusion software module to achieve higher performance than single technology devices alone. By using the three sensors to continuously scan a 360-degree field of view in approximately one second, wide areas of interest are scanned. The images from the infrared (IR) and visible detector sets, along with the radar range data, are updated each second as the sensors rotate. The radar provides range data with approximately one-meter resolution. Current commercial off-the-shelf (COTS) systems do not have integrated three-sensor technologies, nor matched radar and imaging sensor resolutions for sensor fusion.

The *AES* consists of three major components. The Remote Sensor Module (RSM) is a rotating sensor pod that is placed in the field and remotely connected over a high-speed, optical-fiber data link to a high-speed Data Processing Module (DPM). A single Display Control Module (DCM) is used to configure and control both the RSM and DPM. The *AES* system and major system components are discussed in detail in Section 2.

## 1.2 Refurbishment Work Completed in 2004 for the *AES* Prototype

In order to restore functionality to the current *AES* prototype as quickly as possible, only minimum re-engineering has been accomplished to include replacing parts, as available, and noting what modern component equivalents can be used to create the second prototype. The original *AES* prototype has been upgraded to control RSM hardware from the DCM, capturing video images from the RSM and sending the images to the DCM through the DPM. The IR and radar also appear to be sending valid data. The video transmission from the RSM is intermittent, and problems have been detected in the communications (detailed in this report). In order to reach the current level of project progress, several processor chips have been reprogrammed and replaced, and other components have been replaced as problems were detected. The availability of replacement parts has been investigated, and potential suppliers identified. Some equipment for the second prototype has also been manufactured, and some design tools and hardware for the

second prototype electronics design have also been acquired. Solid models of custom system components have been created, and the mechanical drawing sets have been updated and entered into Sandia National Laboratories (SNL) archives to facilitate technology transfer to commercial manufacturers. The review and updating of the electronic drawing set will be completed next fiscal year.

In parallel with the debugging and testing of the RSM hardware and the custom communications input board in the DPM, DCM and DPM processor hardware and software have also been upgraded. The DCM's RSM user interface, and communications to control the RSM, are operating correctly. The DCM also correctly displays the video by degree of view, as requested by the user. In order to test target detection and tracking processing before the RSM data collection is completely functioning, video images were collected and formatted to duplicate the RSM data input to the DPM. These images can be used to help determine if the *AES* specific design parameter goals, as described in this report, are being met. Using these test images, independent testing of the DPM and DCM software has begun. These test images will also be reused for regression testing whenever the DCM or DPM software is upgraded.

Sandia has internal production capability, and the DOE-sponsored *AES* project team has partnered with manufacturing experts at SNL. These entities are contributing their own funding to derive manufacturing estimates and develop manufacturing documentation to support technology transfer activities. The manufacturing group designed and built a fully enclosed outer housing for the *AES* to enable the RSM to be fielded in order to create a complete product for technology transfer and extended, all-weather testing. The manufacturing group is also assisting with the specification and procurement of current technology replacements for older components, and with updating the entire drawing set. The manufacturing group is also assisting with creation of the second prototype, which will incorporate modern components. Initial work for creating the second prototype was started in FY04 using internal SNL funding so the *AES* can be used to support SNL security upgrades.

### **1.3 *AES* Specific Design Parameter Goals and Early Testing**

At the beginning of the *AES* project, the following operational characteristics for a stand-off intrusion-detection sensor system were identified by the original *AES* customers. The *AES* was designed to detect and track humans and vehicles according to the ranges summarized in **Table 1**, which describes current system goals for system testing. Targets moving as slowly as 0.25 m/sec (0.1 m/sec desired) are to be detected as well.

| <b>Table 1. Advanced Exterior Sensor Detection Range Requirements</b> |                        |                         |                        |
|---|------------------------|-------------------------|------------------------|
| <b>Target</b>   | <b>Conditions</b>      | <b>Range (required)</b> | <b>Range (desired)</b> |
| Upright human walk/run<br>0.6 × 1.65m<br>1.0m <sup>2</sup>            | Clear, good visibility | 500m                    | 750m                   |
|   | Light rain, humid      | 350m                    | 525m                   |
| Crawling human head-on<br>0.5 × 0.3m<br>0.15m <sup>2</sup>            | Clear, good visibility | 250m                    | 375m                   |
|   | Light rain, humid      | 200m                    | 300m                   |
| Truck/van<br>1.5 × 1.5m<br>2.3m <sup>2</sup>                          | Clear, good visibility | 1000m                   | 1500m                  |
|   | Light rain, humid      | 800m                    | 1200m                  |

*AES* test video images are being collected to test to these criteria. **Figure 1** is an aerial photograph with critical distances measured and locations identified for gathering test video created to test the DPM and DCM functioning independently of the RSM. By creating test sequences that are digitally videotaped and processed to create RSM-like input to the DPM, any changes to the DPM and DCM software can be regression-tested using the test video without requiring an expensive, full-system field test for each modification. When substantially different capabilities are added, then live field-testing will be required to verify new operational parameters.

Setting up the scenarios to measure *AES* capabilities is part of the system test plan. The initial test plan will be completed in FY04. The test plan is a living document that will continue to be updated and refined as degradation and/or defeat factors are identified for the *AES*. Sensor performance information for ATLAS will be captured next year.



**Figure 1. Aerial Photo: Video Test Scenario Locations at Various Distances**

## 2. AES System Overview

### 2.1 General AES System Description

The Advanced Exterior Sensor (*AES*) consists of three major components, as shown in **Figure 2** and **Figure 3** (block diagram). The Remote Sensor Module (RSM) is a rotating sensor pod that is placed in the field and remotely connected over a high-speed, optical-fiber data link to a high-speed Data Processing Module (DPM). A single Display Control Module (DCM) is used to configure and control both the RSM and DPM. Eventually, multiple RSMs and DPMs (used in combination) can be networked to cover all assessment areas of a very large facility. Two new *AES* prototypes will be built next year so that multi-unit testing may begin

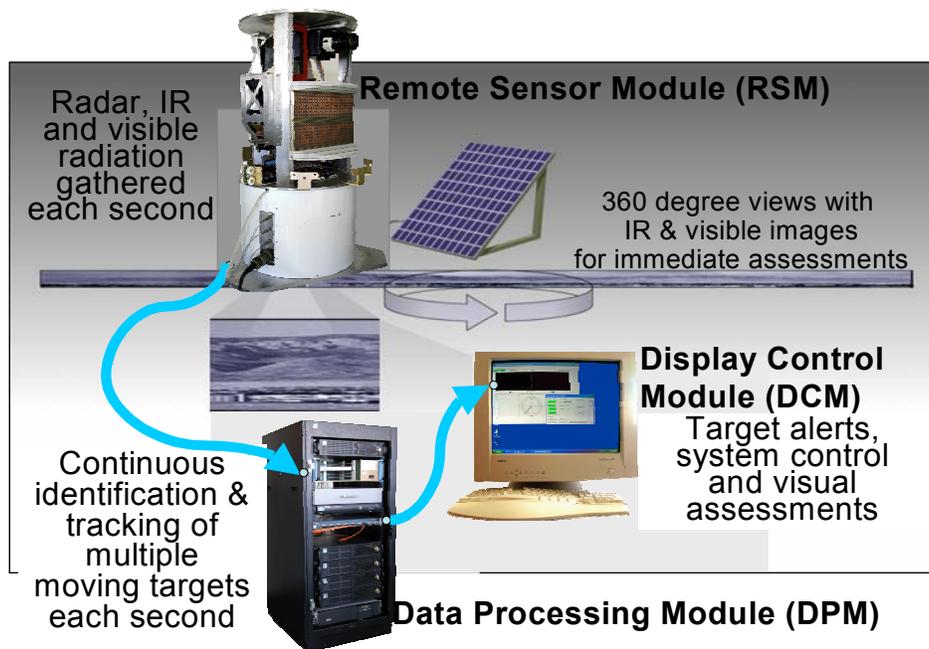


Figure 2. AES Overview: Panoramic Data Gathering, Processing, and Display.

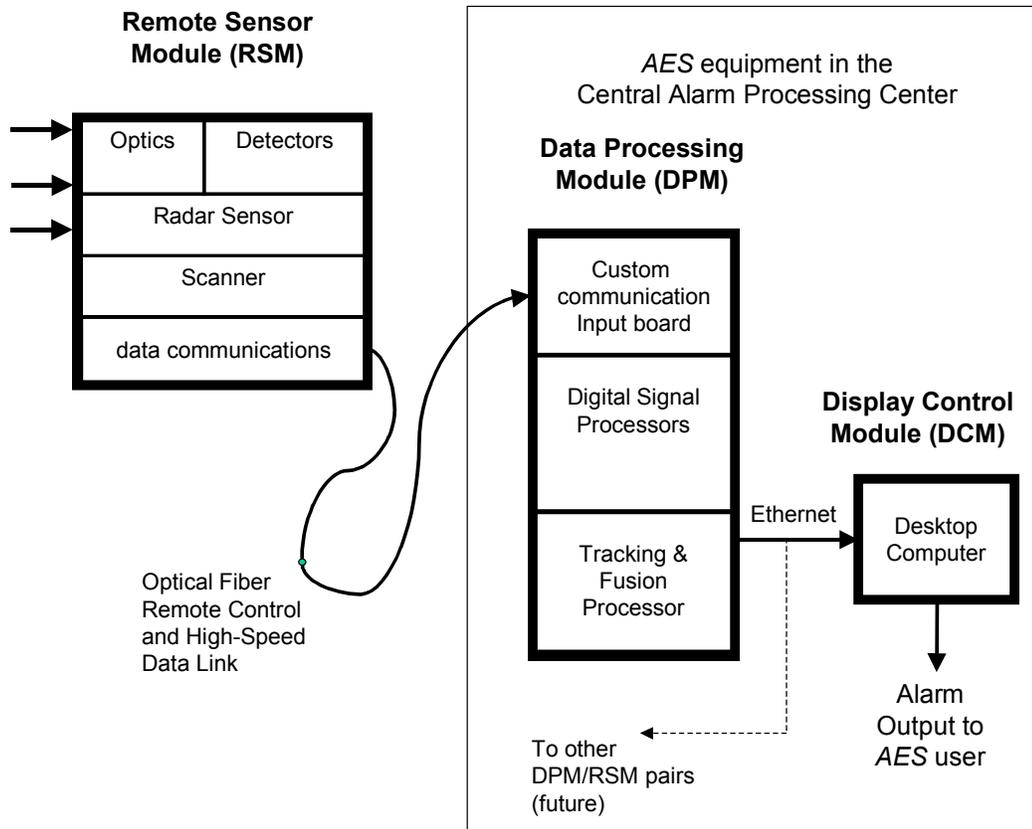
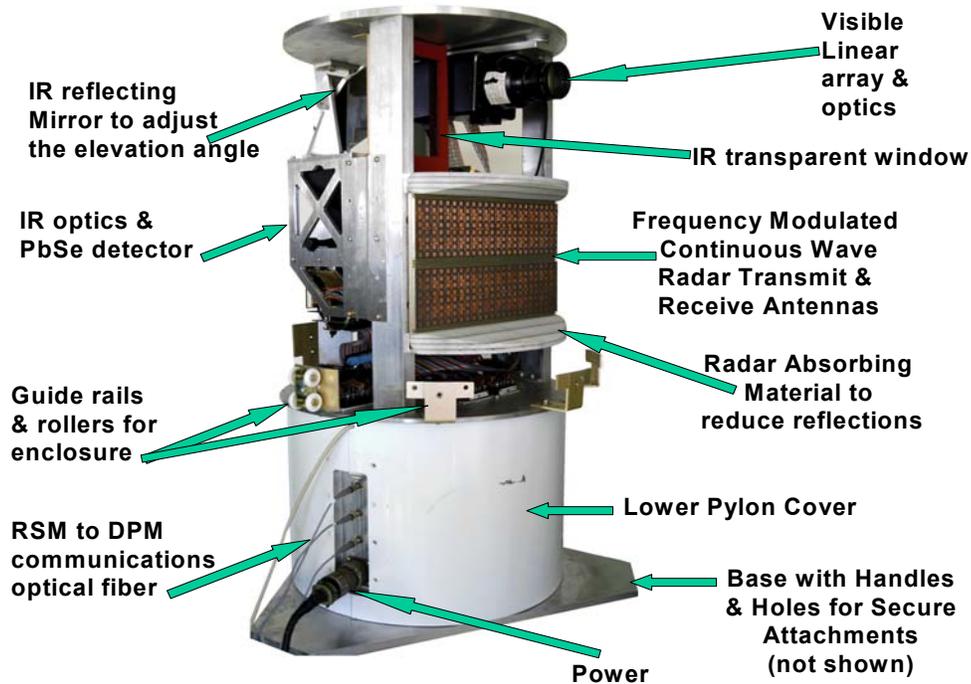


Figure 3. AES Component Block Diagram

## 2.2 Remote Sensor Module (RSM) Overview

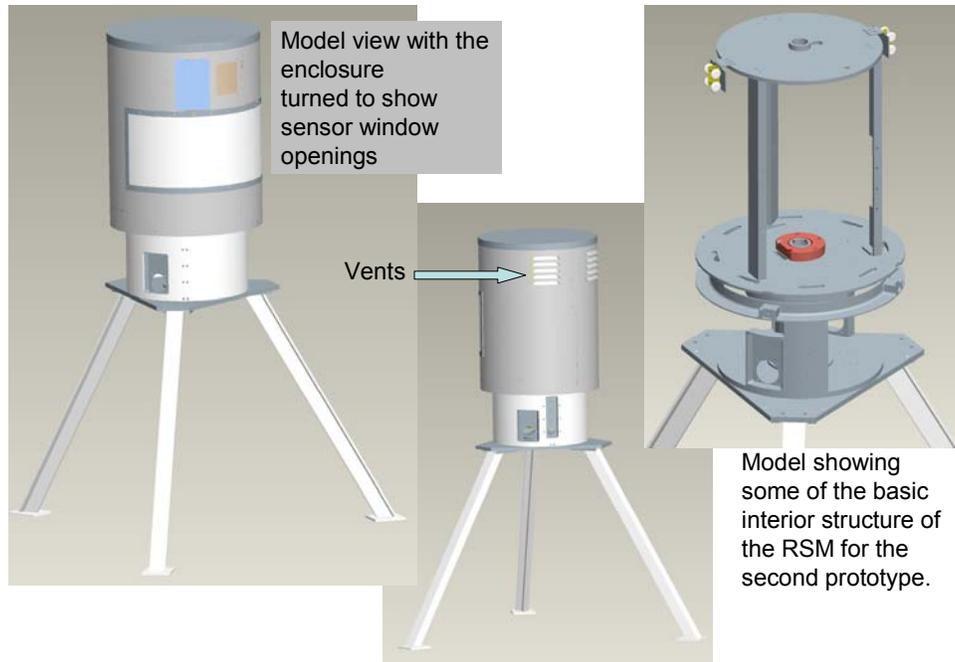
The Remote Sensor Module (RSM) contains three sensors—visible, IR, and radar—as well as the control electronics for sensors and RSM rotation. The RSM is divided into an upper, rotating pylon and a lower, stationary pylon. The framework support structure on the upper pylon holds the three sensors in alignment. **Figure 4** shows the RSM without the all-weather enclosure, which would cover the upper pylon when field-deployed.



**Figure 4. RSM Components**

A weatherproof cover designed for extended field use has replaced the RSM's temporary cover, and an upgraded enclosure design is being completed to enable easier access to the RSM electronics.

Constructed from lightweight 0.030-gage aluminum, the 10- to 12-pound enclosure moves along fixed guide rails and attaches to the upper (movable) pylon platter using captive fasteners. The RSM sensors require transparent material to be installed as protective windows in front of the sensors. For the radar, this material is ABS plastic, and is shown as the large, rectangular portion on the left-most solid model shown in **Figure 5**. The acrylic and bulk polysilicon materials, which span the visible and IR sensor ports, mount to the inner face of the enclosure. The unique curved-port mounting bracket was fabricated using photopolymer Stereolithography technology. Temperature tests have been conducted with the enclosure installed. Vents are included in the enclosure to facilitate forced-air cooling of the RSM electronics, and fans will be added to the second prototype units. Operational tests of RSM sensors have been conducted without the enclosure; radar consultants believe the cover window for the radar is large enough to avoid any internal reflection problems.



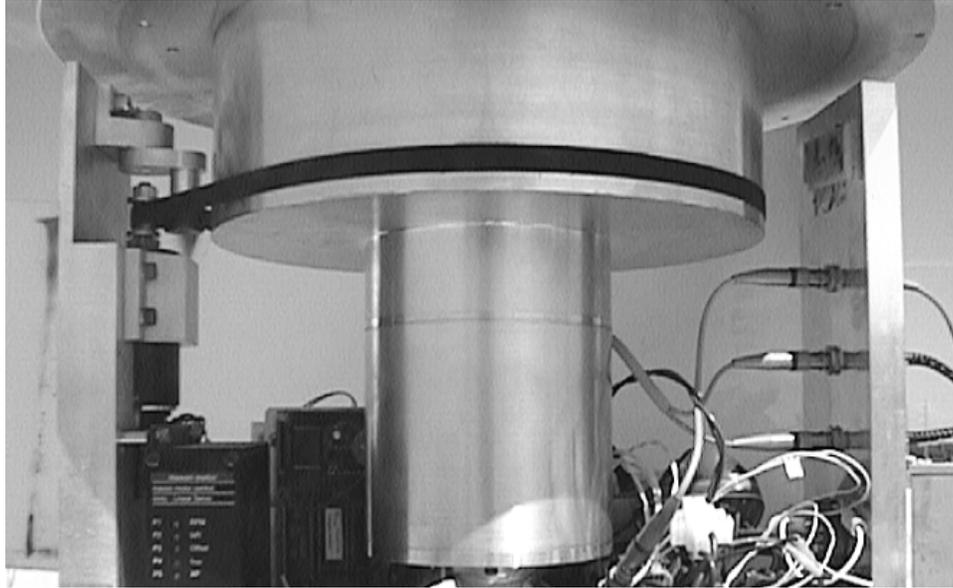
**Figure 5. RSM Solid Models: Enclosure, Base, Legs, and Structure**

Creating solid models has allowed parts to be fitted and checked for operational interference before they are manufactured. The Solid models in **Figure 5** are models of components for the second prototype *AES* units that are being manufactured in FY04 using SNL funding to support perimeter upgrades. An *AES* unit will be fielded next year for extended evaluation, once the long delay time components are received and the unit is assembled. New electronics will also be designed and built for the new units.

### **2.2.1 Rotating Platform and Components**

The drive train (motor controller, motor, pulley and belt drive) facilitates the constant rotational motion of the upper pylon. The motor provides 100 inch-ounces of torque, while the motor controller provides constant speed control. The actual speed is adjustable by a potentiometer. The capability exists to have motor speed controlled by the microcontroller on either the upper or lower pylon, but this is not necessary, as was discovered through practical application.

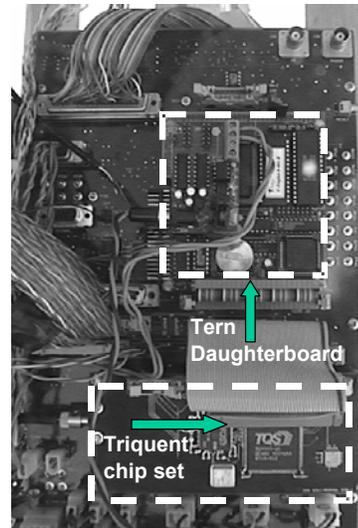
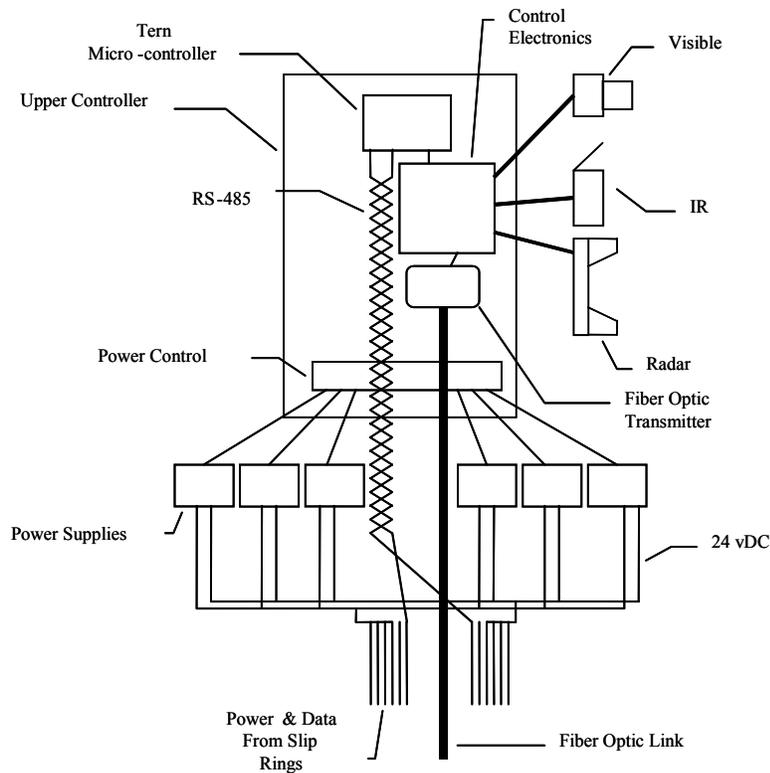
The belt drive was uniquely designed for this application (see **Figure 6**). The spindle attachment for the motor drive shaft has a slight barrel shape, which keeps the drive belt centered on the spindle. A spring-loaded pulley provides constant belt tension, and the configuration of the motor shaft and tension pulley provides for over 180 degrees of wrap on the motor shaft. The majority of the belt is wrapped around a drum containing the high-resolution shaft encoder. During 1998 testing, the drive train had been in operation for over 5000 hours without failure, and ever since power was reapplied the unit in April 2004, the motor and upper pylon have operated smoothly.



**Figure 6. RSM Lower Pylon Drive Train Assembly Containing the Shaft Encoder and Optical-Fiber Rotary Joint**

Sensor IR and visible line scan data readings are triggered by a pulse from the shaft encoder. There are 21,600 pulses per RSM revolution, generating 21,600 lines in the 360-degree panoramic image. The  $160 \times 21,600$  pixels of the panoramic image field are approximately square by carefully sizing the optics to the linear array sensors. Optical data streams are sent back to the DPM in real time, and panels of  $160 \times 480$  pixels with the panoramic 360-degree processing are processed each second. The radar unit is triggered 480 times per revolution, and the radar trigger is generated by dividing the line pulse (21,600 pulses/rev) by 45.

The rotary components between the upper and lower sections consist of a bearing, shaft encoder, and the fiber-optic rotary coupler joint with electrical slip rings. The slip rings are used to transfer power to the upper pylon as well as the low-speed control/status information between the pylons (see **Figure 7**). The RSM operates from a 24 to 28vDC power source. DC-to-DC power-converter modules on the upper and lower sections convert input power to the levels needed by the various components. The Upper Controller Board contains the logic required to receive commands from the DCM, and to collect and format data from the sensors to be sent back to the DPM for processing through the high-speed fiber-optic link.



Picture of the Upper Controller with the Tern Micro-controller Daughter Board. The Triquent chip set is also shown.

**Figure 7. RSM Upper to Lower Pylon Electronics Diagram**

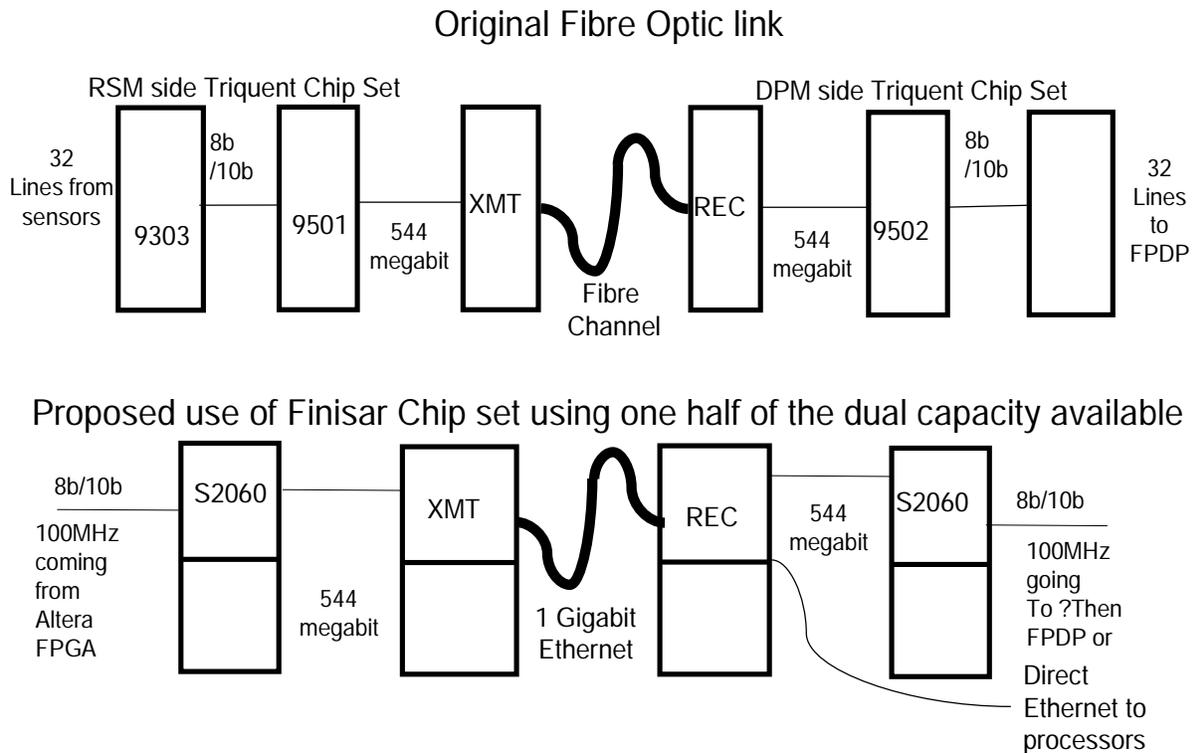
**Low-Speed Optical-Fiber Link: Upper and Lower RSM to the DPM**

The low-speed fiber-optic link provides bi-directional control communications between the RSM and the DPM. The lower pylon of the RSM receives control information from the DPM, transmits the control information to the upper control board through the electrical slip rings, and passes back status information to the DPM through a serial port on the DPM executive controller. The upper and lower pylon processors communicate with each other by means of an RS-485 serial-port link through the slip rings. This link is required because the low-speed fiber-optic link to the DPM is connected to the lower pylon only.

**High-Speed Optical-Fiber Link: Upper and Lower RSM to the DPM**

The high-speed Fiber Channel Link is used to download RSM detection-sensor data to the DPM for processing. The data is encoded by a digital circuit on a board located on the RSM upper pylon, and then transmitted through a fiber-optic rotary coupling to the fiber-optic communications cable in the lower pylon. The fiber-optic rotary joint was replaced in late August 2004, after it was determined that a data validation signal (POSVAL) was only being received at specific rotational positions. The optical coupling joint used to replace the rotary joint has its own weaknesses, since there are visible changes in signal strength when using the new joint. However the new optical rotary joint is observed to transfer the data correctly in all positions. It will take approximately 3 months to get new joints for the second prototype, since the joints being used in the original prototype were specially manufactured for the first prototype.

Before the high-speed fiber-optic data link passes through the rotary joint to the lower pylon and out to the DPM for processing, the Fibre Channel serializer chipset encodes the thirty-two bits of RSM sensor data into an 8b/10b data format. The top portion of **Figure 8** illustrates information flow through the Triquent chip set. The Triquent chip set is used on both the upper controller board, and at the other end of the fiber-optic link in the DPM custom communication board (see the section of this report detailing the DPM for additional information on the DPM custom communications board).



**Figure 8. Comparisons of RSM/DPM Data-Flow Strategies**

Data from each of the sensors (8-bit data streams) is multiplexed into a 32-bit word by the upper controller board. The data from the sensors is synchronized with the Fibre Channel transmitter by logic in the Programmable Logic Device (PLD). Position and offset data is also collected and sent during intervals between the sensor data blocks. The Fibre Channel transmitter is presented with a 32-bit word. Twenty-four bits are used for the data; six bits are used to indicate when each data byte is valid; and two bits are spares.

Thirty-two bit words are transferred to the Fibre Channel transmitter at a 13.6 MHz clock rate. The data is then 8b/10b-encoded to a 544 Mbits/sec serial data stream and sent to the optical driver module. Currently, the optical driver is designed to transmit over multimode optical fiber. Because of this, transmit distance is limited to approximately 500 feet. This has been verified by actually operating the system successfully over a 500-foot optical-fiber cable. If greater distance is required, multimode fiber would be converted to single-mode fiber on the lower pylon. Multimode to single-mode optics connectors have been acquired, but not yet used. This could allow transmission distances of up to 20 kilometers.

Data is decoded by the Fibre Channel receiver at the receiving end in the DPM custom-communications input board. The Fibre Channel encoding/decoding scheme is used to keep the high-speed bus balanced, and to minimize errors.

Communication between the RSM and DPM was instrumented with a logic analyzer to determine if the signals sent and received were the same. Since the signals were not matching, different Triquent chips were replaced as overheating and loss of clock signal were identified in some of the chips. After the optical coupling rotary joint was replaced, video signals were successfully sent from the RSM to the DCM. Replacements for the Triquent chips for the second prototype has been investigated, and possible alternatives identified, but the communication strategy adopted will impact the current software design significantly, and is still being researched.

It is probable that the visible data from the visible line-scan sensor is working correctly, as visible images from the RSM to the DPM are correctly displayed on the DCM. The visible flow through the system has still been intermittent. Both temperature sensitivity and oscillations in the RSM electronics are being examined, as well as the real-time communication process between the DPM custom-communications input board Triquent receiver and the output to the Executive Controller Linux PC through the Front Panel Data Port (FPDP).

### **Upper Pylon Control Processor**

The following are the general duties/functions of the Upper Pylon Control Processor:

- Control IR tilt mirror/program tilt mirror Look Up Table (LUT).
- Receive messages from the lower processor, decode, and take appropriate action(s).
- Control IR LUT for gain and offset.
- Control radar LUT for azimuth gating.
- Turn on/off radar, IR sensor, and visible sensor.
- Monitor the status of all three detection sensors, Fibre Channel communications board, and thermo-electric (TE) cooler.
- Output authentication code to Fibre Channel communications board.
- Generate and periodically output a heartbeat message informing the lower pylon control processor of the operational status of the upper pylon.

Planning includes replacing the Tern processor with a processor loaded into the modern, much larger Altera Field Programmable Gate Array (FPGA) chip to replace the older Altera chip. Because of the greater capacity of the new chip, the microcontroller functions can be downloaded into the Altera. A development environment and new Altera chips have been acquired to assist with the redesign of the upper controller board, and possibly a new DPM communications board (if eliminated), for the second-generation *AES* prototype. These design plans are very preliminary.

### **Lower Pylon Control Processor**

The following are the general duties/functions of the Lower Pylon Control Processor:

- Receive low-speed messages from the DPM, decode, either take action or pass onto upper processor.
- Transmit low-speed messages to DPM.
- Control multiplexer and analog-to-digital converter (ADC) for the following sensors: ambient temperature, ambient light level, battery status, solar array voltage, solar array current when solar and battery is implemented (currently a power converter to supply the RSM with DC power is being used).
- Store and/or analyze sensor messages from ambient temperature sensor, ambient light level sensor, battery, north-seeking sensor and solar array (GPS and electronic compass are supported in the current prototype).
- Receive position data from sensor, calculate difference between magnetic north and 0-degree azimuth.
- Control digital-to-analog converter (DAC) for motor driver/controller.
- Receive/relay messages from upper pylon control processor.
- Generate and output a heartbeat message informing the DPM of the operational status of the RSM.

Fans will also be added to the lower pylon for cooling the second prototype when the enclosure is in place.

#### **2.2.2 IR Sensor**

The current IR sensor is adapted from a Raytheon/Hughes MAG 1200 Hand-Held Thermal Imager, and is no longer available commercially. A limitation of the original IR sensor assembly was the need to manually focus the image. For the new assembly, having controls available to electronically control the focus has been identified as a desirable requirement. The original IR assembly also contains a mirror so that the detector can sit at a 90-degree angle to the camera in the *AES* body, as shown in **Figure 4**. If mechanized, this mirror could also be used for terrain following, although this feature was not implemented in the first prototype. IVAL data coming from the RSM indicates the current IR sensor is working. Current *AES* refurbishment is concentrating on getting the visible sensor data flow working before the rest of the system, so the IR has not been extensively investigated.

Two potential suppliers for the IR detectors have been identified, and each company works with subcontractors to supply optics that will meet our specifications for the IR assembly: one is produced by Northrop-Grumman, Corp.; the other is produced by Sensarray. A Request for Information (RFI) memo has been sent to both companies. Negotiations are still continuing to

determine the price of the replacements and a delivery schedule, as well as including a factory acceptance test. The contents of the RFI memo include the following:

**Infrared Imaging Array and Subsystem Requirements Specification**

Detector

- Spectral band: Mid-wave infrared (2-6 microns, nominal)
- Array type: Linear lead selenide or other
- Number of elements: Minimum: 160 Maximum: 256
- Multiplexer: Require continuous readout of pixels via pixel and line clocks
- Subarrays: If offset sub-arrays are used, electronics must provide for de-stagger
- TDI processing: Optional - prefer high-sensitivity, low-noise, time-delayed integration array
- Detector cooling: Prefer integrated thermoelectric cooler  
May consider closed-cycle mini-cooler, depending upon detector technology
- Digital output: 8 bits per pixel, minimum
- Line clock: Line rate from total detector is to be 10,000 to 24,000 lines/sec  
Nominal line rate will be 21,600 lines/sec
- Pixel clock: Sufficient to support continuous readout at line rate
- Sensitivity: To be determined based upon optics and cooler configurations (maximum desired)
- Digital interface: To be determined. Options include: differential parallel, USB 2.0, other custom

Optics

- Sufficient to provide 0.3mR instantaneous field-of view (IFOV) system resolution
- Outer lens surface to be hard-carbon coated

Packaging/Environmental

- Unit to be used in exterior industrial/military environment. Temperature range: 20° F to +120° F anticipated for some applications.
- Shock and vibration expected to be minimal in use, but units need to survive common shipping shock/vibration environments.

Quantity

Initial purchase: 1 to 5, depending upon cost. Partial delivery by 30 September required; full delivery desired.

**2.2.3 Visible Sensor**

The visible-band sensor was incorporated into the system design because it effectively supplements the limitations of an infrared sensor during periods of low thermal contrast during warm background, daytime operation. The visible sensor is a Dalsa Model CL-E1 with a Cosmimar zoom lens. This exact camera model will be replaced with a more sensitive model by the same manufacturer: a DALSA model Eclipse EC-11-05H40, which is also a 512 pixel unit, so the original optics sized to the camera should be able to be duplicated for the second prototype units. The availability of these optics have not yet been researched or the optics ordered. Integration of the new camera and optics is expected to be very straightforward for the second prototype builds, and replacement cameras have been acquired for the second prototype units.

Specific sensitivity tests have not been performed on the visible sensor. Empirical results from actual images gathered in 1998 demonstrate adequate sensitivity (in accordance with modeled results) in light levels approaching dusk. Next year's system evaluation testing will provide performance capability data.

**2.2.4 Radar Sensor**

The current radar is a custom Sandia patch antenna, Frequency Modulated Continuous Wave radar from the Sandia synthetic aperture radar (SAR) radar group. RVAL indicates that valid data is being sent by the radar system, but little investigation has been accomplished in FY04 as work has concentrated on getting the visible sensor communications working.

Sensor Technologies Systems (STS), Inc. of Phoenix, Arizona, has been identified as a potential radar supplier. STS has developed a radar product based upon the same frequency-modulated, continuous-wave (FMCW) radar technology, which operates at almost the same 17GigaHz frequency as the current *AES* radar, but is a much larger size with a consequent longer range of five kilometers for detecting personnel. The *AES* radar design detection range of 1500 meters allows for a small radar, and is a good match for what can be visually assessed with the visible and IR sensor images matched with the current *AES* radar range. STS also produces a smaller product that is also based upon FMCW radar, with a range of only 300 meters operating at a frequency of 35 GigaHz, which does not meet current *AES* requirements. STS has contacted SNL, and a mid-October meeting is planned to continue discussions to determine if they can commercially pro-

duce the *AES* radar design, or if they are interested in a CRADA partnership agreement that may give them rights to the *AES* design for their own product line.

### **2.2.5 Conditional Operation Approval for Radar Operation**

The USAF Frequency Management Agency foresaw no problems with operating at 17 GHz, but they advised that frequency assignment might take as long as eight months after form DD1494 is submitted. In 1998, SNL applied for, and received, conditional approval for operation of the radar at the following locations:

- Kirtland Air Force Base
- Vandenberg Air Force Base
- Holloman Air Force Base
- Lackland Air Force Base

A “request to implement wireless” request form has been added to SNL procedures, and the form was obtained and submitted in FY04.

### **2.2.6 RSM Microcontrollers**

RSM microcontrollers administer all functions on both the rotating and non-rotating portion of the RSM. This includes high-level control of the rotation motor and high-speed fiber-optic communications link, control and adjustment of the three detection sensors, and performance of self-tests, status checks, and system monitoring. There are currently two processors in the system: one on the upper controller board, the other on the lower controller board. As described previously, the upper pylon of the RSM contains the detection sensors, and rotates at approximately one revolution per second; the lower pylon contains the drive motor that rotates the upper pylon. Because of this organization, each pylon has its own separate processor responsible for the tasks located in that pylon. Therefore, references to the RSM control processor actually refer to a distributed processing system consisting of two loosely coupled microprocessors. It is likely both microprocessors will be replaced with a FPGA in the second prototype design. Meanwhile, they have both been fully restored to operation.

Currently, both RSM control microprocessors are NEC V-25 based V104 controllers from TERN, Inc. Each board is a fully embedded, low-power processor with 128k battery-backed SRAM, debugging and operational EPROMs, a real-time clock, RS-232 and RS-485 capabilities, on-board DACs and ADCs, and all extraneous cables and power supplies. After 4 years in storage, the SRAMs battery backup failed, losing all the original programming. Recreating the original TERN development environment restored the original programming. The V104’s development environment consists of the C/C++ Developer’s Kit from TERN and Borland C++ 4.5.1. The Developer’s Kit consists of a set of V104 C libraries, Paradigm DEBUG/RT software, and Paradigm LOCATE software. A PC was installed with a Windows 98 operating system; a TERN download cable, for communicating to the TERN microcontroller, was located; the

original software, under configuration control, was located; and the TERN processors were successfully reloaded after new batteries were purchased for the SRAMs.

The majority of the upper control logic is provided by an Altera RAM-based PLD. The PLD is loaded from an onboard ROM at power up. The Altera PLD is no longer manufactured, but has operated correctly so far. An Altera development environment, with additional logic modules and chips, has been acquired to investigate implementation with second prototype designs.

All original RSM software was developed under Borland C++ 4.5.1. Some precompiled library functions, supplied by Tern, Inc., were also used (which may not have been developed under Borland C++, but are compatible). The development environments were recreated, and the original software downloaded into the SRAMs. This software appears to be operating correctly, since the control functions of the RSM are being successfully demonstrated using the DCM communication link.

### 2.3 Data Processor Module (DPM) Overview

The DPM contains the hardware and software that processes the RSM data, and passes the results (and images) to the DCM for display. The DPM also passes messages from the DCM through the DPM to the RSM. **Figure 9** illustrates the main processing components in the half rack of equipment that comprises the DPM: the Communications Input Board (shown on the left), and the five PC processors (shown on the right with some board communications detail).

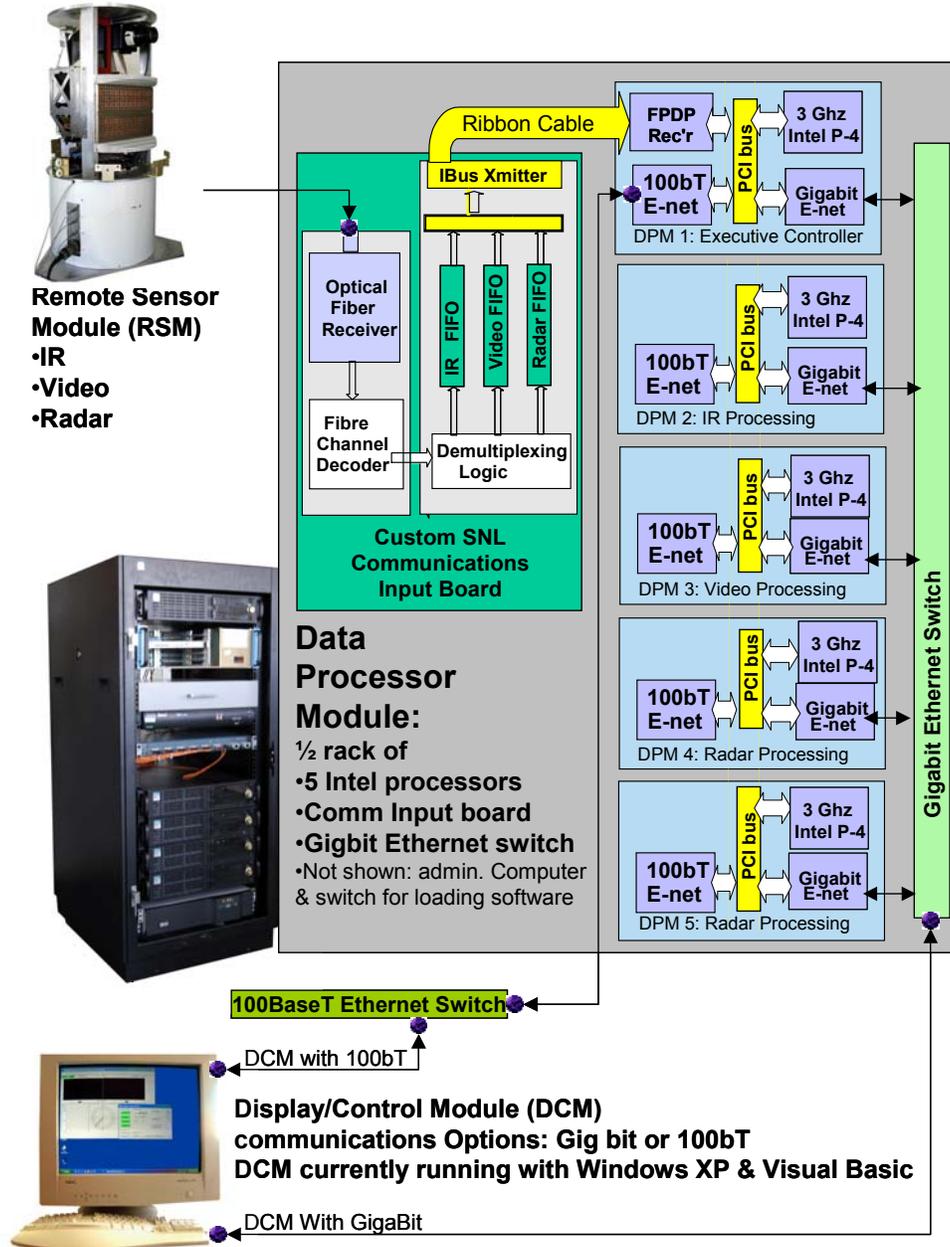


Figure 9. DPM Data Communications

### **2.3.1 DPM Communications Input Board**

The data input board is an SNL custom-designed circuit board that receives data from the optical fiber, checks for errors, reformats the data from each sensor, buffers the data, and then transmits the data to the Executive Controller (the first digital signal processor out of the five PCs in the DPM). The data input board consists of a standard VME board and a Fibre Channel Receiver board. The Fibre Channel Receiver is piggybacked on the VME board.

Data is received as a 544-Mbit/second serial data stream. The data is 8b/10b encoded by the Fibre Channel transmitter at the sending end (the RSM) and is 10b/8b decoded on the Fibre Channel receiver. This encoding/decoding scheme is used to maintain high-speed bus balance, and to minimize errors. The 8-bit data stream is further de-multiplexed into a 32-bit word by the Triquint chip set. Thirty-two bit words are transferred to the communication input board at a 13.6MHz clock rate. High-speed fiber-optic communications details were discussed in the previous section.

Image and radar data is buffered by first in, first out (FIFO) memory devices, and then transmitted to the DPM Executive Controller (EC) PC in blocks by 32-bit parallel data transfer operations through an Ibus interface and a logic card that convert the Ibus to a "Front Panel Data Port," or FPDP, interface. The Ibus is an obsolete interface used on an earlier version of the system. The data format on the Ibus and the FPDP interfaces is very similar, and the Ibus-to-FPDP interface mainly performs signal-conditioning and connector-conversion functions. A standard FPDP interface card is plugged into the PCI bus backplane in the DPM Executive Controller PC. The FPDP interface card is used to further buffer the data and transfer blocks of data directly into the memory of the Executive Controller PC.

### **2.3.2 DPM Executive Controller**

The software for the Executive Controller is written in C++. Initially, this software ran as application software with VxWorks for the real-time operating system on the Motorola MVME 1604 PowerPC VME bus board in a VME chassis. Subsequently, the VME chassis and VxWorks system was dropped to reduce hardware expense, and the software ported to a standard PC running a Linux operating system. This configuration was used in the preliminary test and evaluation previously reported. The EC software appears to be working under the Linux 6.0 system it was ported to in 1998 from a previous VME chassis-based system. Linux is now at version 9.0, but an operating-system upgrade requires that the large memory buffer area compiled into the 6.0 kernel be reproduced in the newer version. The port to Linux 9.0 is underway; however, operation of the 6.0 system requires verification before upgrading to the Linux 9.0-based system. Some of the lower-level operating system calls may also be affected when the operating system is upgraded, but for now, everything appears to be working correctly. A complete test will only be possible when data communication from the RSM is debugged. Meanwhile, test video injected into the Executive Controller to simulate video coming from the RSM is being used.

The modular design of the Executive Controller software should make the upgrades to the DPM easier; however, software executing multiple processes over different machines is inherently complex. An example of the loose coupling between the processes maintained in the code is how the Read Event Data module is used as a mechanism for inter-process communication be-

tween the Fuse process and the DCM I/O process. The purpose of the Read Event Data module is to provide a mechanism for the DCM I/O process to receive an event list from the Fuse process (via the Queue Events module). This intermediary module is internal to the EC process and is used so that the external DCM I/O process does not need to know about, or include, inter-process communication code.

### **2.3.3 DPM Image Processing Software Changes and Testing**

All DPM software has been identified, archived, and placed under configuration management control. Universal Modeling Language (UML) software, for further documentation, has been ordered and received from Embarcadero.

As an *AES* processing requirement, image and radar detection and tracking information must be updated every second. DPM imaging software processes image and radar data in real time; however, radar testing conducted in 1998 revealed difficulties with the COTS digital signal processors: Image data and radar data were properly processed, but image data and radar data could not be processed simultaneously. As a result, performance testing of the *AES* has been limited. At the point in the project when USAF funding was suspended, the *AES* was operating satisfactorily on all IR and visible data. The radar signal processing performance was also satisfactory. Currently, the IR sensor appears to be operating correctly, however simultaneous testing of the visible, IR, and radar will only take place after the visible sensor data flow is operating consistently.

One area requiring review is the error correction for data coming in from the radar sensor, and a through review of radar operations. Additional software debugging will be required as radar data and signal processing is fully integrated with the image-processing portion of the DPM software. The software was ported from Mizar MZ4700 Dual C80 digital-signal processing boards to standard PC boards running LINUX, but final integration was suspended due to funding cuts, and was never completely tested. This is likely to be the area that will require the most software development and debugging, although all processors appear to be operating correctly with the video that has been sent by the RSM.

Another issue identified for review is to add video storage capability to the DPM. Currently, video flowing through the system is not archived. In the event of a multiple-alarm scenario, images recorded during the initial alarm must be recalled and reviewed to ensure an accurate assessment of the incident (the cause of the initial alarm may have moved out the *AES* field of view by the time additional alarms occur). It is probably desirable to keep an archive of alarm-triggering images in the system for later recall and operational assessment.

Although only single-unit testing has been possible, controlling several RSM/DPM pairs from a single DCM in order to protect large areas is an important feature of the *AES*. **Figure 10** illustrates an *AES* multiple-unit configuration and a single-unit configuration.

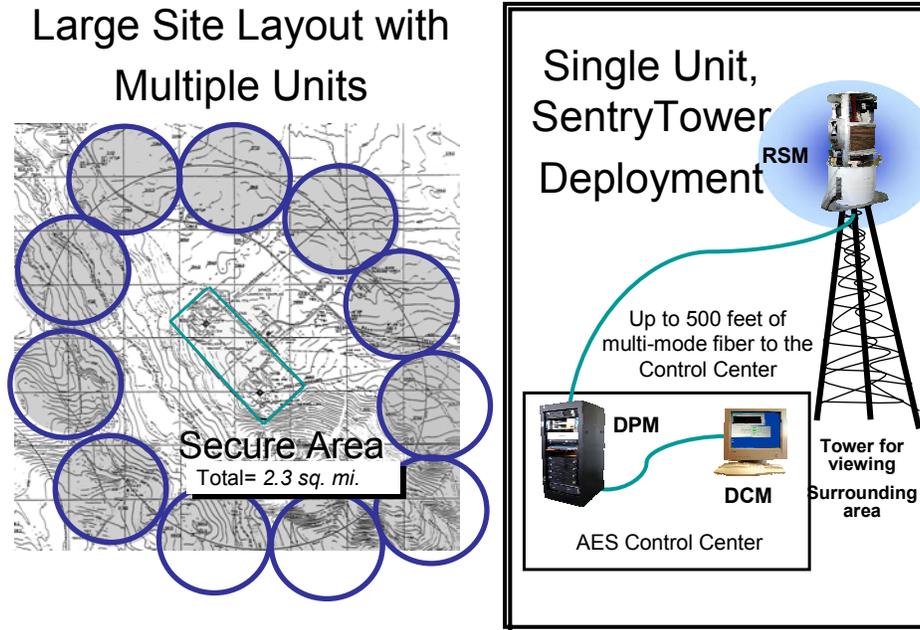


Figure 10. Two Examples of AES Configurations

Multiple systems controlled by a single DCM will make multiple, simultaneous alarm assessment issues even more complicated, as more units will potentially be reporting simultaneous alarms. Adding mass storage in the DPM will allow for accurate multiple-alarm assessments and will facilitate accurate after-event auditing. Multiple *AES* RSM/DPM units will not be operational until next year. DPM software modifications will be required to support alarm queuing and prioritization between RSM/DPM pairs controlled by a single DCM. Additionally, there may need to be additional coordination and “staggering” of individual RSM rotation rates in multiple unit configurations so that RSM units do not interfere with each other’s radar returns.

## **2.4 Display Control Module (DCM) Overview**

The Display Control Module (DCM) is the user interface used to perform RSM start up procedures, solicit requests for images from the DPM, and allows the user to assess, monitor, and track targets identified by the DPM.

### **2.4.1 DCM General Issues**

All DCM software has been identified, archived, and placed under configuration management control.

Original DCM software ran on a PC platform running Windows NT 4.0 and Service Pack 3. The system has been ported to Windows XP, and the Visual Basic 5.0 project upgraded to Visual Basic 6.0. Data between the DCM and RSM are passed through the DPM. The DCM-to-DPM data link is currently Gigabit Ethernet; the DPM-to-RSM data link is RS-232 converted to a fiber-optic link. When sending commands to the RSM, the interface appears to operate correctly. The image display appears to be functioning correctly; however, target detection and tracking boxes have not been tested because thorough testing of DPM software using simulated video input has yet to be accomplished. RSM control and status information is correctly displayed on the DCM.

### 3. Summary of Accomplishments and Planned Activities

The *AES* will be ready for extended field-testing early next year.

The current *AES* prototype is being refurbished with minimal or no re-engineering in order to field the *AES* system as soon as possible for evaluation by interested customers. This report has described the work accomplished thus far, and has identified areas of work that will be pursued to ensure the *AES* prototype is maintainable with modern technology, and to facilitate seamless *AES* technology transfer to industry.

The original *AES* prototype has been upgraded to control RSM hardware from the DCM, capturing video images from the RSM and sending the images to the DCM through the DPM. Valid data signals from the visible, IR, and radar sensors indicate the sensors are operating correctly; however, visible-image data flow has been intermittent, and both the RSM and DPM systems are being tested in parallel to isolate the problem. The optical coupler is being replaced, as it has ceased working. An enclosure has been designed to protect the RSM for extended field-testing, test video has been acquired, and a test plan is being developed for system testing next year.

Documentation to support technology transfer for the original unit is almost complete, and development of documentation to support technology transfer for the second prototype build has been initiated.

The second prototype *AES* is being built to enable multiple unit testing, provide *AES* units for evaluation and security upgrades at SNL, and to update the *AES* design to use current technology to facilitate easier technology transfer.

The original RSM mechanical drawings are complete, and have been entered into the Sandia Drawing System for controlled archiving.

Solid models for creation of the second prototype have been created. Some parts have been manufactured and equipment has been ordered for building units of the second prototype using current technology: this drawing package is being updated.

The electronic drawing set is substantially complete, is being reviewed and revised, and will be completed this fiscal year; however, work has not yet been initiated to complete the second prototype electronic design upgrade drawings. More connection detail and drawings are required to complete the DPM hardware documentation, which will also be completed this year, and will not require updates for the second prototype.

All the source software has already been identified and archived, but additional documentation will be added to illustrate the structure of all system software. System testing of the software ported to the current version of Linux has not been completed.

## Bibliography

### Current Conference Papers

M. R. Ashby and D. A. Pritchard, “Beyond the Perimeter: The Advanced Exterior Sensor *AES*” *45<sup>th</sup> Annual Meeting Proceedings of the Institute of Nuclear Materials Management*, Orlando, FL, June 2004.

M. R. Ashby and D. A. Pritchard, “Seeing Beyond the Perimeter: The Advanced Exterior Sensor *AES*” *38<sup>th</sup> Annual IEEE Proceedings of the International Carnahan Conference on Security Technology*, Albuquerque, NM, October 2004.

### Reports

*Advanced Exterior Sensor Project—Motion Sensor Design Validation Report*, prepared for the Defense Nuclear Agency by Sandia National Laboratories, Albuquerque, NM, August 1994.

*Advanced Exterior Sensor Project—Knowledge-Based Tracker Design Validation Report*, prepared for the Defense Nuclear Agency by Sandia National Laboratories, Albuquerque, NM, October 1994.

*Advanced Exterior Sensor Project—Radar Design Validation Report*, prepared for the Defense Nuclear Agency by Sandia National Laboratories, Albuquerque, NM, October 1994.

*Advanced Exterior Sensor Project—Visible Detector Design Validation Report*, prepared for the Defense Nuclear Agency by Sandia National Laboratories, Albuquerque, NM, January 1995.

### Other

An *AES* DVD showing image processing sequences from 1998 is available.

DNA/DSWA – older reports with valuable overview content are available for internal distribution.

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