UNIVERSITY OF MINNESOTA

CENTER FOR TRANSPORTATION STUDIES

INTELLIGENT TRANSPORTATION SYSTEMS INSTITUTE

Advanced Portable Wireless Measurement and Observation Station

Final Report

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CTS 05-07

HUMAN-CENTERED TECHNOLOGY TO ENHANCE SAFETY AND MOBILITY

Technical Report Documentation Page

1. Report No. CTS 05-07	2.	3. Recipients Accession No.
4. Title and Subtitle ADVANCED PORTABLE WIRELESS MEASUREMENT AND OBSERVATION STATION		5. Report Date July 2005 6.
7. Author(s) John Hourdakis, Ted Morris, Panos Michalopoulos, Kyle Wood		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil Engineering University of Minnesota 500 Pillsbury Drive SE Minneapolis, MN 55455		10. Project/Task/Work Unit No. CTS Project Number 2002030 11. Contract (C) or Grant (G) No.
12. Sponsoring Organization Name and Address Intelligent Transportation Systems Institute Center for Transportation Studies University of Minnesota 511 Washington Avenue SE, Suite 200 Minneapolis, MN 55455		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes http://www.cts.umn.edu/pdf/CTS-05-06.pdf		

16. Abstract (Limit: 200 words)

The authors of this project designed, assembled, and deployed a temporary detection and surveillance system to collect real-time data on traffic conditions. This information is critical in construction, Advanced Traffic Management Systems, Advanced Traffic Information Systems, and other design and operational activities. Because traditional, permanent systems collect data by sensors in the pavement and transmit it through land-based communications, this equipment is subject to failure in construction areas. Through advancements in wireless technology, the developed system integrates machine vision sensors to collect data, compress digital video for surveillance, and use wireless communications for information retrieval and remote control. This new system can be added to current installations or used to create temporary traffic monitoring systems.

17. Document Analysis/Descriptors Advanced Traffic Management Systems (ATMS) Advanced Traffic Information Systems (ATIS)	Real-Time Surveillance System Traffic Simulation	18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Classified	20. Security Class (this page) Classified	21. No. of Pages 80	22. Price

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Acknowledgements

The authors express appreciation to the Intelligent Transportation Systems Institute for its continuing trust and support. Additionally thanks go to the Regional Traffic Management Center of the Minnesota Department of Transportation for its support of this research. Specifically the authors are indebted to Mr. Nick Thompson for his valuable support and assistance.

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Executive summary

Real-time information on traffic conditions is vital in construction, Advanced Traffic Management systems (ATMS), Advanced Traffic Information Systems (ATIS) and other operational or design activities. Traditionally, at most permanent installations such information is captured by in-pavement sensors and transmitted through land-based communications. However, at construction sites, during special events, or communication/sensor failures temporary detection and surveillance is often needed as an alternative to the permanent sensor and camera systems. In such cases, temporary detection and surveillance needs to be reliable and low-cost. Recent advances in wireless technologies have enabled development of portable detection and surveillance systems which can detect traffic, collect measurements, capture live video and transmit this information wirelessly back to the supervising station to facilitate rapid, inexpensive and efficient deployment. However, to make widespread use practical, further improvements are needed in terms of robustness, ease of use, functionality, and cost reduction. In this project a low cost, easily deployable detection and surveillance system is designed, assembled, and deployed. The system integrates machine vision sensors for data collection, compressed digital video for surveillance, and wireless communications for information retrieval and remote control. Furthermore, it can be placed on existing or mobile structures and assembled with off-the-shelf components to serve both DOT needs for temporary traffic monitoring and planning/research data collection. Four of these advanced detection systems were deployed at a 1.7-mile-long site for wireless, continuous coverage, allowing detailed real-time data collection and surveillance. This data and video-intensive deployment currently serves as a live laboratory for applications ranging from evaluating new technologies (such as sensors, video, wireless communications) to the testing of advanced traffic-simulation models or refinement of accident-prevention studies. To date, 70 accidents have been recorded over a period of nine months along with 74 unreported near misses. With the exception of a few days where transmission was interrupted due to malfunctions of the Ethernet radios, traffic measurements were collected continuously during this period resulting in more than 5000 hours of detailed traffic measurements both microscopic and macroscopic.

Chapter 1. Introduction and background

Information describing the traffic conditions and roadway performance is crucial for successful operation of the transportation network. As noted in the Federal Highway Administration Transportation Equity Act for the 21st Century (FHWA TEA-21) reauthorization proposal: "Operating the highway system to achieve security, safety, and reliability objectives requires an ability to know what is happening on the system. Real-time information on highway system performance and weather conditions/events is vital to assist highway professionals in managing the available capacity." In response to this need for information, comprehensive permanent detection and surveillance infrastructures have been installed in most major cities worldwide during the last several decades. In such permanent installations information is commonly captured by in-pavement sensors and transmitted through land-based communications. However, in addition to the permanent infrastructure there is a need for low cost, easily deployable, portable monitoring systems for temporary detection and surveillance. These systems have a variety of applications such as for detection and surveillance during periods of equipment malfunction, at road construction sites or special events, for homeland security applications, and data collection for evaluation or research purposes.

When the first Intelligent Transportation Systems (ITS) projects were conceived in Minnesota in the late 1980s, engineers recognized the need for wireless, portable detection and surveillance systems to evaluate new traffic management systems and technologies through detailed data collection. In response during the early 90s Mn/DOT supported the design of a seven-mile, live-data collection laboratory on I-394, which was jointly deployed with the University of Minnesota [1]. Along with this effort an innovative state-of-the-art video detection system was deployed at this site [1, 2] for continuous wide-area detection and surveillance. In all, 41 machine vision cameras were set up for this purpose. Unfortunately, this embryonic state-of-the-art laboratory was plagued by major communication failures, which could not be rectified due to cost. In addition, there was no long-term budget for maintenance and modifications required by a permanent installation and interference with daily Mn/DOT operations exacerbated the problem. At that point it was clear that fixed detection and surveillance systems were not suitable for intensive data collection and evaluation. Thus, the search for portable systems was recently accelerated to accommodate several simulation, evaluation and safety studies.

Recent advances in technology have allowed development of a few wireless mobile detection and surveillance systems [3, 4, 5]. However, their use has been limited partly because of cost and partly because they are still evolving and therefore do not meet all user needs in terms of deployability, reliability, or functionality. In general, they come in different versions, custom made to meet the requirements of each client. In the majority of cases these products are configured for either detection or surveillance but not both simultaneously. Additionally, they all require roadside installation, which limits deployment choices and wide-road coverage.

Based on such considerations, we decided to develop and deploy a low cost, portable system for detection, surveillance and data collection. The system consists of machine vision sensors for non-intrusive data collection, CCTV cameras and digital video compression equipment for surveillance, as well as wireless Ethernet radios for information retrieval, video transmission and remote control. This design facilitates quick and flexible deployment on existing structures such as light poles, buildings, or any fixed or mobile structures at or near the roadway.

Following its development, the system was deployed at a 1.7-mile-long freeway site in the Minneapolis/St. Paul area for capturing live accidents on video, while simultaneously detecting individual vehicles and extracting continuous detailed traffic measurements for the study of accident dynamics. This temporary deployment also facilitated data collection and surveillance for evaluating ITS technologies such as new sensors, traffic simulators, incident and traffic management concepts, or studying traffic characteristics and flow dynamics. In order to provide continuous, wide-area coverage, four such systems were deployed at the test site for obtaining detailed measurements effectively forming a live-traffic laboratory. During its first year of operation 70 accidents were captured on video along with more than 5000 hours of detailed traffic measurements both microscopic and macroscopic.

In this report we present our approach to developing and deploying a wireless, mobile detection and surveillance system. In chapter two, we discuss our methods for selecting the best equipment according to the functional requirements of the system. In chapter three we follow with a description of the system's architecture. Actual field deployment is described in chapter 4. The latter was accomplished in two phases, demonstrating how adaptation to the available equipment can change the conceptual design. The system's performance and data collected so far at the deployment site suggest that the technology is effective and reliable. In chapter five these results along with conclusions and future plans are also presented.

Chapter 2. Functional requirements and technologies selected

Functional and cost requirements as well as design of the detection and surveillance system drove component selection. Many functional requirements were considered and some were ultimately dropped to minimize complexity and cost or to ensure reliability. In the end we decided that the integrated system should have the following characteristics:

- Capability to detect traffic and collect real-time measurements.
- Capability to capture and transmit surveillance video.
- Portability. The system (sensors, camera and other components) should be easy to disassemble and reassemble at new deployment sites. Minimum cabling or site wiring is required.
- Installation effort and time are minimal, causes no traffic disruptions, and does not require proximity to the roadway.
- Low power consumption to allow operation through a solar panel when no regular power source is available.
- Unified communication system for data and video. This minimizes the number of components and simplifies communication to achieve a real-time link between the deployment site and the supervising station.
- Remote access capabilities for component reconfiguration, debugging and monitoring.

Based on these characteristics, we developed specifications for the technologies used in the system's three components: traffic detection, surveillance, and communication. These specifications are presented in the rest of this section.

2.1 Detection Technology

Although widely used, loop or other in-pavement detectors do not present a feasible choice for a detection system because installation of sensors requires disruption of traffic operations, and it is time consuming and costly. Therefore, we concluded that non-intrusive technologies such as radar or machine vision would be a better choice. This type of detection technology should have the following characteristics:

- Non-intrusive.
- Easily configured to minimize deployment time and effort.
- Capability for robust placement to allow freedom in locating the sensors. Ideally, the sensors will function some distance from the roadway.
- Capability of providing detailed, individual vehicle detection and measurements like speed, headway, and classification.
- Capability of providing information with a single sensor in order to minimize installation/relocation time.
- Capability of supporting real-time extraction of comprehensive microscopic and macroscopic measurements.
- Low power requirements.
- Demonstrated reliability, accuracy and robustness in real-life installations.

These requirements narrowed the options for detector selection to two major technologies. The first is based on the Doppler principle and includes radar, microwave or laser and the second on machine vision.

The first group satisfied the cost, power consumption, and ease-of-use requirements but it was restrictive on sensor placement. Doppler-type devices need to be close to the roadway but best operation is achieved if the sensors aim perpendicular or parallel to the roadway; this implies detection in only one direction (one dimensional) rather than simultaneously in two directions (two dimensional detection). In addition, some users of these technologies have expressed concerns about their reliability during adverse weather conditions. Another inherent problem of this technology apparently is poor stopped-vehicle detection [6, 7].

Machine vision sensors, on the other hand, do not have most of the aforementioned restrictions. Specifically, assuming proper camera selection (telephoto versus wide angle lens), machine vision detection equipment can be very robust in terms of placement since it can be installed hundreds of feet away from the roadway. For example, they may be placed on top of very tall buildings as long as they have a clear line of sight. The greatest advantage of machine vision is that it provides the means for checking accuracy and operation since along with the measurements it also supplies video from the scene which allows both surveillance and recording of the traffic conditions for off-line verification or analysis. Thus, machine vision sensors can, with proper lens and options selection as well as placement, double as a surveillance camera. Finally, these sensors allow two-dimensional detection, i.e. a single sensor can cover multiple lanes over a wide area or multiple approaches and lanes at intersections. Their costs are similar to comparable Doppler-based sensors. The machine vision technology was therefore selected for deployment in the detection stations.

2.2 Surveillance Technology

The majority of permanent surveillance systems currently deployed use analog video capture and transmission. However, analog video, albeit of very good quality, is expensive to transmit over anything other than land-based copper or fiber optic lines. Specialized wireless devices can transmit analog video but they can only transmit images from a single camera and they work in dedicated pairs (transmitter/receiver). For each additional camera another radio pair is necessary. Such constraints render analog video unsuitable for a temporary, portable design. Contrary to analog, digital video can be of comparable quality but in a more robust, easier to transmit form. Based on such considerations, the major functional specifications of the surveillance technology employed are the following:

- Video should be in digital form when it is transmitted to the supervising station, regardless of the video-capture format.
- The refresh rate of the video images should be at least 15 frames per second (fps) (analog video is 30 fps). This requirement ensures the observer a clear view of the traffic stream, the traffic-stream speed and other flow conditions.
- The technology should allow the recording of multiple video feeds at the remote site to assist in system communications. Not all video feeds need to be watched simultaneously, so it would be a waste of bandwidth (and increased cost) to transmit video from all cameras at all times.
- The image resolution must be of sufficient quality to allow the viewer to easily distinguish vehicles for manual identification and classification as well as to confirm

detection/measurement accuracy. A minimum size field of view ensure a minimum vehicle size in the observation monitor.

- The system needs to cover as wide an area of the roadway as possible. This and the previous requirement can both be satisfied if the selected technology allows the combination of video feeds from more than one camera.
- The system should be compact, requiring minimum cabling in order to be easily moved from place to place.
- The system should have low power requirements.

Digital video is superior to analog because it can be compressed at the source to a small fraction of it's original size. This reduces transmission cost while preserving speed and quality. Video digitization and compression are relatively new technologies that are evolving rapidly. Originating from the security industry, a limited number of products have recently been adapted to transportation needs. Real-time video digitization typically uses proprietary hardware devices and cannot be easily customized by the end user. In contrast, because of the lack of recognized standards, video compression still uses mainly software/firmware. As a result, a plethora of proprietary, non-proprietary, and experimental CODECs (Compression-Decompression algorithms) applications are available. All of these factors make it difficult to grade and select a particular compression technology, but also allow for customization to fit specific requirements.

The most organized video compression effort is being undertaken by the Moving Picture Experts Group (MPEG), which is a working group of (ISO/IEC) in charge of the development of standards for coded representation of digital audio and video. Established in 1988, the group has produced MPEG-1, the standard used by Video CD and MP3 formats, MPEG-2, the standard used within Digital Television set top boxes and DVD technologies, and MPEG-4, a standard for multimedia for the fixed and mobile web.

All MPEG compression algorithms take advantage of the fact that video scenes change little between frames. Therefore, instead of the entire video frame, only the temporal differences are stored or transmitted. The differences between MPEG-1, MPEG-2 and MPEG-4 are on the working resolution (MPEG-2 has twice the resolution of MPEG-1) and the way they treat differences between frames (MPEG-4 compresses more than the other two, resulting in lower picture quality but with considerable gain in size). MPEG-1 and MPEG-2 were designed for applications with a lot more bandwidth than a portable surveillance system can afford. In contrast, MPEG-4, being the newest of the three, was designed for this purpose, i.e., multimedia support for mobile equipment. Unfortunately, for the same reason, the MPEG-4 standard is still open to interpretation. Because of this, there is no interoperability or image-video format exchange between products that claim to be MPEG-4 compliant.

These issues necessitated the exploration and testing of a number of compression solutions during the design stage. The objective was to capture and transmit video and store it in a format that either can be played back or processed through imaging algorithms for vehicle tracking, classification, or extraction of other information. The proprietary implementations of MPEG-4 that were tested, although very successful in compressing the signal and maintaining a good visual quality, lack the translation tools and robustness that allow use of the stored information by other applications. The final implementation, as described later in this report, depends on in-house integration of off-the-shelf hardware components with software applications employing MPEG-4 compression that can be obtained at no cost. This solution afforded considerable latitude to experiment and fine tune the CODEC to achieve the optimal balance between picture quality and bandwidth requirements.

2.3 Communication Technology

Having established the requirements for traffic detection and surveillance, the key component that pulls everything together is the technology that transmits the information from the field to the supervising station. In permanent infrastructures this is accomplished through a web of cables buried in the ground. Such methods are incompatible with the temporary, portable nature of the intended system. With the recent progress in wireless data communications, there are better solutions. The basic functional requirements of the communication technology are as follows:

- Transmits both data and video.
- Supports two-way communications, allowing remote monitoring of the system..
- Deploys in any location on or near the roadway because it does not depend solely on ground-based communications. .
- Relocates easily because of compact, portable design and it operates license free.
- Only requires low power.
- Allows interaction with the system from any location with internet access (optional).

As mentioned in the previous section, a few wireless analog video-transmission devices are available in the market but their cost and the fact that they only support one way communication reduces their applicability in this system. Therefore, alternative options were considered based on the observation that when all information is in digital form (data and digital video), wireless Ethernet radios can be used to establish a two-way link between the field and the supervising station. The basic characteristic of these radios is that they work in pairs. In the case where communication with a single site is desired, a point-to-point wireless link is the best choice. In the case of several deployment sites a point-to-multipoint configuration, although slower, is required. In both of these configurations an Ethernet radio is located on the base side acting as the Access Point and is connected to the Local Area Network (LAN) of the supervising station. Another Ethernet radio is located in the field, acting as the client or subscriber unit and is connected with the station LAN. In the case of a point-to-multipoint configuration one access point can be connected simultaneously with several subscriber units. In metropolitan areas where an infrastructure for wireless computing exists, there might be several access points available.

The major factor that drives equipment selection is bandwidth. While fiber and copper lines provide nearly unlimited bandwidth, wireless solutions are greatly constrained. One of the aforementioned requirements is that the selected solution does not require an FCC license, ruling out several high-gain radios (ample bandwidth). With the recent increase in demand for portable computing, the technologies supporting low-power, license-free, wireless Ethernet radios have increased dramatically (e.g., 802.11a/b/g protocols) [8]. These radios have the same bandwidth constraints of distance, line-of-sight, and interference. The effect of distance is straight forward; longer distances result in lower bandwidths. Radios that require line-of-sight usually achieve the highest bandwidths. The constraints due to interference are the most difficult to overcome. The location of the radio antenna plays a major role in performance. For example, large concrete structures can block the signal; large surfaces like the sides of tall buildings in the path of the signal can deflect it, reducing signal power, increasing noise, and even confusing the receiver with echoes that are out of phase. Even the ground features between receiver and transmitter can play a major role in performance.

We decided to focus on a high-incident-prone area (described in chapter 4) which was fortunately within five miles of our supervising station. We needed more bandwidth and deterministic response to large streams of data. We deployed 802.16 radios operating within the

UNI-II band (5.4 GHz). They use QUAM (Quadrature phase Amplitude Modulation) to encode bits within the RF signal over Time Division Multiplexing (TDM). Under this scheme, each base station is given an equal short time slice (a few milliseconds) over the frequency spectrum range. Data transfer efficiency is at its highest only when there is enough to fill the entire time slice—which is most likely the case during streaming and high transfer rate applications (e.g., streaming video and data transfers from multiple stations).

Chapter 3. System Architecture

A combination of three separate technologies, machine vision (for vehicle detection and measurement), digital video recording, and wireless data transmission comprise the proposed system. A brief description of each module along with the final integrated design is given in this section.

3.1 Detection Module

For implementation of the detection component of the system, the Autoscope Sole Pro machine vision (MV) sensors were selected [9]. The selection of this sensor was based on the results of the second phase of the Minnesota DOT and FHWA's Evaluation of Non-Intrusive Technologies (NIT II) study [7] in which it had the highest ratings and on its reputation, familiarity and support. Except for power and mounting restrictions, there is no limit on the number of MV sensors that can be placed in a single station. Depending on the location of the station (roadside versus tall building or other structure) a single sensor can cover a maximum of 600 feet of roadway with at most eight lanes (regardless of direction) and still maintain high accuracy on individual vehicle-speed measurements. If the latter is not required, this area can increase to a maximum of 1000 feet of roadway. These particular sensors work by establishing regions (virtual detectors) on the video image in which the sensor needs to detect and measure traffic. There is practically no restriction on the number of virtual detectors that can be placed in a single camera view, but for practical purposes one every 100 feet/lane for speed detection is the working limit (closer than that, the speed detectors overlap). The integration of three MV sensors in a single station is shown schematically in figure 3.1. As the figure suggests not all sensors double as surveillance cameras. In addition, since the sensors communicate through a RS-485 port, a converter to Ethernet is required for integration with the LAN.

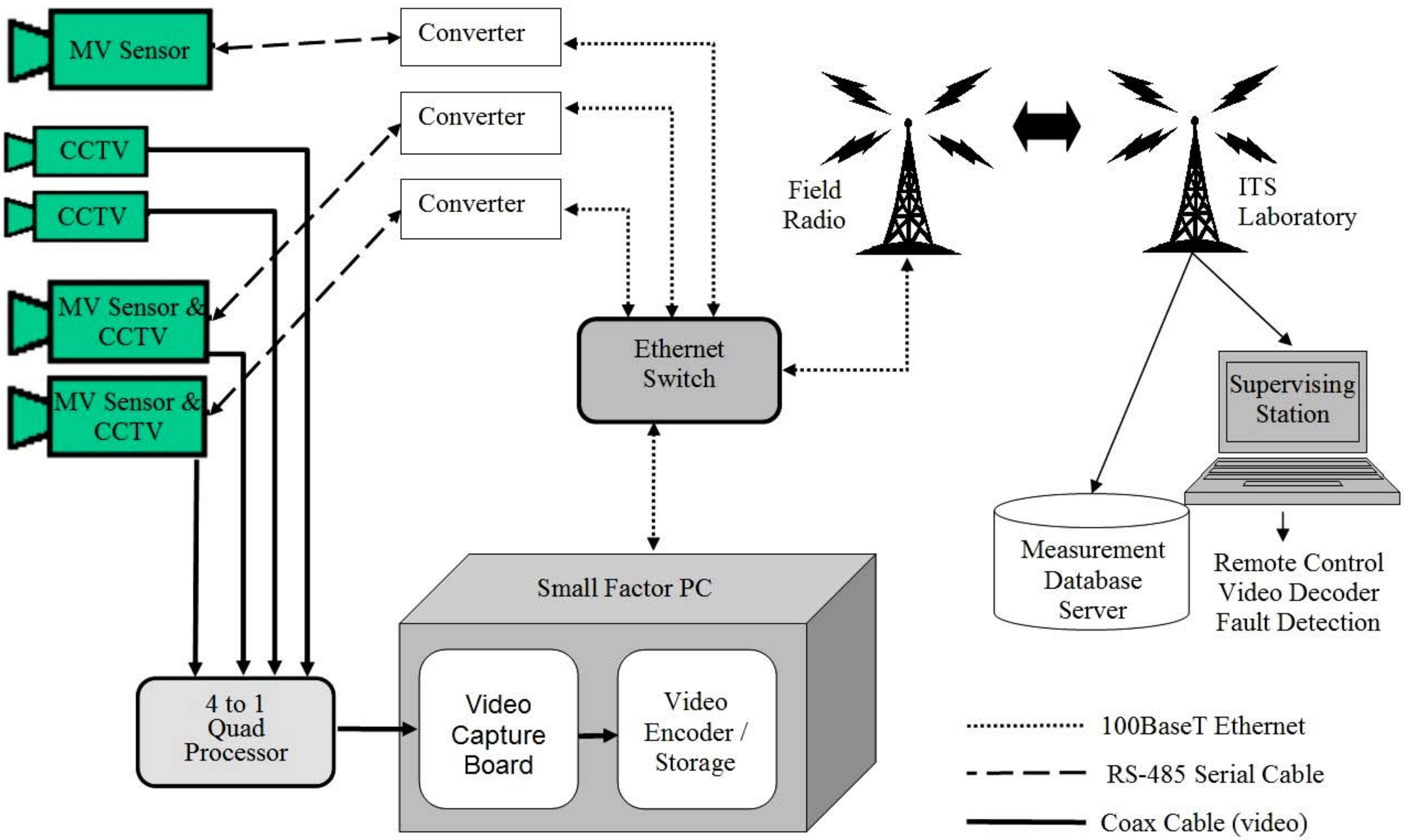

Figure 3.1. Integrated System Architecture

Two types of data are collected by the MV sensors; real-time measurements of presence, speed, headway, and vehicle length as well as flow, time mean speed, space mean speed, density and Level Of service (LOS). These are provided in aggregated total or average form, over a user-specified time period. The sensors can transmit all information in real time back to the supervising station over the wireless link and/or store the aggregated data locally for later download.

3.2 Surveillance Module

The objective of the surveillance module is twofold. First, it has to provide a clear real-time picture of the site that can be transmitted (streamed) back to the supervising station; second, it must save the video in digital form for later viewing or download. In the current application of the system long-term storage is not required for all video as only the sequences containing accidents need to be stored; after quick inspection, only the desired one-hour chunks are downloaded and burned in DVDs.

In the current design a single system can accommodate one or four CCTV cameras. When one camera is used the maximum resolution of the video is 720x480 pixels or D1 as it is known in the industry. With four cameras, each view occupies one quarter of the screen, having a resolution of 352x240 pixels or SIF. In the case of two or three cameras the configuration for four is used. Depending on the user requirements for video streaming, storing, and later manipulation, the four-camera version can either transmit four individual streams each having SIF resolution or combine all four through a quad processor and digitize the combined image on a single D1 resolution. Both versions were tested during the first phase of the implementation. Based on the specific deployment requirements the second version was finally selected. It was achieved through a combination of common off-the-shelf equipment like a small form PC computer with digitizing board and free software applications for MPEG-4 compression and recording. The schematic of the integrated surveillance module can be seen in figure 3.1.

The final configuration is the result of considerable customization, designed to meet additional needs such as seamless vehicle trajectory extraction and testing of new experimental vehicle tracking algorithms.

3.3 Communication Module

The detection and surveillance modules are integrated into a unified system through the communication module. As described in the functional specification section, the most efficient method for this integration is to establish a “mini” LAN at the deployment site. For this purpose the I/O interfaces of the detection and surveillance modules are first translated into Ethernet compatible ones. A common off-the-shelf network switch connects all devices together and forms the LAN.

During the course of the systems’ design a number of different communication solutions had to be explored for functionality and integration testing. These ranged widely in respect to bandwidth which varied from 19Kbps CDPD modems to 30Mbps Ethernet radios. However, because bandwidth is critical in the case of a fully configured system (multiple sensors and cameras), the 30Mbps Ethernet radio was chosen. The key advantage of the proposed architecture is it can be customized to meet specific deployment requirements and connectivity choices and therefore save on equipment cost and installation time. For example, a clear line of sight between the deployment location and the supervising station (or an adjacent tall building)

are likely to be found in metropolitan areas. In this case a single point-to-point (or multipoint) wireless link will perform the best. On the other hand, in cases where there is no clear line of sight, a shorter range Spread Spectrum wireless link can connect the system with the nearest controller or communication cabinet. From that cabinet the information can join the permanent detection and surveillance infrastructure (usually a fiber or Copper SONET network), thereby closing the gap with the supervising station. In extremely rural installations miles away from the nearest telecommunication hub, a simple residential satellite Internet link can be used. Regardless of the variety and combinations of communication mediums, the basic system architecture remains the same, ensuring portability and quick deployment. This architecture was designed to leverage the fact that Internet connectivity has become extremely ubiquitous.
As we will describe in section 4.3, we selected a single point-to-multipoint 30Mbps wireless link for the current system deployment. The wireless link acts both as a router, facilitating connectivity between the field and supervising station LANs, and as a security firewall prohibiting unauthorized access to the field system. The communication module, the integrating agent of the overall system architecture, is shown in figure 3.1.

3.4 Data Management at the Supervising Station

Although not a part of the deployed system, the software running in the supervising station plays an essential role in the operation. When the link between the field system and the supervising station is established, traffic measurements and video begin to arrive. As explained in the surveillance module section, video is preferably stored in the field; therefore a simple FTP connectivity is used to download only the selected files. For real-time surveillance/inspection an off-the-shelf video streaming application is used to transmit video to the supervising station.
The most challenging problem is the traffic measurement retrieval. Specifically, in the case of the systems deployed for the accident study, individual vehicle speeds, headways, and classification information need to be collected every 150-200 feet for a section totaling 2500 feet and to be transmitted in real-time. This process is continuous, 24 hours a day, seven days a week; considering that the particular freeway site carries in excess of 80,000 vehicles daily, the amount of data is enormous. To cope with this, a relational database server has been established at the supervising station along with the necessary software that receives and stores the measurements. To develop such software it is important to select a traffic detection system that is accompanied by a well documented Applications Programmers Interface (API) and a robust Software Development Kit (SDK). The greatest risk in this process is the creation of a bottleneck in the information flow, due to inefficient software. Such an occurrence could result in the interruption of the transmission and loss of information.

Chapter 4. Implementation

Following the initial design, the system was deployed at a 1.7-mile-long freeway site in the Minneapolis/St. Paul area. The site is located at the westbound direction of the I-94 freeway at the I-94/I-35W commons section in Minneapolis between Highway 55 and the Lowry Hill tunnel. The selection of the site was in response to a current accident study which aims to explore the hypothesis that certain accidents (collisions) are caused in part from detectable traffic conditions. If so, they can be prevented by taking actions to improve these conditions, or raise the attention level of the drivers.

I-94 is a connector-type freeway crossing the cities of St. Paul and Minneapolis. It carries daily traffic in excess of 80,000 vehicles per direction and it is congested at least five hours a day, especially in the afternoon peak period. The I-94/I-35W commons is a section where I-94 and I-35W (another major freeway) travel in parallel and a number of short ramps allow transfer from one to the other. An aerial photo of the site is depicted in figure 4.1. The selected site starts approximately 2000 feet before the entrance ramp from southbound I-35W, continues for 1.5 miles downstream and ends at the entrance to the Lowry Hill tunnel. The amount of daily congestion and accidents that occur at this site make it the highest accident rate location in the state of Minnesota [10]; in comparison, the second highest location experiences half the rate of this site. In section B (figure 4.1) excessive weaving takes place due to the high volumes entering from the ramp which combines traffic from 35W, HW55, and downtown Minneapolis. The site includes two entrance ramps and three exit ramps; the average number of lanes is three with a 3000 feet auxiliary lane in the weaving area. In total, four detection and surveillance systems were deployed in two phases for capturing live accidents on video at the selected site. Simultaneously they detected individual vehicles and extracted continuous detailed traffic measurements.

4.1 Initial Deployment

Preliminary investigation identified sections A and B in figure 4.1 as the ones generating the majority of the accidents. From this information two stations were deployed on the rooftops of high-rise buildings A and B, respectively. Details about the buildings and their locations are shown in figure 4.2. Station A is equipped with one MV sensor, doubling as a camera looking east and one regular camera looking west with a field of view that covers halfway to building B. Station B is equipped with two MV sensors and two surveillance cameras. The sensors are pointed down on the roadway east and west of the building (as indicated by the shaded areas in figure 4.1) while the surveillance cameras are observing the same areas but with a lens configuration that provides a much longer field of view.

During this initial deployment the stations were equipped with one commercially available video-streaming and digital video storage device, each based on a proprietary implementation of the MPEG-4 compression algorithm by Stradient. In addition, each station was equipped with a 3Mbps BreezeAccess Ethernet radio subscriber unit by Alvarion for communication with the supervising station.

During the initial period of operation three problems were discovered. The first and most alarming was that the section under observation was not the location of point of impact for the

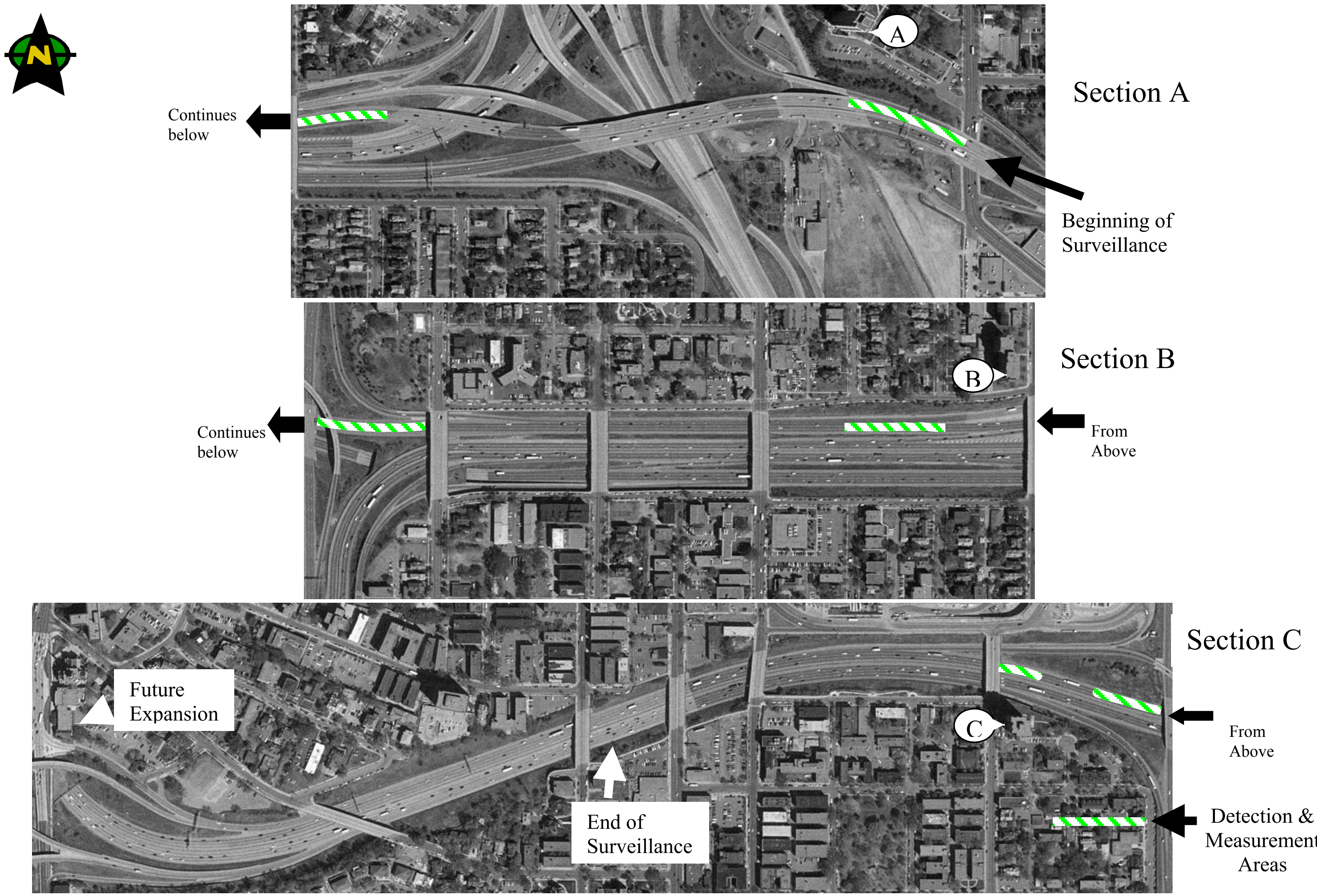

Figure 4.1. Aerial Photo of Deployment Site and System Locations

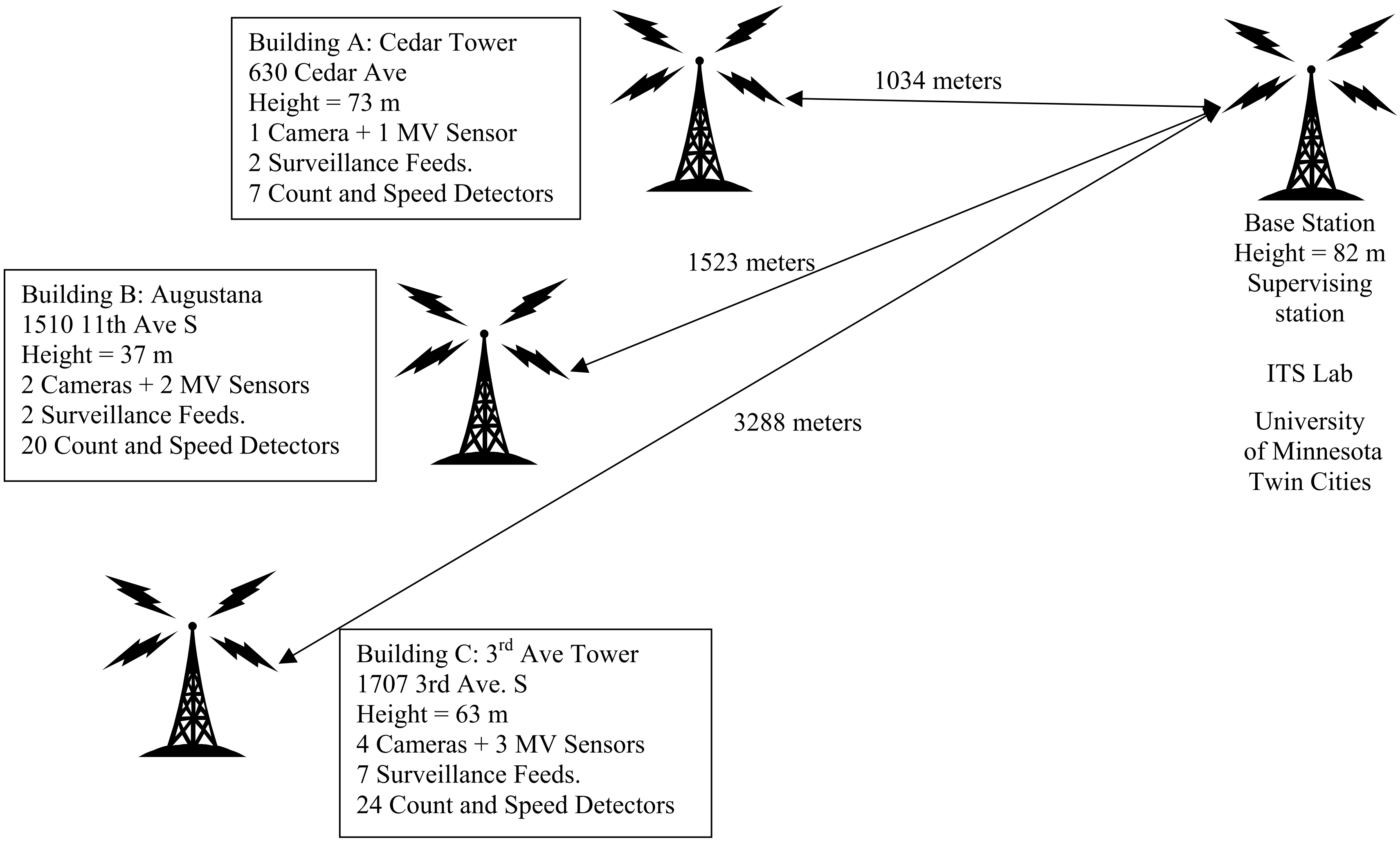

Figure 4.2. Deployment Site Topology

majority of the collisions. As a result only a few accidents were recorded. Second, the realized bandwidth of the selected wireless link was in the range of 1Mbps. This was due to the nature of the particular design which assigns each direction (from and to the base station radio located in the CTS lab) half the available bandwidth, even if the actual data transfer is consistently higher in one direction. The result was very slow communications, prohibiting the streaming of video from all cameras simultaneously. Finally, the third problem arose from the video-streaming device. Although the algorithms employed produce a high quality picture requiring relatively small bandwidth, the video storage format was not compatible with any other image analysis software. This prohibits replaying the video through anything other than the user interface provided by the manufacturers. In addition, the manufacturers did not provide a working SDK which would have allowed in-house authoring of translation utilities to more widely accepted formats.

These particular problems could not have been anticipated at the time of equipment selection. The information gained during the initial deployment proved valuable in selecting surveillance and communications equipment for the second deployment which performed similarly but without the problematic limitations. In addition, we had collected valuable information about the traffic conditions (since the detection module operated reliably). This data, in conjunction with the visual observations, assisted us in selection of the next set of sensors and camera placements substantially improving the accident recording capability. The previously installed stations were also upgraded but not moved as they continued to play an important role—complementing the continuous wide-area coverage of the entire site.

4.3 Second Deployment Phase

After the initial deployment we selected a third rooftop as the next deployment site to complement the area coverage. The rooftop of building C, shown in figure 4.2, is located west of the initial buildings. Because of the ideal location of the building, a large section of roadway is visible from its rooftop, therefore two additional stations were deployed. New wireless links were selected and an in-house video streaming and storage solution was developed without affecting the system design. Specifically, all wireless links at all three sites were replaced with 30Mbps TSUNAMI Ethernet radios (in the new deployment one link services two stations rather than just one)..

The new surveillance module, although conceptually similar to the previous one, was composed entirely of common, off-the-shelf components. Specifically, for portability this surveillance module (figure 3.1) consists of a regular half-height PC compatible with a 1.8GHz Intel Pentium4 processor, with 512MB of RAM and a 60GB HD. A Haupaugge WinTV video capture board, located in one of the two expansion slots of the motherboard, digitizes the signal from the cameras. A license-free video-recording application named VirtualVCR, written by Shaun Faulds and available from the Free Software Foundation, runs under a scheduling application. The video recording employs the DIVx MPEG-4 compression algorithm which is available in the market at minimal cost (less than $50). Since the video capture card has only one input, four video feeds are first combined into one with a video 4-1 quad processor. This video solution was subsequently implemented in all stations. In summary, at the third location, three MV sensors, four surveillance cameras, two quad processors, two video streaming PCs and one wireless link were deployed. All of the MV sensors are doubling as surveillance cameras allowing for seamless coverage of approximately 3,200 feet of roadway.

4.4 Final Deployment Configuration and Data Collected

The four detection and surveillance stations overseeing the deployment site provide detailed data and large amounts of wide-area measurements. In conjunction with the video recordings, this unique database facilitates advanced studies of traffic characteristics, flow dynamics, as well as safety and traffic management concepts. Specifically, the sensors collect and transmit in real time individual vehicle *speed, length*, and *time headway* as well as aggregated every x seconds measurements of *flow rate*, *volume count, time mean speed, space mean speed, space occupancy, density, LOS* and *vehicle class count*. The aggregated measurements can be saved in the sensor for later download. The aforementioned data are collected on a 24/7 basis in six areas of the freeway site as can be seen in figure 4.1. Each of these areas is 300 to 500 feet long and measurements are extracted approximately every 100 feet for a total of 51 detection points (18 series times 3 lanes, plus exit and entrance ramps). To date the laboratory has been operational during a heavy Minnesota winter and a stormy summer season, providing detailed measurements during extreme weather conditions. For purposes of data management,, video recording takes place between 7:00 A.M. and 8:00.P.M. during weekdays and 12:00 P.M. until 8:00 P.M. on Saturdays and Sundays. At the moment not all video is stored long term but selectively as needed. Apart from this, a collection of video from all 11 cameras at important times, days, and weather conditions is stored for future research needs. During the periods of the initial and final deployments a verification of the systems data-collection performance was undertaken by comparing the collected information with the video records. Currently, a more detailed evaluation and calibration is being carried out by comparing speed measurements taken manually with a laser gun with those automatically collected.

The detailed nature of the measurements directly obtained from the MV sensors allows derivation of additional metrics. These metrics take into account traffic flow fluctuations in space and time, and in some cases describe phenomena like shockwaves with greater detail. Some of the metrics currently being calculated for the accident study include Space Mean Speed based on measurements collected over a wide area, Standard Deviation of Speed in space and time, Coefficient of Variation of Speed [11], Standard Deviation of Time and Space Headways, Quality of Flow Index [12], Acceleration Noise [13], Mean Velocity Gradient [14], and Traffic Pressure [16].

To date, 70 accidents have been recorded over a period of nine months along with 74 unreported near misses. With the exception of a few days where transmission was interrupted due to malfunctions of the Ethernet radios, traffic measurements were collected continuously during this period resulting in more than 5000 hours of detailed traffic measurements both microscopic and macroscopic.

Currently, we have identified the location where 90% of the collisions occur, based on the initial measurement analysis and video records. Due to the particular geometry of the section, drivers mainly in the rightmost lane are busy negotiating the difficult weaving area at section B (figure 4.1) and fail to notice on time the shockwaves propagating backwards from section C. Specifically, underneath the Portland Avenue overpass the limited visibility in conjunction with the diversion of attention results in frequent and some times severe rear end collisions. Traffic conditions during and preceding the time of the accident were identified through qualitative observations and quantitative measures based on the measurements collected (individual vehicle speeds and headways). These observations and conclusions would not have been possible without the detection and surveillance stations described here.

Chapter 5. Summary and Conclusions

Since the 1980s, engineers have recognized that systems for temporary detection and surveillance of traffic conditions were needed at construction sites, during special events or communication/sensor failures as an alternative to the permanent sensor and camera systems. In addition, fixed detection and surveillance systems were not suitable for intensive data collection and evaluation. We began looking into developing a portable system to accommodate several simulation, evaluation and safety studies. Commercially available systems that were affordable and ready to deploy could not be found. We decided to develop and deploy a low cost, portable, wireless system for detection, surveillance and data collection.

While this system is compact, easy to deploy and built with off-the-shelf components, perhaps its greatest advantage is that it does not require close proximity to the road simplifying installation and removal. Furthermore, it does not rely on in-pavement sensors or land communications for detection, measurements and data transmission. In addition to temporary surveillance and detection, its rich data collection and simultaneous video recording capabilities open new possibilities for understanding traffic phenomena through rigorous data examination and analysis, rather than incomplete empirical observations.

It is worth noting that actual deployment of the system in its present form takes less than two hours and, weather permitting, can be performed at any time without disrupting traffic. Furthermore, the cost of assembling one system is low in spite of purchasing components at retail prices; for example, the field equipment cost was below $9,000 per single machine vision and surveillance camera station including communications, while the supervisor station which can accommodate multiple systems was below $5,000.

These advantages could lead to more effective traffic management and planning solutions, such as automatic incident detection, identification of accident-prone conditions, improved ramp and corridor control, safety improvements or any others which require hard-to-collect data or observation of random events. Its remote wireless control and data and video recording capabilities render it ideal for central location placement (control centers, counting, maintenance, traffic operations offices, etc.). These capabilities also make it suitable for research purposes such as the accident video and data recording described herein.

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Appendix A:

System Setup and Operations Manual

The following sections describe the steps taken in the design, assembly and deployment of three surveillance and detection stations. Through these steps the system setup and general operation parameters are presented. In the future, users who want to replicate this deployment can follow these steps and use the provided connection diagrams.

Section 1: Hardware List:

-Autoscope Solo MPVs
-Solo Communications Panel (power supply)
-Lantronix Device Servers
-Ethernet Switch
-CDPD modem
-CPU
-RJ45 cables (straight and crossed)
-Serial Cables (null modem, DB9 to DB25)
-Breeze Wireless Local Loop Hardware
-RS-232 to RS-485 converter
-Proxim Tsunami Wireless Hardware
-Quad Processors
-Divx Capture Boxes

Section 2: Installation of Software

There were two main software programs necessary for our configuration of this Autoscope system. They are:

1) Lantronix Comm. Port Redirector Software

The Redirector Software is responsible for creating virtual COMM ports on a computer that can be accessed via Ethernet. One Lantronix Device Server is necessary for every port used.

2) Autoscope Solo V4.00

The Autoscope software connects the scopes to the CPU and allow data transfer between them.

Section 3: Configuring the Lantronix Device Servers

To begin with we started with three device servers, one for each of the Solos. Each of the devices had to be assigned an IP address and various other parameters to operate correctly. Below are the steps for configuring a server. Table 1 shows the parameters programmed into each device server.

1) Connect the Lantronix to the local Switch via RJ45 cable

2) Use a network port login to set the initial IP via the DOS prompt with:
arp –s 128.101.111.190 00-20-4A-64-2A-8B
(the first four groups are the intended IP address and the last six groups are the Ethernet address)

3) Telnet to port 1 via the command:
telnet 128.101.111.190 1

4) Then use the network login command:
telnet 128.101.111.190 9999

5) Immediately press 'enter' to configure the parameter using the menus.
-Set the IP address to 128.101.111.190
-Set the gateway address to 128.101.111.254
-Set the Netmask to 255.255.255.0

6) Once all of these parameters are set you can easily change them through the web page server. This can be accessed simply by typing the assigned IP address in the browser window.

Table 1 shows the values used for each of the three Lantronix servers.

Section 4: Configuring the Port Redirector Software

The port redirector software allows virtual COM ports to be set up via an ethernet connection. Once this software was installed we set up we set up six COM ports (although we only used at most three at a time)

1) Using the 'COM Setup' button in the redirector software, we enabled the first six available ports (COM 2-6)

2) We then selected the COM 2 and clicked the button 'Add IP.' The host is simply the IP address of the Lantronix server you want on it. For us it was 128.101.111.190 on Port 2. The TCP Port is 3000.

3) This was repeated for each of the servers.

Section 5: Setting up the first Autoscope

The first Autoscope was connected directly to the power supply and then to the Comm. port in the back of the computer via a null modem cable. Figure A5.1 shows a diagram of the connections.

Table A5.1: Lantronix Ethernet setings

Server Configuration		
Product	Lantronix Universal Device Server	
Model	Ethernet 1 Channel	
Firmware Version	V4.20	
Serial Number	6410891	
Hardware Address	00-02-4A-64-2A-8B	
IP Address	128.101.111.190	
Subnet Mask	255.255.255.0	
Gateway Address	128.101.111.254	
Port Configuration		
Local Port Number	14000	
Serial Port Speed	115200	
Flow Control	0	
Interface Mode	4C	
Dissconnect Mode	0	
Flush Mode	0	
UDP Datagram Type	Disabled	
Pack Control Byte	Disabled	
Serial Port Settings	Channel 1	
Serial Protocal	RS 232	
Speed	115200 >>	(note this is set to come out of the serial db9
Character Size	8	port on the power supply, set it to 485-2wire
Parity	None	for direct connection with the autoscope)
Stop Bit	1	
Flow Control	None	
Connect Mode Settings	Channel 1	
UDP Datagram Mode	Disable	
UDP Datagram Type	None	
Incoming Connection	Accept unconditional	
Response	Nothing (quiet)	
Starup	Manual Connection	
Dedicated Connection	Channel 1	
Remote IP Address	128.101.111.99	
Remote Port	111	3001(new)
Local Port	14000	3001(new)
Flush Mode Input Buffer (Line to Network)	Channel 1	
On Active Connection	Disabled	
On Passive Connection	Disabled	
At Time of Disconnect	Disabled	
Flush Mode Output Buffer (Network to Line	Channel 1	
On Active Connection	Disabled	
On Passive Connection	Disabled	
At Time of Disconnect	Disabled	
Packing Algorithm	Channel 1	
Packing Algorithm	Disabled	
Idle Time	Pack Algorithm Disabled !	
Trailing Characters	Pack Algorithm Disabled !	
Send Characters	Disabled	
Send Character 01	Not Set	
Send Char 02	Not Set	
Additional Settings	Channel 1	
Send Immediate	Disabled	
Disconnect Mode	Ignore DTR	
Port Password	Disabled	
Telnet Mode	Disabled	
Inactivity Timeout	Disabled	
Inactivity Timer	Not Set	
Terminal Type/Port Pwd		

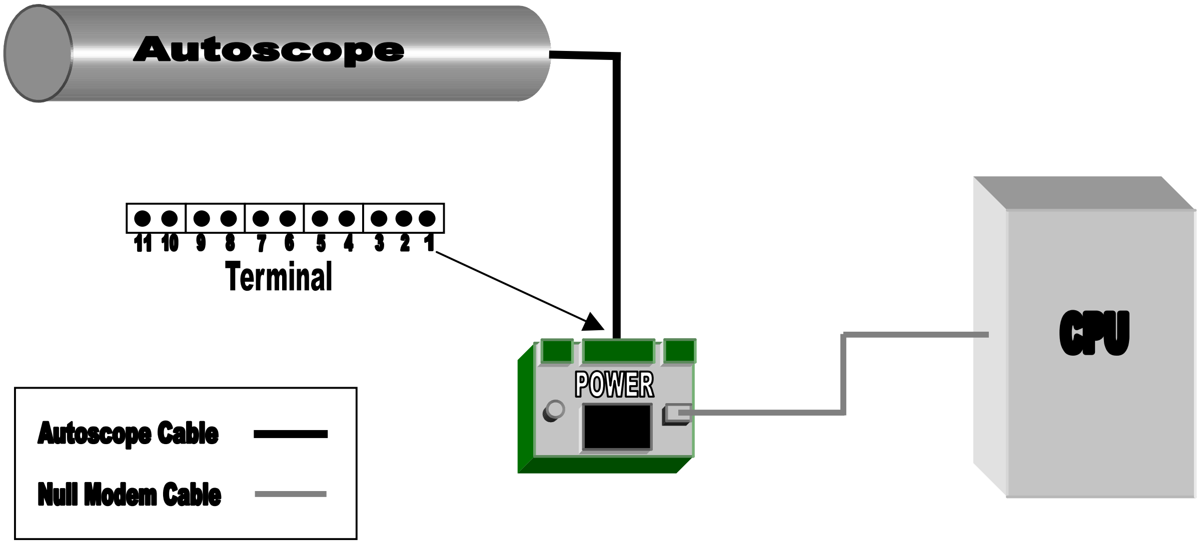


Figure A5.1: Single Autoscope connection diagram

Table A5.2: Single Autoscope Wiring table

Solo MVP ____ (write in MVP number)			Branch Power Cable (write in wire color)	Branch Communications Cable (write in wire color)			Communications Panel	
PIN	PAIR COLOR	WIRE COLOR	WIRE COLOR	PAIR	PAIR COLOR	WIRE COLOR	SIGNAL	TERMINAL
A	BRN/BLK	BRN	*Black*				24V PWR	1
B	BRN/BLK	BLK	*White*				24V RTN	2
N	----	GRN/YEL	*Grn/Yel*				EARTH GND	3
P	BLU/BLK	BLU		1	*BLU/WHI*	*BLU*	SUP RX+	4
U	BLU/BLK	BLK		1	*BLU/WHI*	*WHI*	SUP RX-	5
D	RED/BLK	RED		2	*ORG/WHI*	*ORG*	SUP TX+	6
R	RED/BLK	BLK		2	*ORG/WHI*	*WHI*	SUP TX-	7
F	YEL/BLK	YEL		3	*GRN/WHI*	*GRN*	DET+	8
E	YEL/BLK	BLK		3	*GRN/WHI*	*WHI*	DET-	9
J	WHI/BLK	WHI		4	*SLA/WHI*	*SLA*	VIDEO+	10
H	WHI/BLK	BLK		4	*SLA/WHI*	*WHI*	VIDEO-	11

After the Autoscope connections have been made, the next step was to adjust the setting of the solo. This is done through the Autoscope Solo V4.00 software. With the scope power on, we started the software. Right click on the COMM port that the scope is connected to and click 'learn channel'. Once the Autoscope is found, the next step was to right click on the Autoscope itself and highlight 'properties'. We then set our description to 'Mobile 1.' Then under the communications tab, we set the IP address, connection type, baud rate, and sensor number. Then under regional settings we set the Time Zone and Location. This process was repeated for each of the three autoscopes. Table A5.2 shows the settings used for each.

Table A5.3: Three Scope network setup

Autoscope Table

	Scope 1	**Scope 2**	**Scope 3**
Description	Mobile 1	Mobile 2	Mobile 3
etwork Address	128.101.111.191	128.101.111.193	128.101.111.195
Connection Type	Direct Connection	Direct Connection	Direct Connection
Baud Rate	115200	115200	115200
Sensor Number	1	1	1
Time Zone	Central Time	Central Time	Central Time
Country	USA	USA	USA
State	Minnesota	Minnesota	Minnesota
City	Minneapolis	Minneapolis	Minneapolis

Once we had one Autoscope operating correctly connected via a null modem cable we had to test the delay between transfer of images. Here is the table of data:

Autoscope to Power Supply to CPU via Null Modem Cable

Series 1		Series 2		Series 3	
Trial	Time(s)	Trial	Time(s)	Trial	Time(s)
1	3.86	1	3.91	1	4
2	4.05	2	4.08	2	3.99
3	3.95	3	4.04	3	3.95
4	4.02	4	3.88	4	4
5	4.04	5	4.02	5	4.04
6	4.05	6	3.97	6	3.95
7	3.99	7	4.03	7	4.1
8	3.99	8	4.05	8	3.83
9	4.02	9	4.04	9	3.97
10	3.99	10	3.98	10	4
Total(sec)	39.96	Total(sec)	40	Total(sec)	39.83
	Grand Total(sec)		119.79		
	Average Delay(sec)		**3.993**		

Section 6: Connecting the Autoscopes via Lantronix

In order to connect the autoscopes using the Lantronix, the four transmit and receive data wires from the Autoscope must be spliced off in to a 485-4wire 25 pin male serial connector. Here is the diagram of the wire hookup.

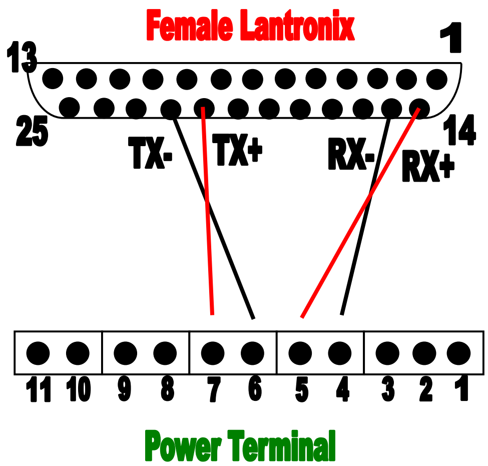


Figure A6.2: Lantronix to Autoscope wiring

An overall layout of the system looks like this:

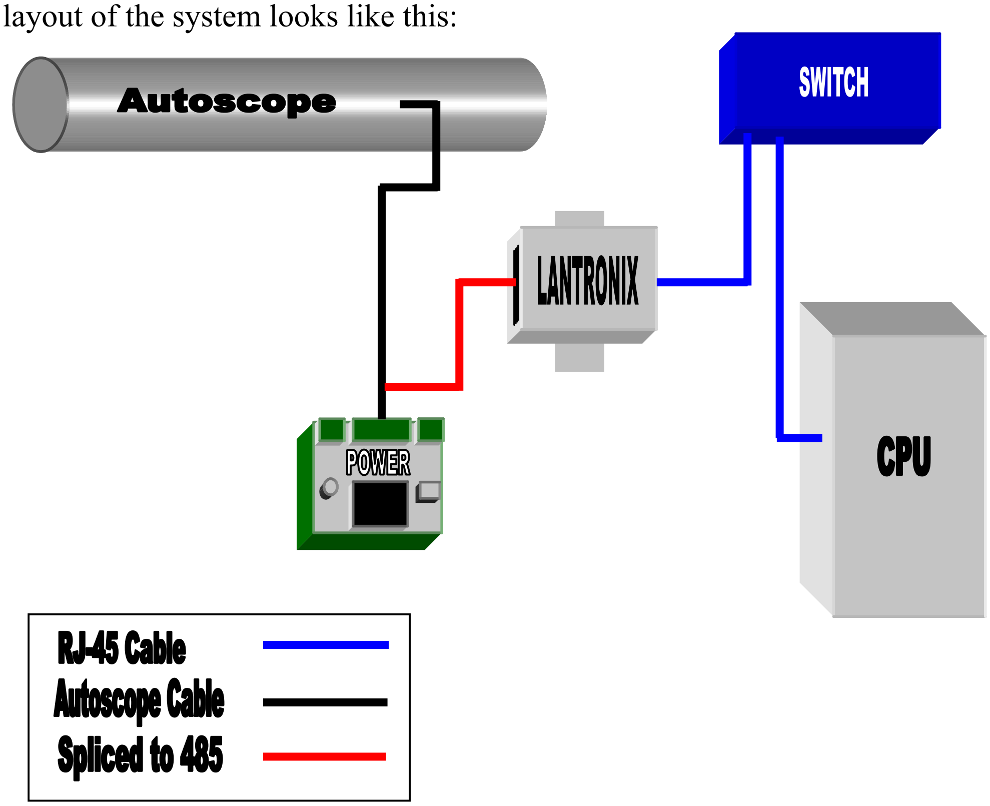


Figure A6.3: Autoscope Ethernet connection

We are using Lantronix # 1 with an IP address of 128.101.111.190. Since the Lantronix will be accepting a 485 signal directly from the Autoscope (the 485 to 232 converter in the Autoscope power supply is bypassed) we must set the Serial Protocol on the Lantronix to accept a 485 input. This is done through the Lantronix internal web page. The Lantronix was then connected to the switch via an RJ45 cable. Because we are now using the Lantronix devices, we now have to start using are virtual ports. Then we had to set Lantronix #1 to COMM port 2.

Once the Lantronix was operating correctly we tested the delay of the transfer of the jpeg images from the Autoscope to the CPU. Here is the table of data:

Table A6.4 Comminication delay measurements

Autoscope to Power Supply to Lantronix(via485) to Switch(viaRJ45) to CPU(via RJ45)

	Trial 1		Trial 2		Trial 3
1	6.38	1	6.85	1	6.99
2	7.02	2	7.45	2	7.48
3	6.54	3	7.51	3	6.93
4	6.95	4	7.05	4	7.53
5	7.52	5	6.48	5	7.96
6	6.55	6	7	6	6.66
7	7.98	7	7.03	7	6.94
8	7.56	8	6.51	8	7.49
9	6.46	9	6.99	9	7.07
10	7.47	10	7.49	10	7.97
Total(sec)	70.43	Total(sec)	70.36	Total(sec)	73.02
	Grand Total(sec)		213.81		
	Average Delay(sec)		**7.127**		

The other two autoscopes were then connected in the exact same fashion. Scope number two was connected to Lantronix #2 on port 3. Scope number 3 was connected to Lantronix #3 on port number 4.

Section 7: Testing the Lantronix Port Parameters

The next step was to test the effect of changing the port parameters through the Lantronix Web Server. Here is a table of Results. This was tested for the preceding configuration.

Table A7.5 Communication configurations

Packing Algorithm Tests

	Parameter	Tested	Result
Configuration 1	Packing Algorithm Idle Time	Enabled 12ms	Delay = 9 seconds
Configuration 2	Packing Algorithm Idle Time	Enabled 52ms	Delay = 12 seconds
Configuration 3	Packing Algorithm Idle Time	Enabled 250ms	Delay = 21 seconds
Configuration 4	Packing Algorithm Idle Time	Enabled 5000ms	Delay = A Lot
Configuration 5	Packing Algorithm Idle Time Trailing Char	Enabled 12ms One	Delay = 10 seconds
Configuration 6	Packing Algorithm Idle Time Trailing Char	Enabled 12ms Two	Delay = 10 seconds
Configuration 7	Packing Algorithm Idle Time Send Char	Enabled 12ms Enabled	Delay = 10 seconds
Configuration 8	Packing Algorithm Idle Time Trailing Char Send Char	Enabled 12ms One Enabled	Delay = 10 seconds
Configuration 9	Send Char	Enabled	Delay = 9 seconds

Section 8: Connecting Three Autoscopes Through Three Device Servers

The next step was to connect all three Autoscope through three different Lantronix servers. They are all hooked up exactly the same as Phase VII, just three fold. Here is a diagram of the configuration:

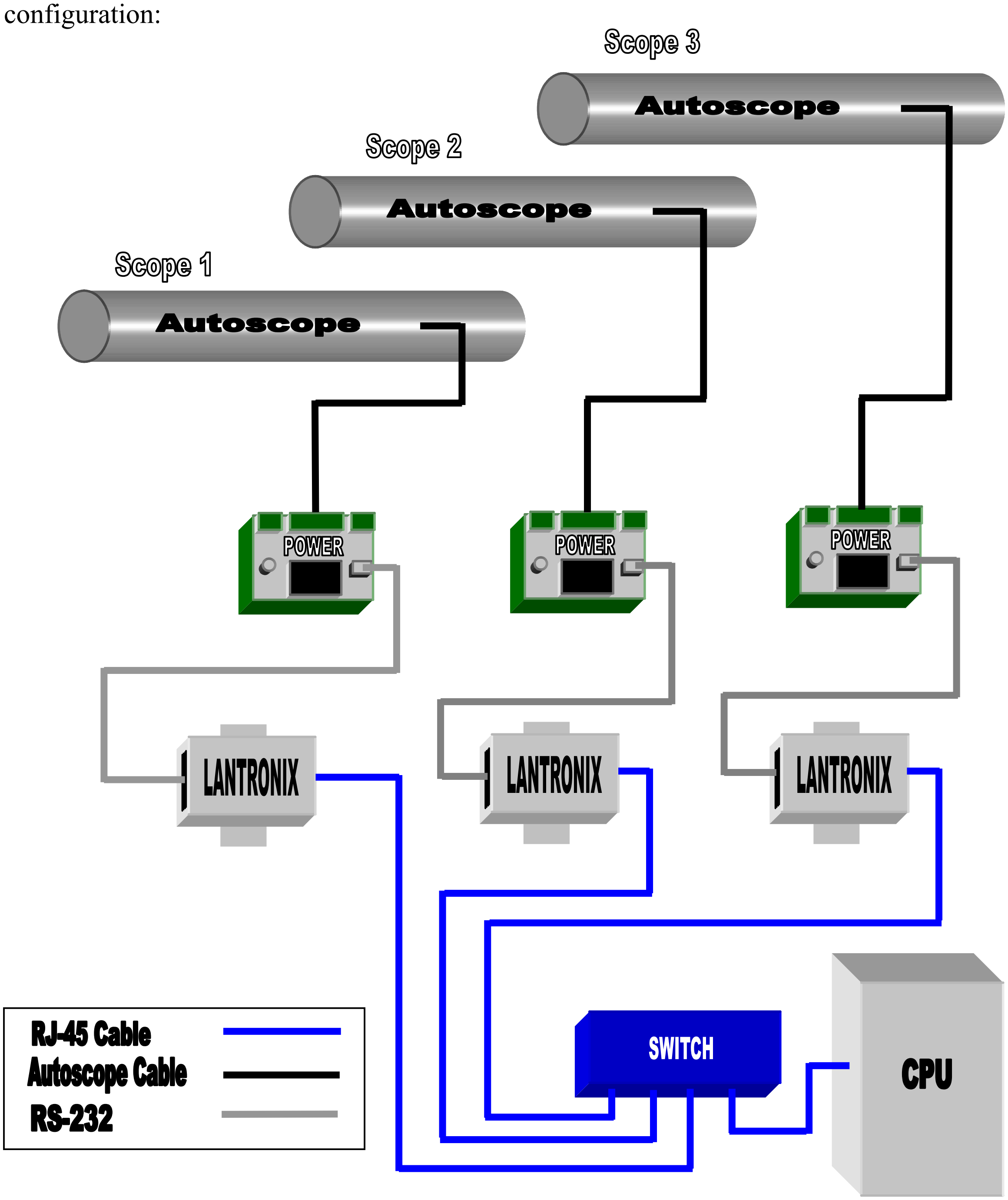
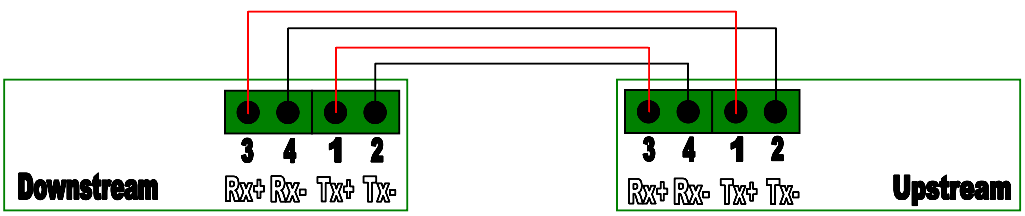


Figure A8.1: Three Autoscope Ethernet connection verison A

Section 9: Connecting Three Autoscopes through One Device Server

Next we connected all three scopes using one COMM port. This was done by networking the upstream and downstream connectors on the power supplies. The autoscopes were all connected to their respective power supplies with the standard connections. Scope three is the furthest downstream so it's downstream connectors are not used, likewise, scope one is the furthest upstream so its upstream connectors were not used. Note that power supply 1 is not functioning correct. It only operates correctly when it is in the most upstream position. This is not a problem for our configuration. Also note that the Lantronix is connected to the furthest upstream power supply. This is done via RS232 connection, which had to be changed in the Lantronix web page. The next step was to connect the upstream and downstream cables via twisted pair connections. This is shown in the diagram below:



Here is a diagram of how the entire system is hooked up:

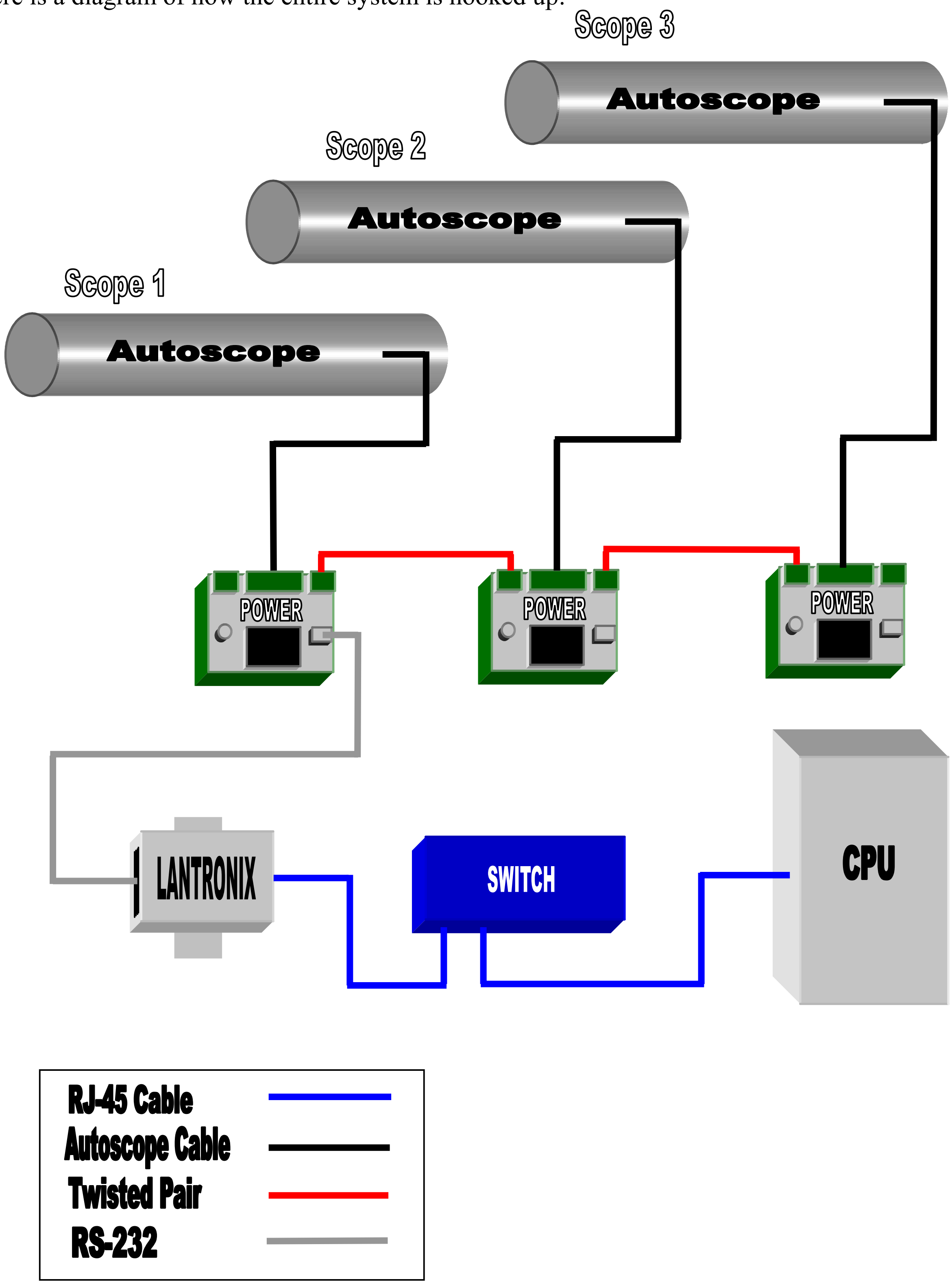


Figure A9.2: Three Autoscope Ethernet connection version 2

Section 10: Wireless Network Setup

The wireless network is a fairly simple next step. It is very similar to the previous setup with the exception of a wireless base station hooked into the switch, and a wireless communication panel hooked to Autoscope 1. Here is the diagram of the setup:

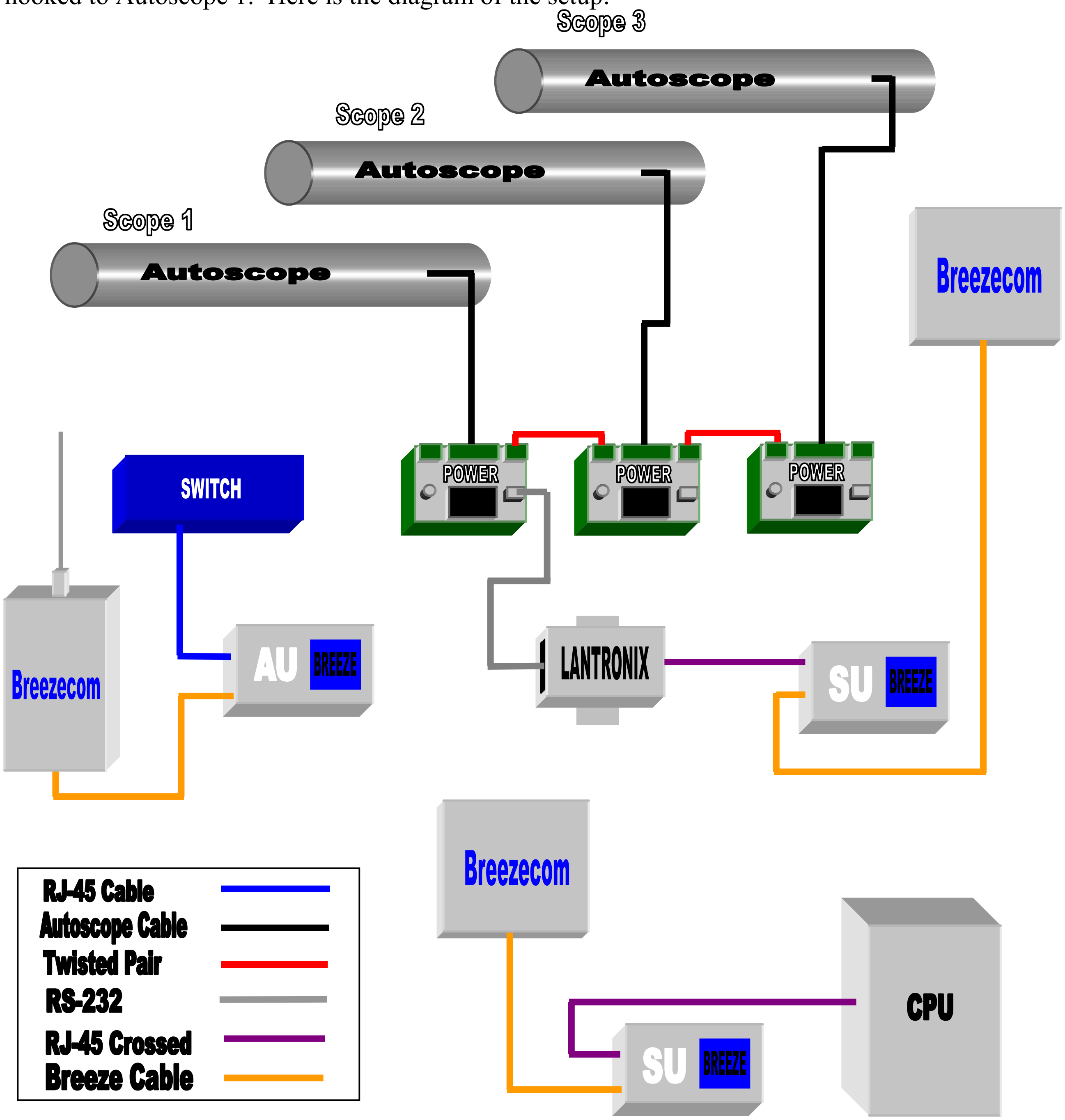


Figure A10.1: Three Autoscopes Wirelless Ethernet connection version 2

Similar Delay Tests were performed under the previous wireless configuration. The results were a significant delay in the transfer of images. We believe however that the majority of the delay is due to the upstream/downstream configuration. Virtually the same amount of delay was seen in the same configuration without the wireless apparatus. Here are the results:

Table A10.1 Network comminication delays

Wireless Network

	Mobile 1		Mobile 2		Mobile 3
1	24	1	21	1	25
2	25	2	20	2	26
3	25	3	19	3	26
4	25	4	21	4	23
5	23	5	21	5	24
6	25	6	20	6	23
7	23	7	22	7	26
8	26	8	20	8	26
9	25	9	18	9	23
10	25	10	21	10	24
11	23	11	18	11	24
12	26	12	18	12	22
13	24	13	23	13	23
14	26	14	19	14	26
15	25	15	20	15	27
16	25	16	19	16	22
17	28	17	20	17	26
18	26	18	21	18	21
19	25	19	20	19	25
20	27	20	21	20	26
Total(sec)	501		402		488
Ave(sec)	**25.05**	**Ave(sec)**	**20.1**	**Ave(sec)**	**24.4**
	Total Ave(sec)		**23.18333**		

Section 11: Portable Configuration for Traffic Detection (no video)

Several factors had to be taken into account before determining the final configuration. Factors such as: delay, size, power consumption, etc. Our final configuration makes use of the RS485 direct connection from the autoscopes to the lantronixes. Scope one and two will be using the wireless configuration and scope three will be use a direct RS485 connection from the camera. The output from the two lantronixes and form camera one will then be connected in parallel and fed into the RS485 to RS232 converter. The 232 signal is then connected either directly to COMM 1 in the back of the computer or will be fed into the Raven CDPD wireless modem. Here it will be broadcast to the U of M Network and fed into another Lantronix which will convert the Ethernet signal back to RS-232 and into the COMM port of the CPU. Here is the diagram of the setup:

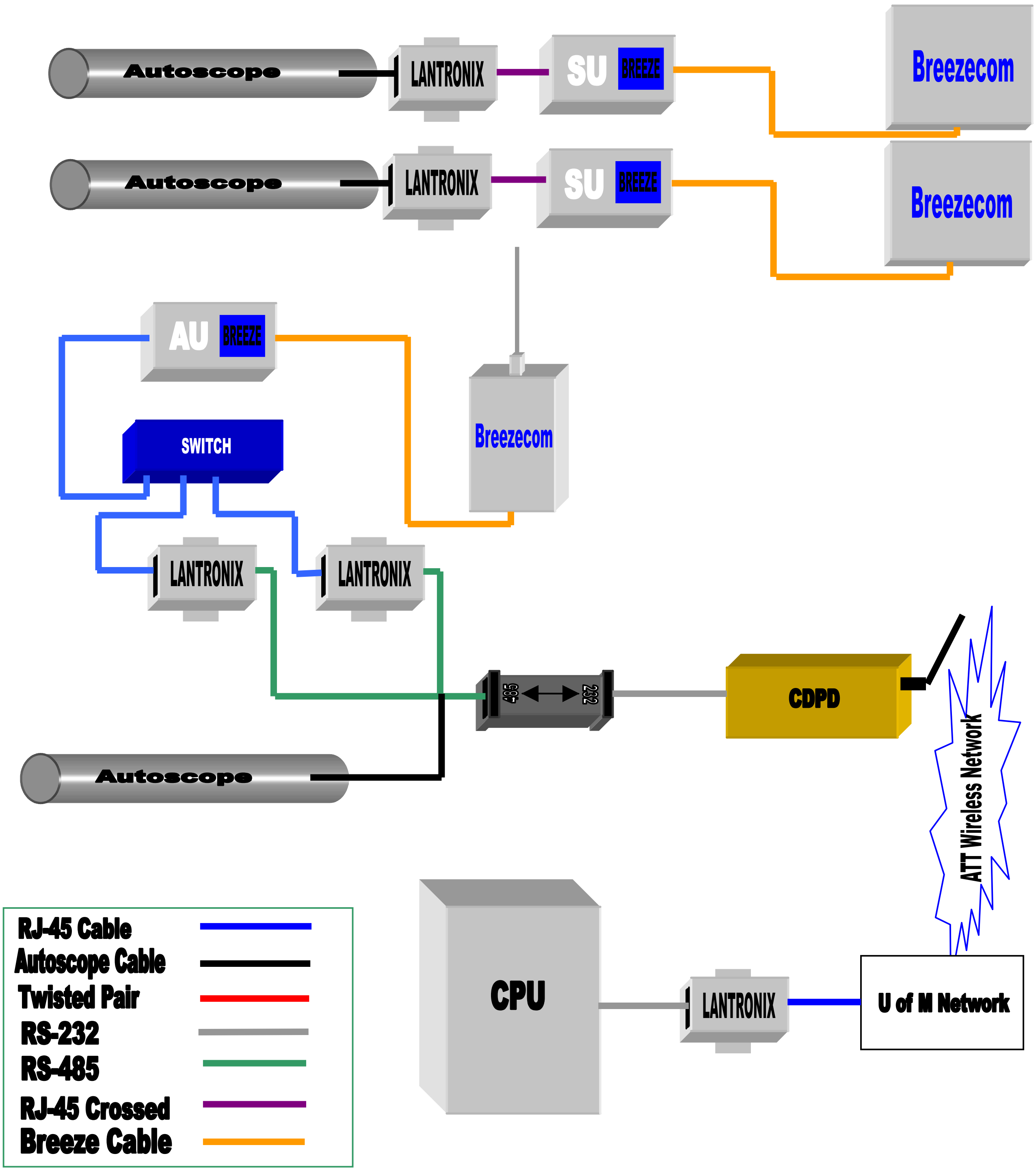


Figure A11.1: Long distance Wireless Autoscope configuration

Note the power supplies have been omitted

Power Measurements

The next phase was to measure the consumption of each of the components and then together as units. Here
Are the results graphically:

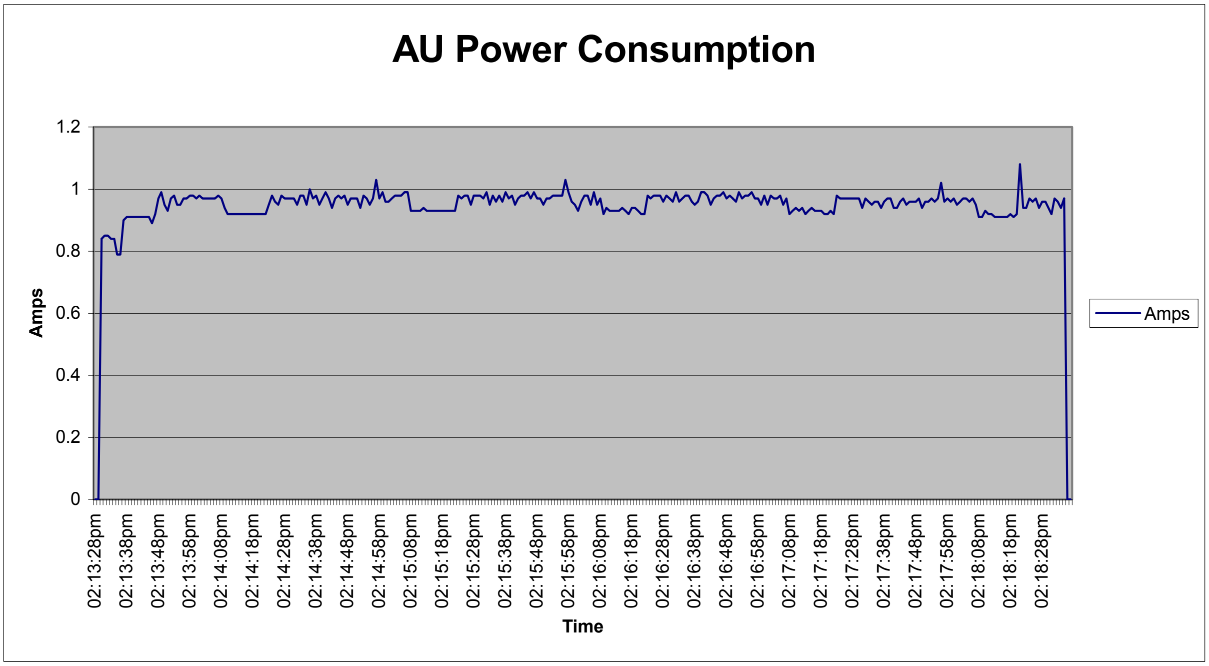


Figure A11.2 Acces point power consumption

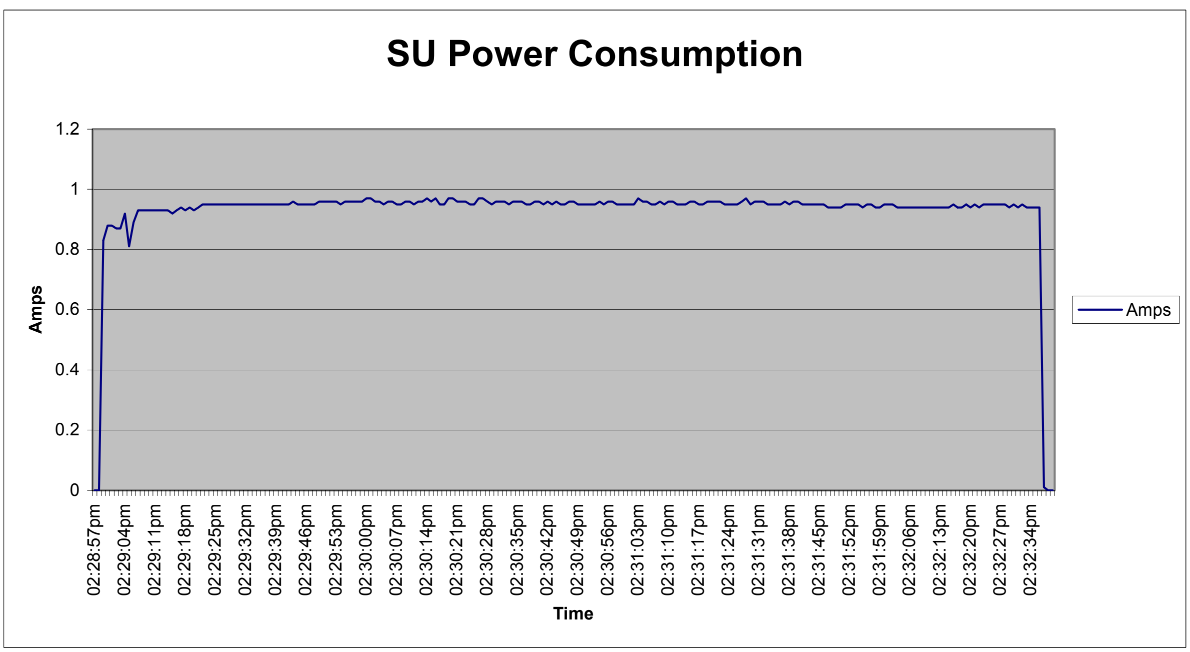


Figure A11.3 Subscriber unit power consumption

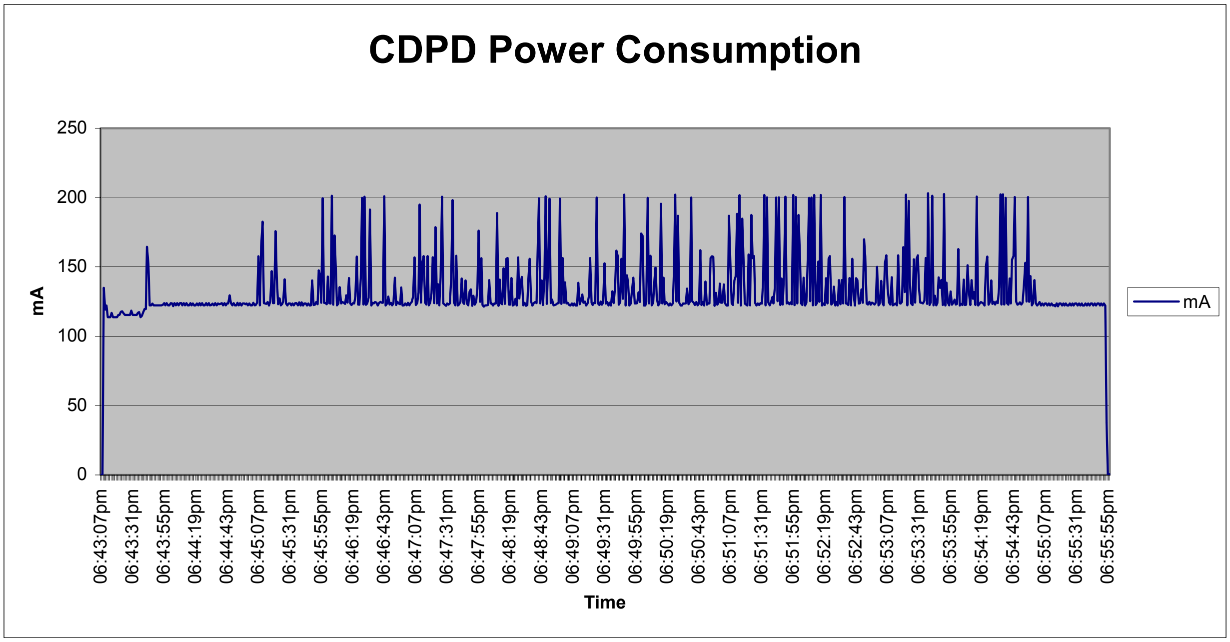


Figure A11.4 Cellular Modem power consumtion

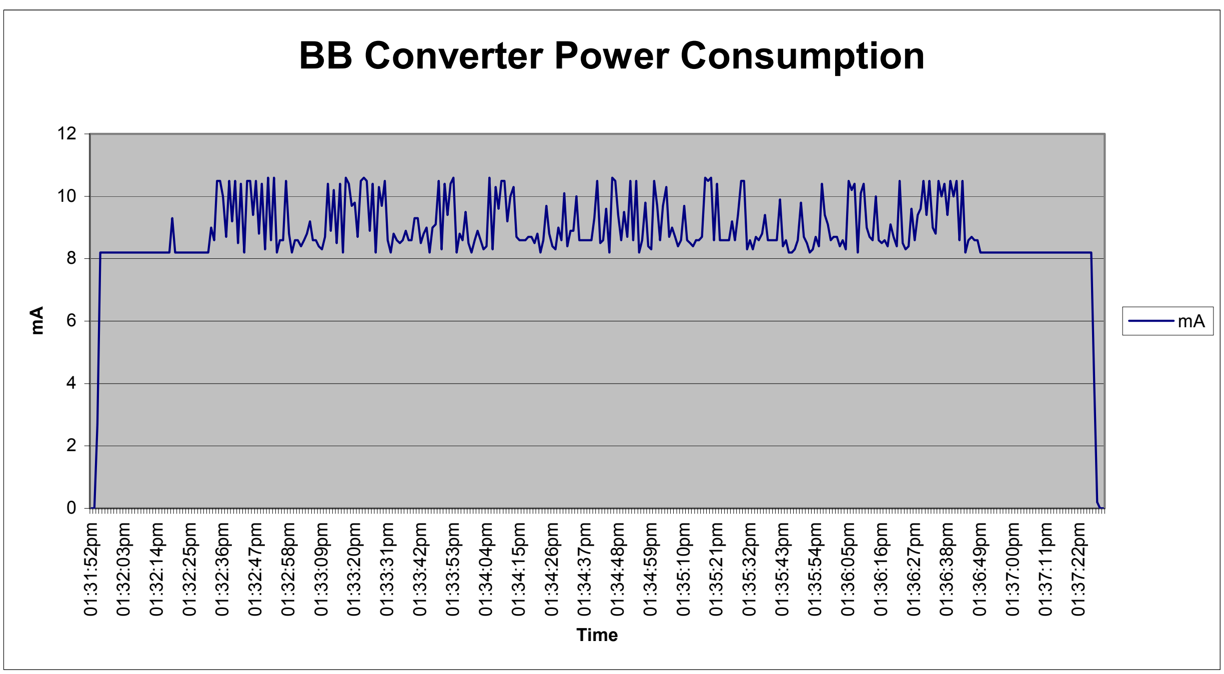


Figure A11.5 RS485 to RS232 Convertere power consumption

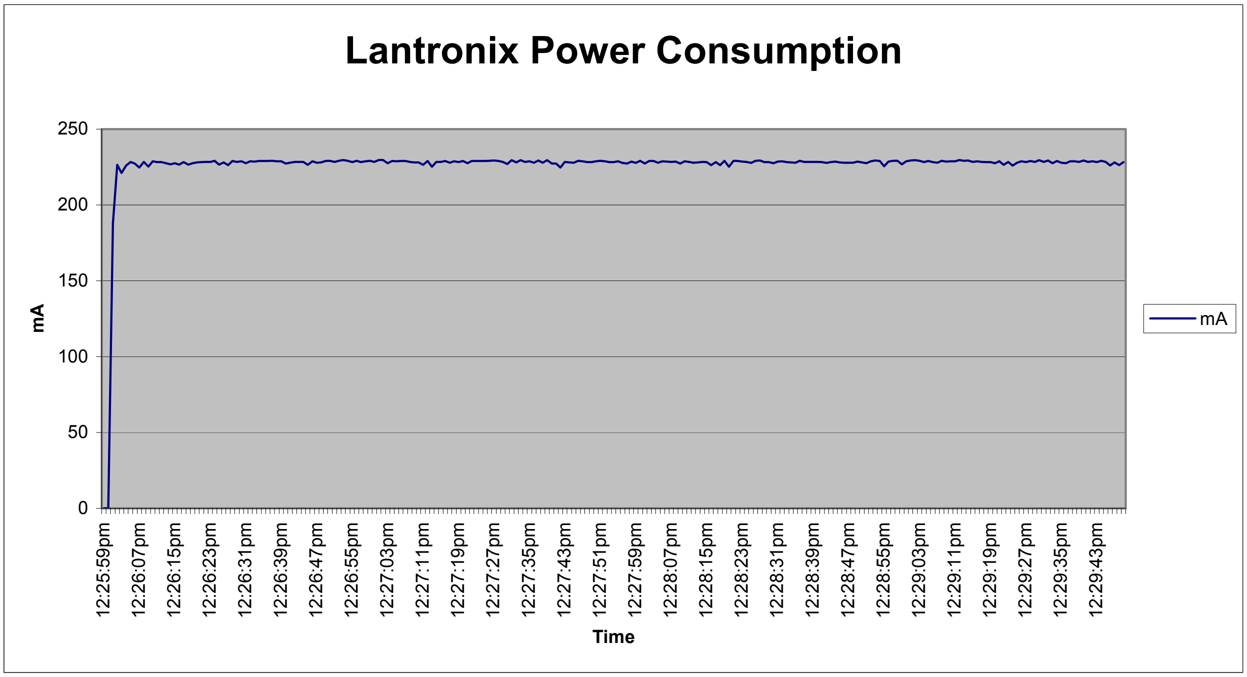


Figure A11.6 Lantronix server power consumption

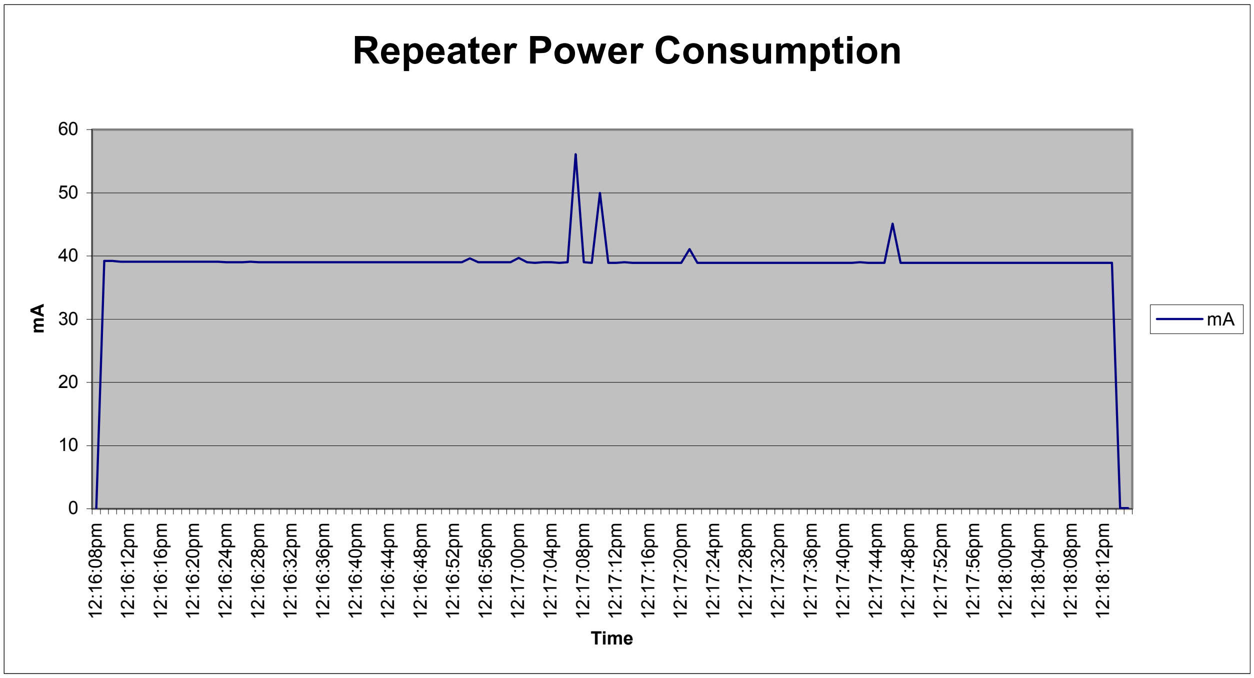


Figure A11.7 Repeater power consumption

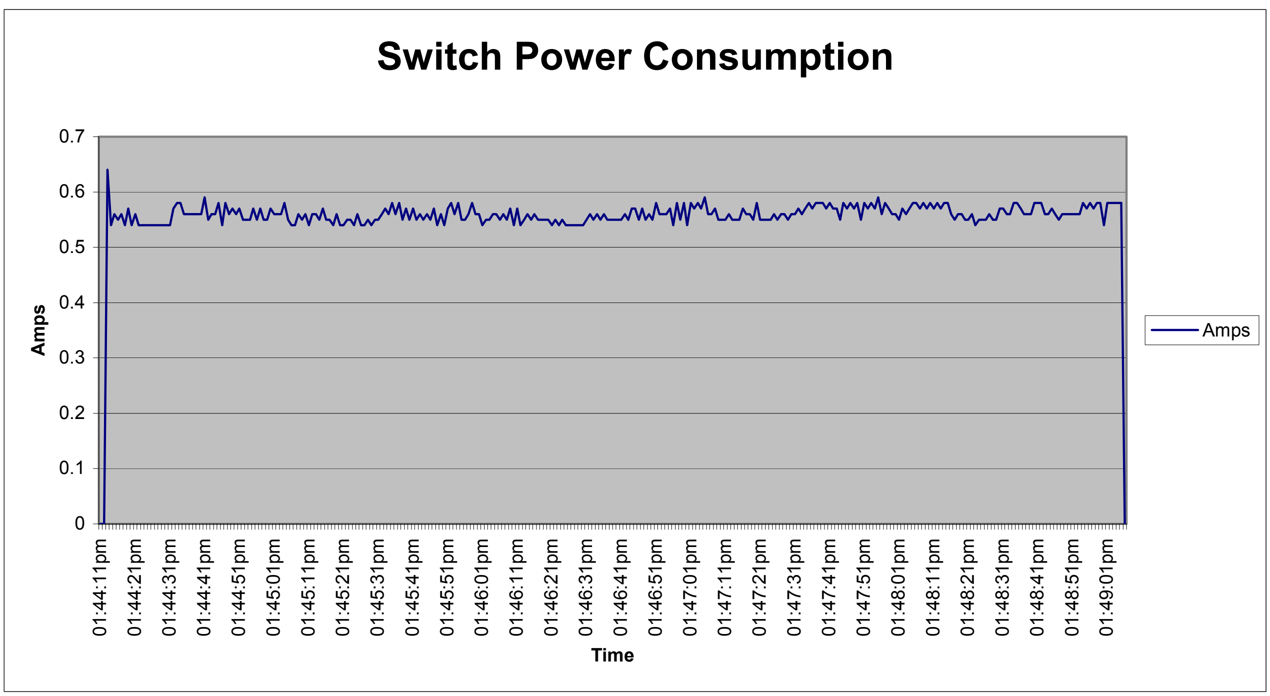


Figure A11.7 Ethernet switch power consumption

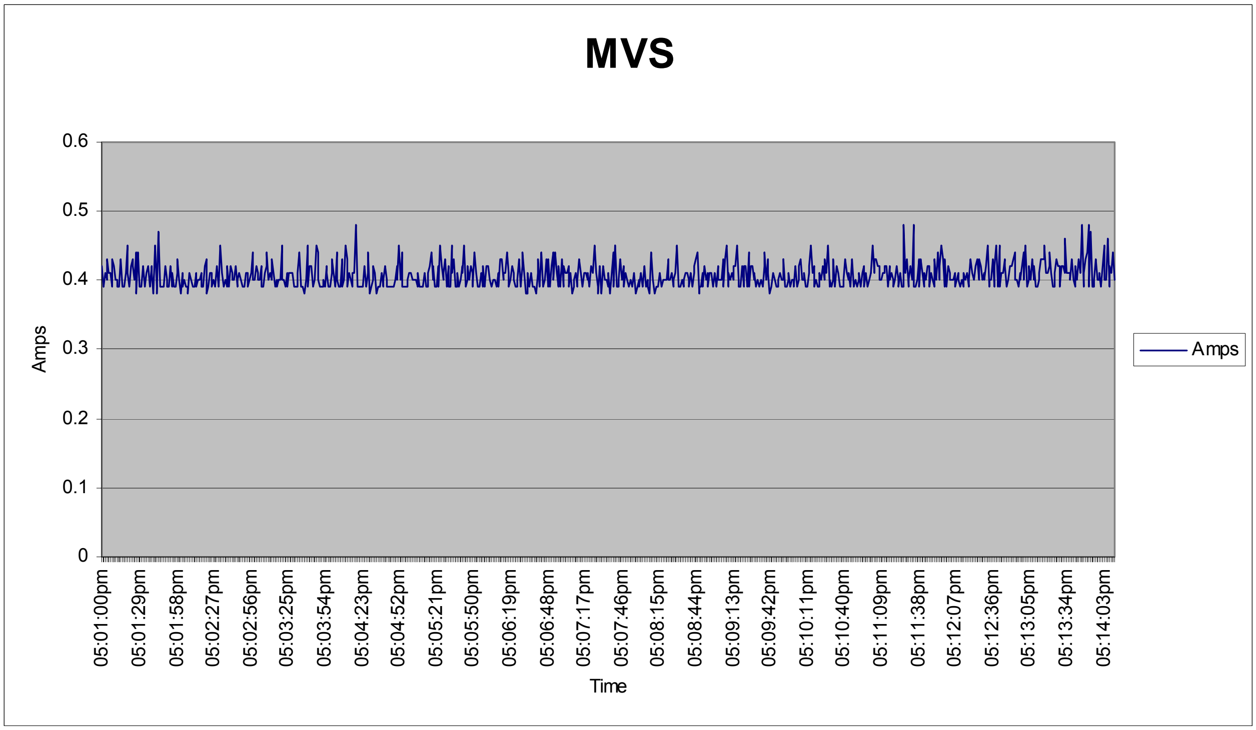


Figure A11.8 Machine Vision Sensor power consumption

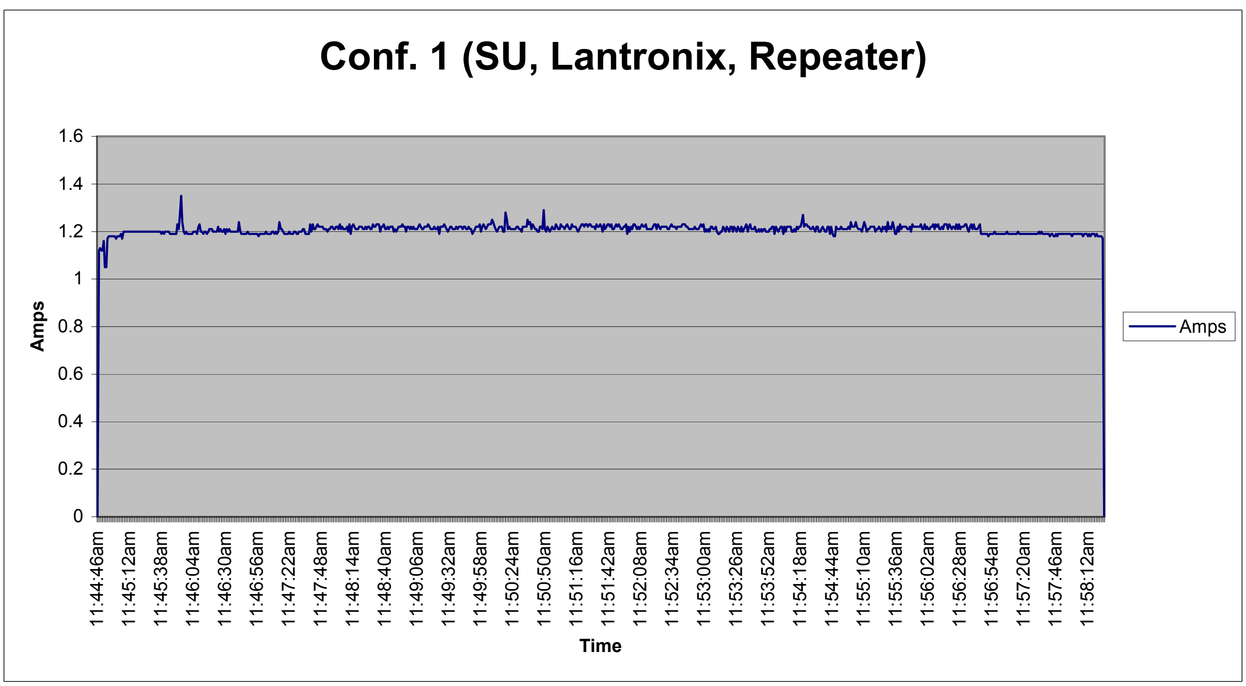


Figure A11.9 Configuration 1 cumulative power consumption

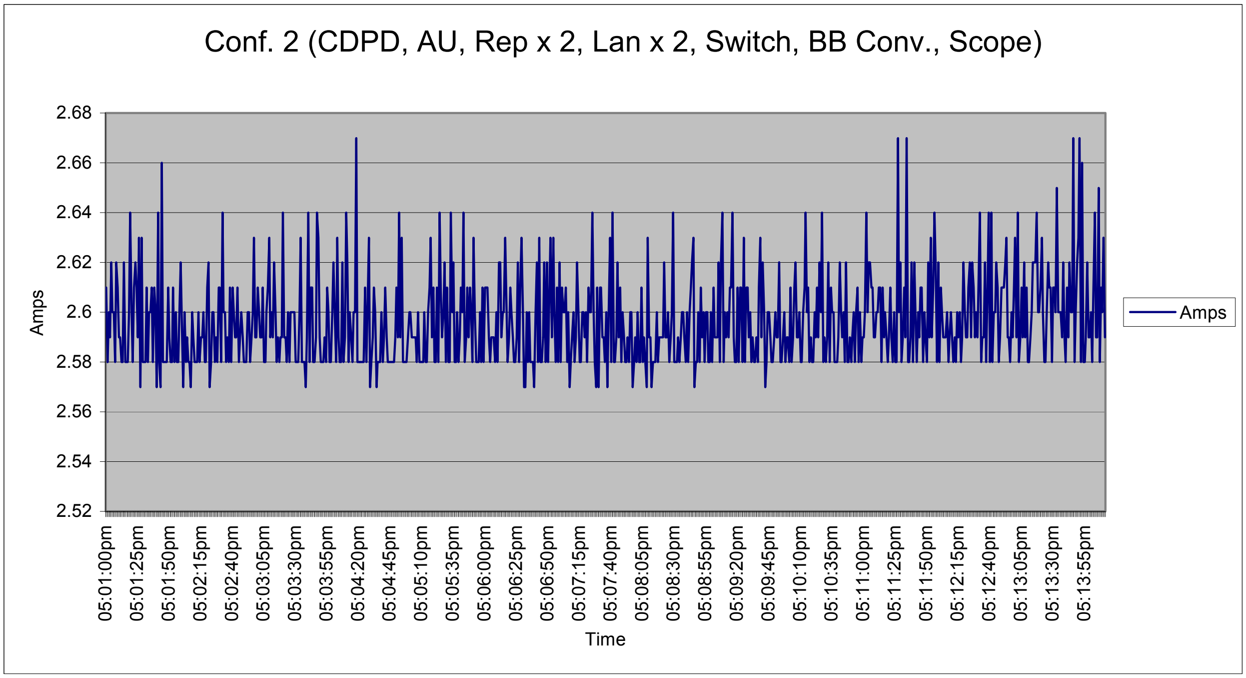


Figure A11.10: Configuration 2 cumulative power consumption

Summary of Consumption:

AVERAGE AMPERAGE (A)	
AU	0.953594771
BBCONV	0.008913772
CDPD	0.132897778
LAN	0.228062882
SUAMPS	0.947889908
REP	0.0392656
SWITCH	0.560068259
SCOPE	0.406434113
CONF 1 *	1.208190709
CONF 2 **	2.596565657

*Consists of the SU, Lantronix, and Repeater

1) **Consists of the CDPD, AU, Repeater x 2, Lantronix x 2, Switch, BB Converter, and Autoscope)

Connection Pin-outs and Circuit Board Design:

To maximize space and order, it was opted to design a circuit board to house the components in Configuration 2. All of the components wired together consisted of 9 basic nets. These nets are listed below for ease of connection:

The circuit board was designed using Orcad Layout. It uses three of the nets (2, 3, and 4). Two repeaters, two lantronixes, one converter, 1 AU, and the network switch are all mounted to the board and interconnected through the board itself (with the exception of the RJ45 connections, which will just use regular cable). Here is the printed layout the board. Note that the green layer is the top and the red is the bottom.

Table A11.2 Long distance Autoscope station connection table

NET 1

Raven	BB 232
1	4
2	2
3	3
4	6
5	7
6	20
7	8
8	8
9	10

NET 2

BB 485	Rep 1	Rep 2	Lan 90
2	IN A-	IN A-	22
14	IN B+	IN B+	(*) 21
5	OUT A-	OUT A-	15
17	OUT B+	OUT B+	(*) 14

NET 3

Rep 1	Scope 3	
OUT A-	BLACK	pair
OUT B+	RED	
IN A-	BLACK	pair
IN B+	BLUE	

NET 4

Rep 2	Lan 92
OUT A-	22
OUT B+	21
IN A-	15
IN B+	14

NET 5

COM 1	Lan 196
1	8
2	3
3	2
4	20
5	7
6	6
7	4
8	5
9	22

NET 6

	Scope 1	Rep 3
pair	RED	OUT B+
	BLACK	OUT A-
pair	BLUE	IN B+
	BLACK	IN A-

NET 7

Rep 3	Lan 190
OUT B+	21
OUT A-	22
IN B+	14
IN A-	15

NET 8

	Scope 2	Rep 4
pair	RED	OUT B+
	BLACK	OUT A-
pair	BLUE	IN B+
	BLACK	IN A-

NET 9

Rep 4	Lan 192
OUT B+	21
OUT A-	22
IN B+	14
IN A-	15

*Include a 300ohm resistor in series for termination.

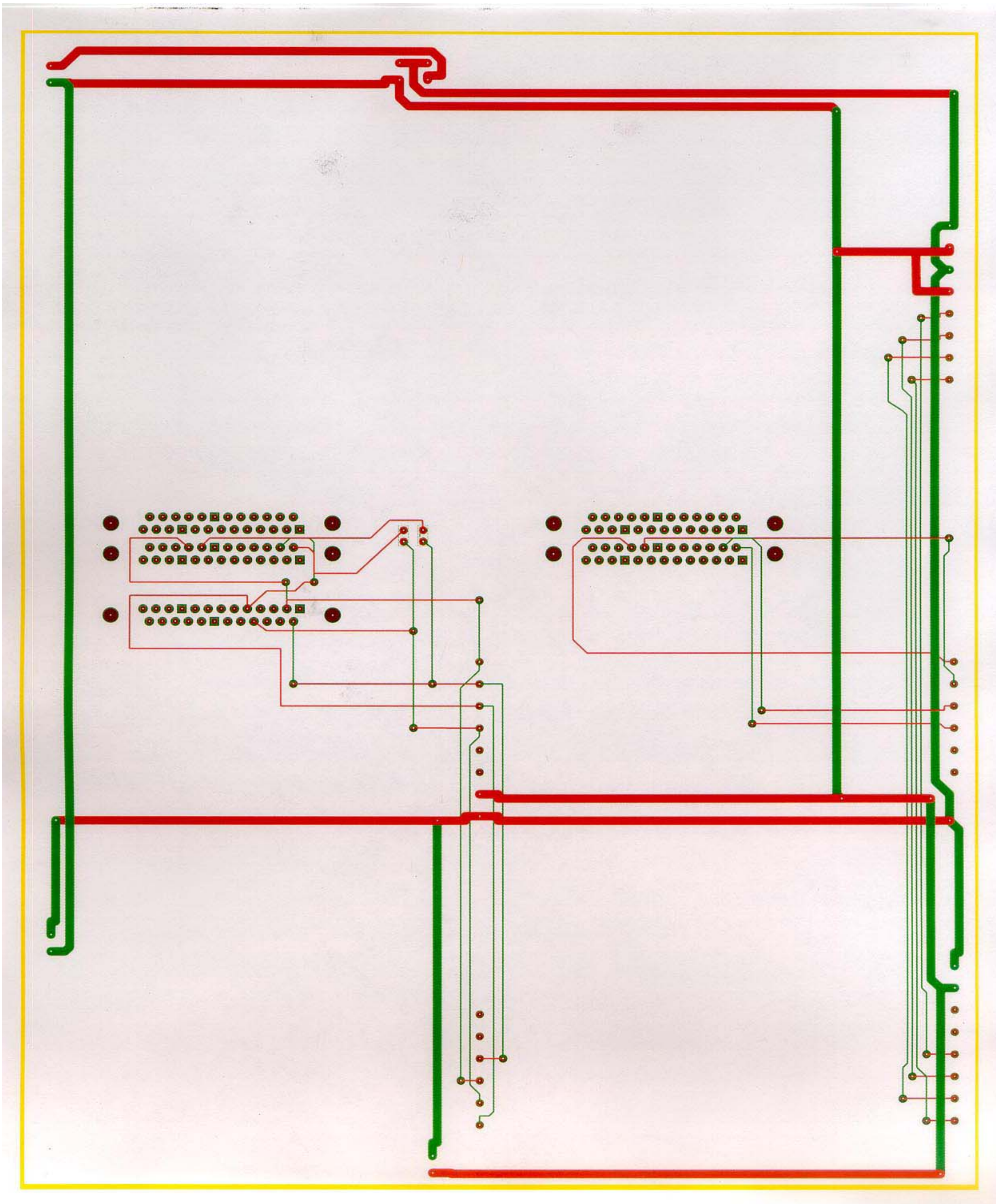


Figure A11.11 Long Distance Autoscope power and information transfer circuit board

Section 12: Testing and Optimizing the Breeze Wireless Loop

The next phase of the project was to determine the bandwidth our wireless loop for a Point-to-Point connection. This type of connection was accomplished by using two computers. The AU was connected to one of the computers and an SU to another. Then we set up a shared directory on one of the computers and downloaded a large file (16.9MB) to the other computer. The transfer rate was determined in two ways. The first was by using a program called ZDNet Monitor. It gave us a continual reading of the bandwidth during the file transfer. It had an average reading of about **.9 to 1Mbps**. We felt that this reading was relatively inaccurate because it only gave us incremental readings and not an overall average of the transfer. Hence we proceeded to calculate the bandwidth manually. We followed the same procedure as before and merely timed the file transfer. With this method we found that a 16.9MB file took 86 seconds to download. Here are the calculations of the bandwidth:

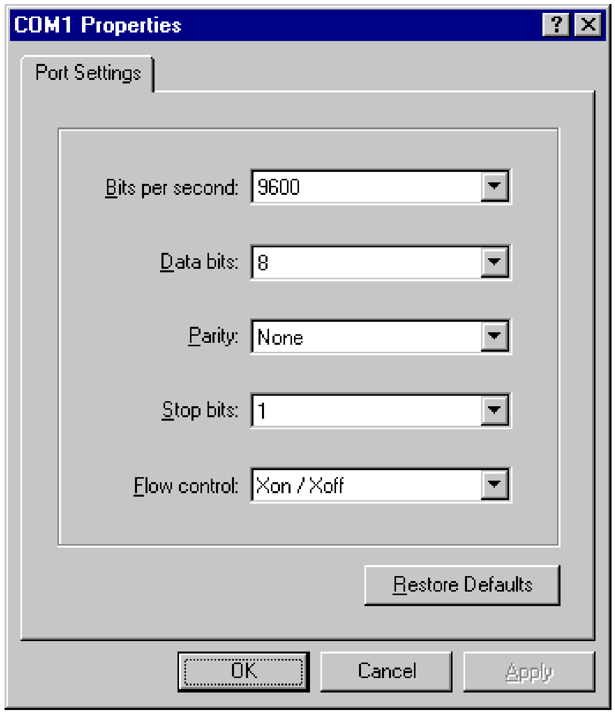
16.9MB = ? Mb
16.9MB x 8bits = 135.2Mb
Mbps = ? for 86 seconds
135.2Mb / 86s = **1.572Mbps**

We feel that this value of 1.572Mbps is a much more accurate representation of the actual bandwidth because it looks at the overall picture.
These calculations are dependent on the signal strength of the loop. When we test in the field there is an option to use called RSSI (received signal strength indicator) that will continually monitor the signal strength. Currently we have the Max Data Rate set to 3Mbps because our RSSI level is very high. When we are out in the field that MDR may have to be lowered to

RSSI	MDR (mbps)
>62	3
53<62	2
48<53	1
<48	Realine Antenna

ensure proper data transfer. Here is a table of what the MDR should be set to according to the RSSI:

The RSSI level can be monitored by using the monitor cable and connecting it to the front of the SU and the CPU's COM port. Then you must make a HyperTerminal connection using the following settings:



Once connected press Enter to start and enter the main menu. Type 4 twice to get to the Continuous Link Quality Display. Now there will be a RSSI measurement that will be continually updated. If the RSSI is to low then go back to the main menu and press 3 then 5 and change the MDR accordingly.

Section 13: Design of the Scope Mounting Pole and Enclosure

The next step was to design a pole to mount the autoscopes on. The pole had to be rigid enough to withstand the high winds on high-rise buildings. It is essential that there be no play in the pole. The pole is made of steel and five feet high. It's welded on a 2x2ft steel plate which is bolted to a 3x3ft pallet constructed of 2x4s and plywood. The pole itself will be removable from the rest of the structure. On top of the pallet will sit concrete block to add weight and support to the structure. Because these are designed to be movable, they had to be able to enclose the computer equipment themselves. Therefore there was an enclosure build out of plywood, and then sealed with a plastic shell to protect it from the elements. The top of the enclosure is attached with hinges and locks to allow service. Here is what the system looks like:

Figure A13.1 Cedar Ave prototype measurement station

Section 14: Addition of Video Data

The next phase of the project was to expand on the amount of information attainable. With the previous configuration we only gathered the numerical traffic data. The video data wasn't being gathered. Two steps were taken to remedy this. First was to determine how to collect the video feeds. It wasn't practical to use conventional VCR with tape because that required constant interaction with the VCR which would be placed on remote sites. Therefore the process had to be automated. Digital encoding posed a unique solution because not only was it able to be automated, but through the already existing wireless network, it had remote administration capabilities. A company called Stradient was contracted out to build MPEG4 digital recorders using their proprietary format. Two of these were purchased and added to the infrastructure along with several new stand alone cameras to increase surface coverage. These boxes built by Stradient were capable of recording 4 video sources simultaneously, storing them on the hard disk for future use, and streaming them in real-time to view them over the network. The interface to the Stradient recorders looked as followed:

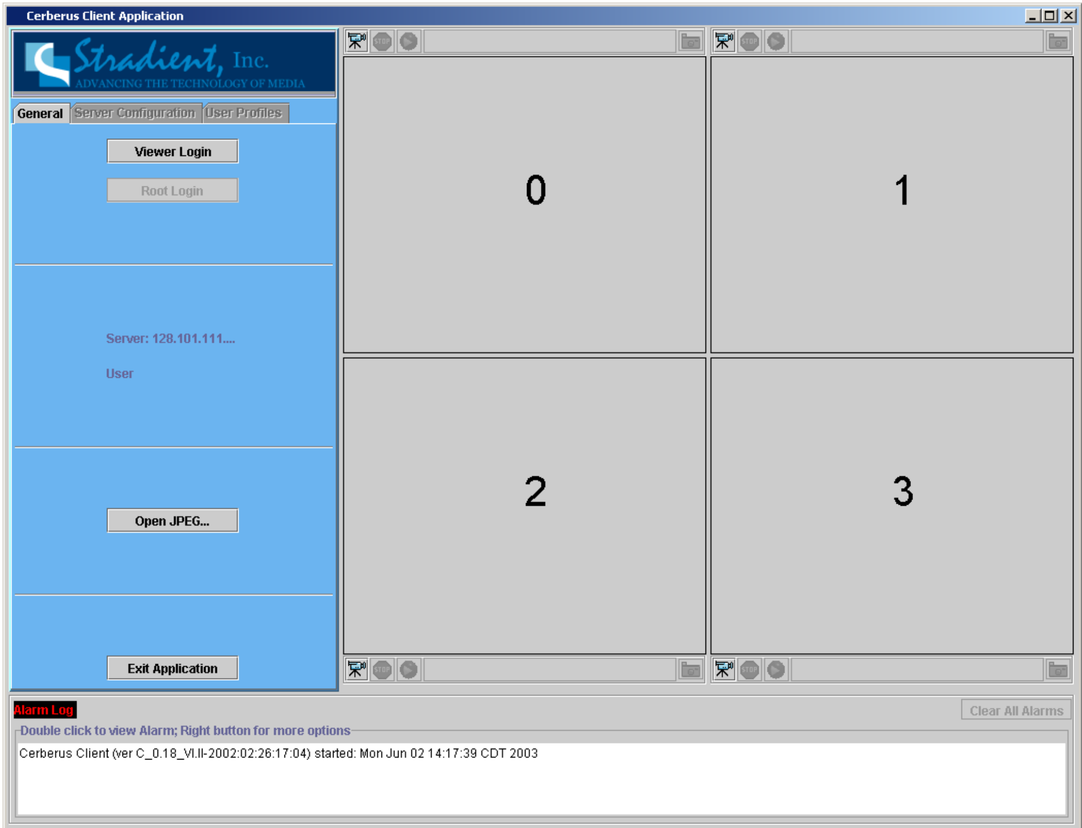


Figure A14.1 Stradient video surveilance interface

Section 15: Expanding the Scope of the System

The desire for more coverage area led to the installation of a third site. However it was know that the addition of another site would further congest the bandwidth of the wireless network. The decision was made at this time to upgrade from the 3Mbit/s radios to the current Tsunami Multipoint 20Mbit/s radios. These Multipoint radios operated in the same fashion as the Breezcom however they utilize the 802.16 frequency hopping protocol. Setup was the same for both the base station and the subscriber units. The base station was placed on top on moose tower using the same fiber optic link back to the lab. The subscriber units were placed on each of the three sites and aimed at moose tower. Using the Tsunami Subscriber software the best signal could be achieved. The IP addresses of all the equipment being used at the sites had to be entered into the radio database using the Tsunami Base Station configuration software. This is a security precaution so that only our equipment can access our wireless network.

A second major revision was made at this point…due to several technical problems with the Stradient MPEG4 recorders, and lack of technical support from the company, the decision was made to
design dedicated digital video computers at the ITS lab. This way the researchers would have full control over the entire system. The design included a Windows 2000, flexATX-board computer setup with P4 1.8GHz processor, 256MB DDR system memory and a Hauppauge WinTV capture card along with a Quad Processor to combine several video sources. The system looks like this:

The system utilizes a next generation MPEG4 codec, specifically DIVX5, to do the encoding in real-time at 640x480 and 15fps. American Systems "EZ Scheduler" software is then utilized to automate and cut up the video clips. More details on the setup are included in **Appendix B**. The video is encoded in 59min 45sec clips from 7:00AM to 8:00PM. The clips are help to under an hour for two reasons. The first is so that segments are faster to download for permanent storage. The second is that the systems requires a 15 second time window to stop the recording applications, finish writing to the disk, and then begin again. A more detailed description of the setup is in Appendix A. Here is a screenshot of how the captured video looks from the Augustana site.

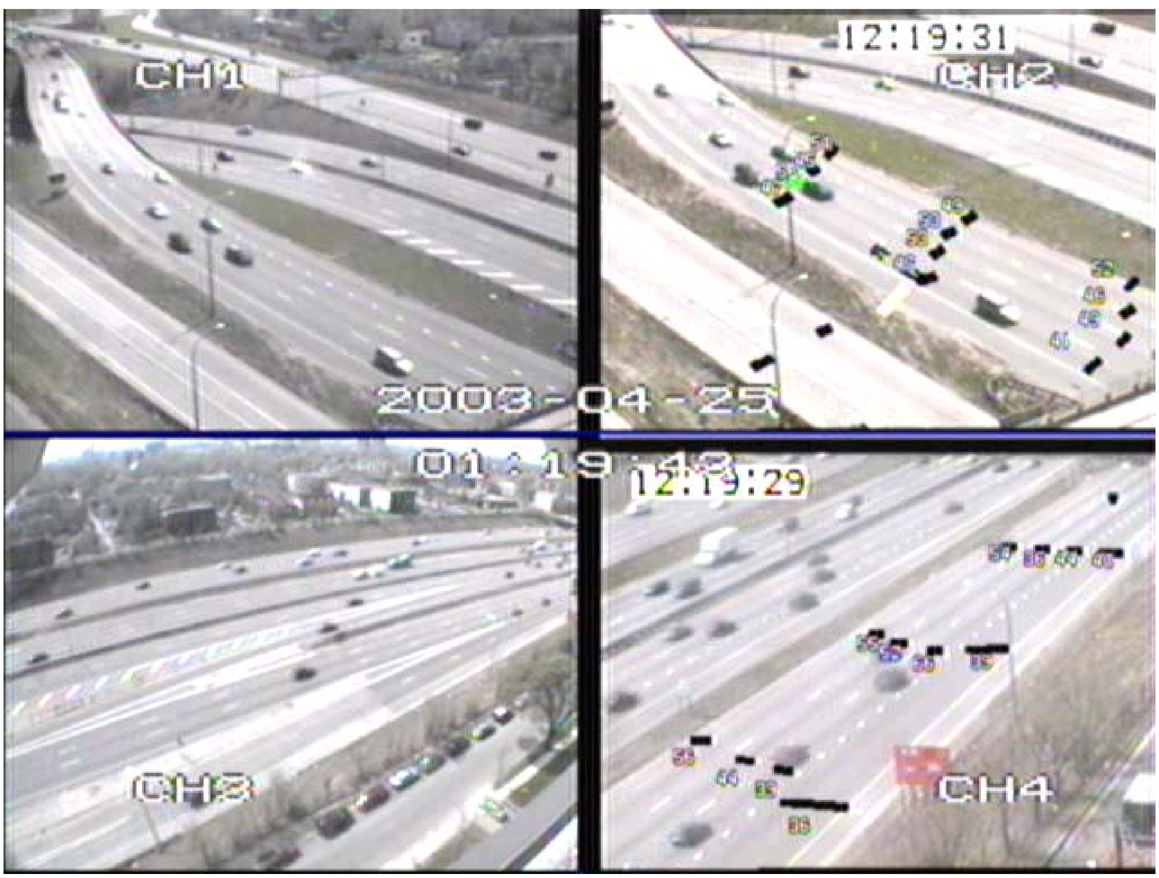


Figure A15.1 4-1 custom video surveilance setup

Section 16: Remote Administration

One of the key advantages to doing everything digitally is everything can be controlled remotely. The key piece of software is VNC (Virtual Network Controller). This is a freeware application distributed by ATT. It allows a user to control another computers desktop via a network connection. Using this software, one can do anything to a remote computer as if it was right in front of them. One merely needs to install VNC on the remote computer as a service, then choose a password. The user can then use the client software to connect to the computer from anywhere on the network using the IP address of the remote computer and the password.

Section 17: Proxim Tsunami Multipoint Settings

Here is a brief listing of the commands used to configure the wireless radios via the Base station Configuration Software located on Artemis in the ITS Lab used in the setup.
All commands are entered in thought the Base station Configuration Software.

To configure the Base Station

1. On the computer that has the Base Station Configuration Software installed, change the IP address for its Ethernet card to 192.168.20.xx with a 255.255.255.0 subnet mask (xx can be any number between 1 and 255 with the exception of 254). The computer and BSU must be members of the same IP subnet to communicate.
*The best method of communication with the base station when setting the initial commands is to use an isolated switch. Plug the computer into any port on the switch, and then plug the radio into the switch. Both connections should be using a CAT-5 cable.
When using the Multi-BSU software, the BSU and SU can be on different subnets (see "Using the Multi-BSU Configuration Software" in the Tsunami Multipoint Version 1.3 Reference Manual for information).

Note: The BSU's default IP address is 192.168.20.253 with a subnet mask of 255.255.255.0.

2. Run the Base Station Configuration Software on the computer. To do this, from the Windows Start menu, select Programs □□ Base Station Configuration Software.

3. Configure the BSU's IP settings: Type setIP <IP address> and press Enter, where <IP address> is the new IP address you want to assign to the unit. For example, the ITS Lab command should be: setIP 128.101.111.186 to assign this IP address to the BSU.

A. Close the Base Station Configuration Software and change the IP address of the computer's Ethernet card so that it is in the same IP network as the BSU's new IP address; restart the computer if necessary.

B. Open the Base Station Configuration Software and use the dspconf command to verify that the BSU and computer can communicate.

C. Enter setSubnet <subnet mask> where <subnet mask> designates a subnet mask. Proxim does not recommend using a subnet mask wider than 255.255.248.0.

D. If desired enter gateway <gateway address> where <gateway address> designates the IP address of the network's gateway.

4. To set the BSU's Terminal ID, enter setID <Terminal ID> where <Terminal ID> is a number between 1 and 2048). For example, setID 1 sets the unit's Terminal ID to 1.

Note: Each BSU and Subscriber Unit (SU) in a cell must have a unique Terminal ID.

5. Set the desired data rate using the modulation command (modulation <0 (60Mbps) | 1 (40 Mbps) | 2 (30 Mbps) | 3 (20 Mbps)>). This step is not applicable for BSUs that support 20 Mbps operation only.
The ITS lab currently uses 20Mb (as of 09/08/03).
Set the desired frequency plan using the freqPlan command. (freqPlan < 4 (four channel | 5 (channel) | 6 (channel)>). Tsunami Multipoint offers several frequency plans and operating frequencies to provide a means for overcoming interference. If one part of the 5.8 GHz spectrum is occupied when you deploy the product, you can select a different frequency plan to bypass the interfering frequency.

8. Set the desired frequency plan using the frequency command. (frequency < a | b | c | d | e| f >; with e being available for the 5- and 6-channel plans and f being available for the 6-channel plans only.
*Note that the default value is < a >. The frequency had experienced problems so the current frequency is < c >.

9. Set the BSU's desired transmit power level using the txPowerLevel command.
Typically the power level is set to 17 dBm in the field (maximum setting) and 6 dBm for indoor range testing (minimum level).

10. Set the desired transmit power auto-enable mode with the txPowerAutoEnable command (txPowerAutoEnable < 0 (off) | 1 (on)>. When auto-enable is set to on the BSU automatically starts transmitting after any power cycle.

Set the desired routing mode with the routingMode command. (routingMode < 0 (IP routing | 1 (Bridging)>).

Note: After you issue the routingMode command, you may need to clear the PC's arp table; restarting the PC used to configure the BSU will do this.

12. Turn on the BSU using the txPower command (txPower <0 (off) | 1 (on)>).
At this point the BSU is configured, transmitting, and ready to operate. Also, see "Advanced Configuration Options" in the Tsunami Multipoint Version 1.3 Reference Manual for information about the other commands used to configure the BSU (such as setting proxy, RIP, static IPs, and so on).

Add Subscriber Units to the Base station

Subscriber units cannot enter the network until they are added to the BSU database.

1. Identify the Subscriber Units (SUs) you intend to use with this BSU and write down each device's MAC address (which is printed on the product label).

2. Add the first SU to the BSU's database by entering addSU <MAC address> <Terminal ID>.

º When typing the MAC address, separate each pair of digits with a colon or a blank space.
º The Terminal IDs range from 1 to 1023; assign a unique ID to each BSU and SU in a cell.
Note: Add an SU to the BSU's database before installing or turning on the SU.

3. Configure the SU IP settings:
º Enter setSUIP <Terminal ID> <IP address> to set the SU IP address. Proxim suggests that you configure each SU with a unique IP address in the same IP subnet as the BSU in Bridging mode and configure each SU with a specific subnet in IP routing mode.
º Enter setSUSubnet <Terminal ID> <subnet mask> to set the SU subnet mask.

4. Repeat Steps 2 and 3 for each SU that you want to add to the Tsunami Multipoint system.

5. Enter dspSU to view the list of SUs that have been added to the BSU's database.

6. Install the SUs as described in the next section.

Testing for a bad connection

There are two special commands that can be used to show bit rate errors and determine if the wireless connection is poor. These are:

uplber < term id >
berlog 1

The first starts the logging process for a chosen terminal and the second starts the bit rate error testing.
After the berlog 1 command is entered, the user will see several numbers being updated on the screen. The important number is "ber=xxx." The xxx values should read on the order of 0e-6 or less. If they are higher, that means there is a communication problem between the base station and the subscriber unit. The best resolution to this problem is to use the frequency command described above to change the operating frequency. Communication errors are usually due to some interference on the same bandwidth.

Section 18: Summary of Network Settings:

Here is a summary of the networking settings used in the Beholder Project:

Table A18.1 Summary of settings

Device	Description	Location	IP Address
Base Station Radio	20Mbit Wireless Base Station	Moose Tower	128.101.111.186
Subscriber Unit Radio	20Mbit Wireless Subscriber Unit	Cedar	128.101.111.187
Subscriber Unit Radio	20Mbit Wireless Subscriber Unit	Augustana	128.101.111.188
Subscriber Unit Radio	20Mbit Wireless Subscriber Unit	3rd Ave.	128.101.111.189
Divx Box	Dedicated Digital Recording Computer	Cedar	128.101.111.150
Divx Box	Dedicated Digital Recording Computer	Cedar	128.101.111.151
Divx Box	Dedicated Digital Recording Computer	3rd Ave.	128.101.111.160
Divx Box	Dedicated Digital Recording Computer	3rd Ave.	128.101.111.161
Lantronix Server	Convert Serial to Ethernet Communication	Cedar	128.101.111.92
Lantronix Server	Convert Serial to Ethernet Communication	Augustana	128.101.111.190
Lantronix Server	Convert Serial to Ethernet Communication	Augustana	128.101.111.192
Lantronix Server	Convert Serial to Ethernet Communication	3rd Ave.	128.101.111.141
Lantronix Server	Convert Serial to Ethernet Communication	3rd Ave.	128.101.111.143
Lantronix Server	Convert Serial to Ethernet Communication	3rd Ave.	128.101.111.145
Autoscope	Traffic Monitoring Equipment	Cedar	
Autoscope	Traffic Monitoring Equipment	Augustana	
Autoscope	Traffic Monitoring Equipment	Augustana	
Autoscope	Traffic Monitoring Equipment	3rd Ave.	
Autoscope	Traffic Monitoring Equipment	3rd Ave.	
Autoscope	Traffic Monitoring Equipment	3rd Ave.	
Switch		Cedar	
Switch		Augustana	
Switch		3rd Ave.	
Switch		Moose Tower	
Quad Processor	Video Combination Unit	Cedar	
Quad Processor	Video Combination Unit	Augustana	
Quad Processor	Video Combination Unit	3rd Ave.	

Section 19: Streaming Real-time Video

The one drawback to the current video encoding configuration was that the video was being encoded in one hour segments and couldn't be viewed until the recoding was completely finished. A new approach was designed using the Window Media Encoder along with the Encoder SDK. This software has the ability to both stream and record video at the same time. All the details of the setup are in **Appendix C.** There is a slight quality difference between the Divx and Windows Media 8 codec. The Divx is slightly better. Therefore the decision was made to make the system switch able. By default the system would just encode in Divx, but at any time the researchers can merely stop the scheduling software and start the windows media encoder. Adding this step made the system the equivalent of the Stradient boxes which cost $5000, compared to approximately $700 for the ITS version of the system.

Section 20: Switching Between Archiving/Streaming Video Servers.

Assuming you have completed both installations as directed in Appendix A and B, you now have the ability to choose the live stream in Windows Media format, or the archiving servers using Divx. The following are instructions on how to switch between the two.

Scenario 1: Switching from Divx to Windows Media

Step 1) If the VirtualVCR application is currently running, stop it and close the application.

Step 2) Stop the EZ Scheduler application by right clicking on it's icon that appears in the start bar and choosing the 'close' option.

Step 3) From the Start Button, chose the 'Windows Media/Windows Media Encoder' to start the application.

Step 4) Click 'File/Open' and choose the appropriate .wme profile to load. (On the ITS machines there is a profile named 'DEMO.wme' which has all the default settings for streaming the video)

Step 5) Start the encoding by clicking the 'start encoding' button.

Scenario 2: Switching from Windows Media to Divx

Step 1) Stop the Windows media encoder and close the application

Step 2) From the start button open up the 'American Systems' and choose the EZ Scheduler to start up the application. That will automate the rest of the process and video will begin recording at the start of the next hour.

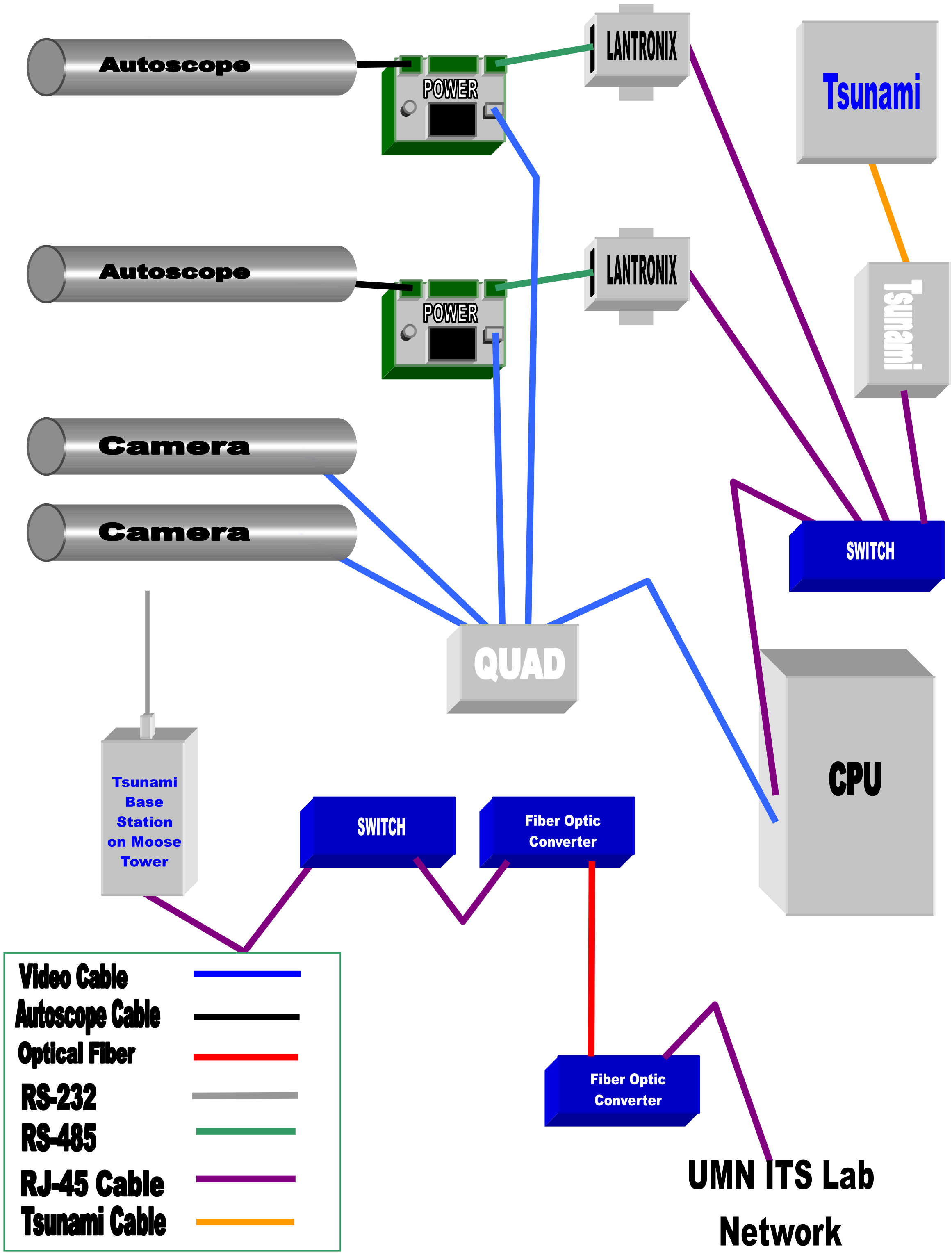


Figure A20.1The Final Configuration

Appendix B:

Divx Recording Box Instructions

Portable Digital Video Recorder

Parts List:

Spacewalker Barebones System (mfg. Shuttle)
Hauppage WinTV 879 PCI
P4 1.8 GHz
256 DDR Memory
IBM 60GB ATA100 hard disk
1.44 floppy drive
CD-ROM

Software
Windows 2000
VirtualVCR (v. 1.1.8 or newer)
EZ Scheduler
Divx Pro 5.0.2 Codec
VNC

Purpose:

The purpose of this project is to create a fully automated digital video recorder using the Divx Codec that can encode in real time. To record in real time using divx, requires a lot of processing power which is why we chose to use a P4 1.8Gz. The minimum processor speed required is approx 1.2 GHz

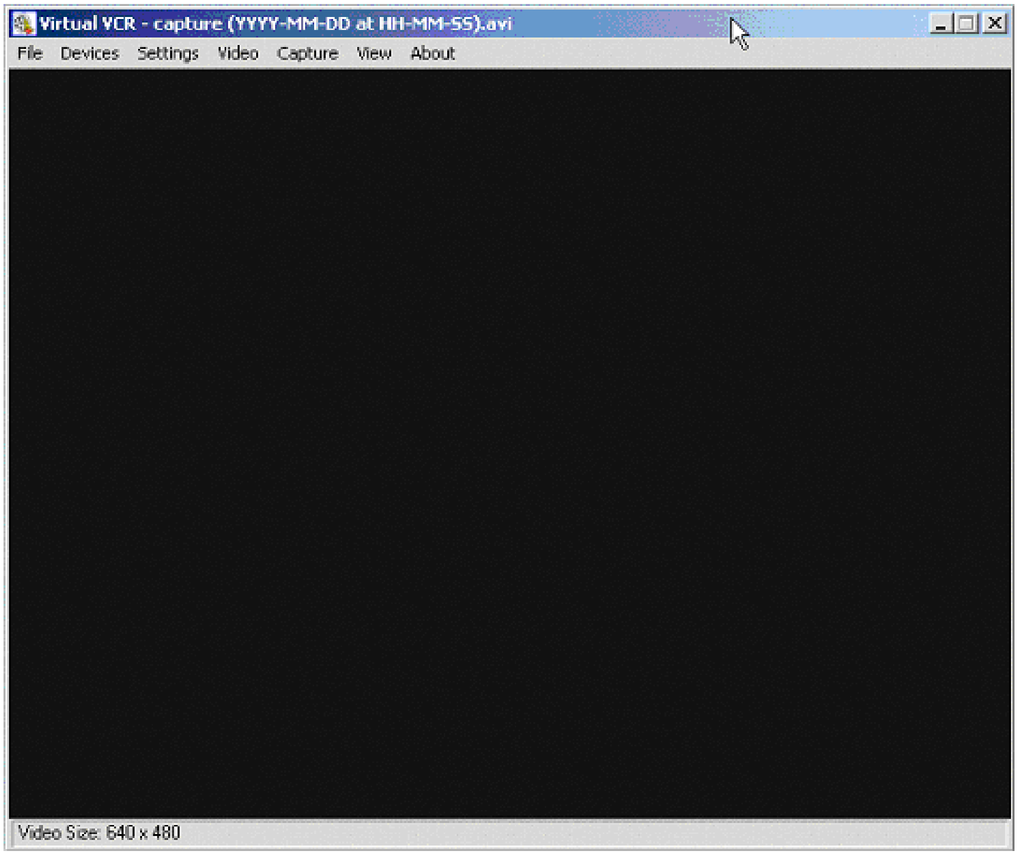
Setup:

The first step was to assemble the computer (processor, memory, hard disk, CD-ROM, floppy, TV-card). Then install the Win2K operating system, along with any updates from hardware manufacturers or Microsoft.

The next step was to install the Divx Codec which is available from www.divx.com. We chose the Pro version because it has better encoding features. After that we installed VirtualVCR which is available at www.digtv.ws/index.php. This program acts just as the title implies, it records from an analog source using a video capture card in digital format with virtually and compression type. This program has two features that set it apart from several other recorders:

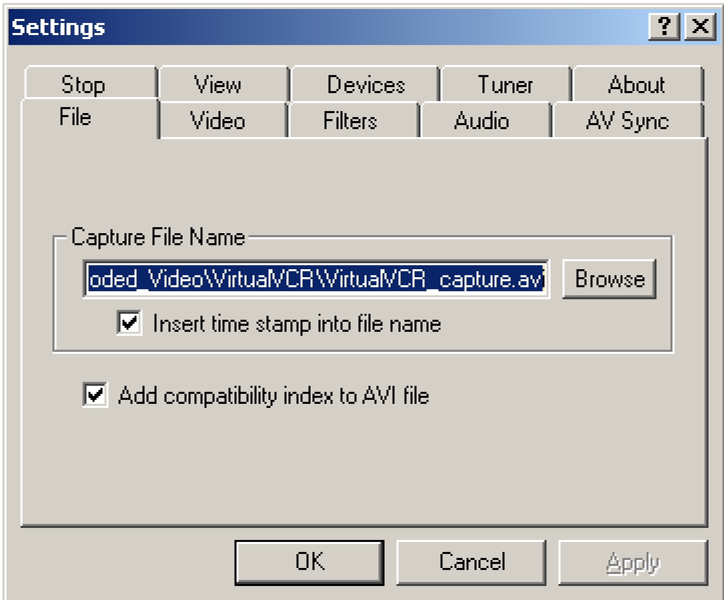
2) It integrated well with the Divx codec
3) It could be run from a command prompt (explanation later)

Now we needed to setup VirtualVCR to record. Here is what the interface looks like:

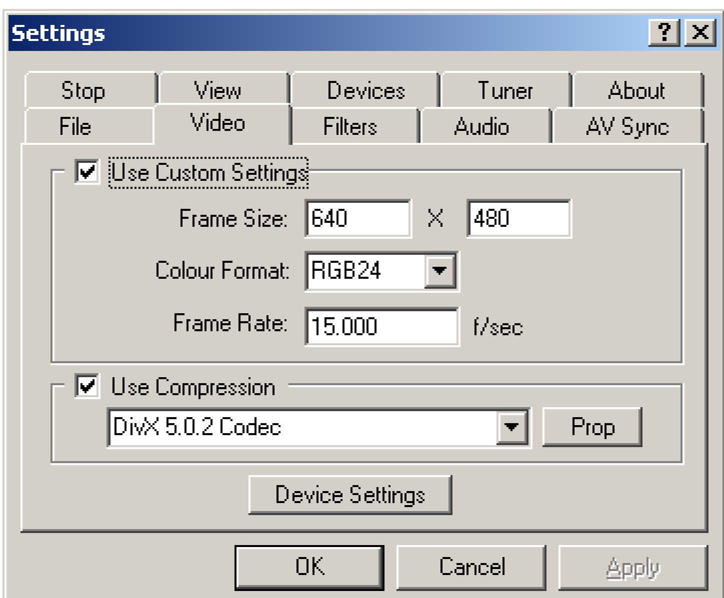


Virtual VCR Settings

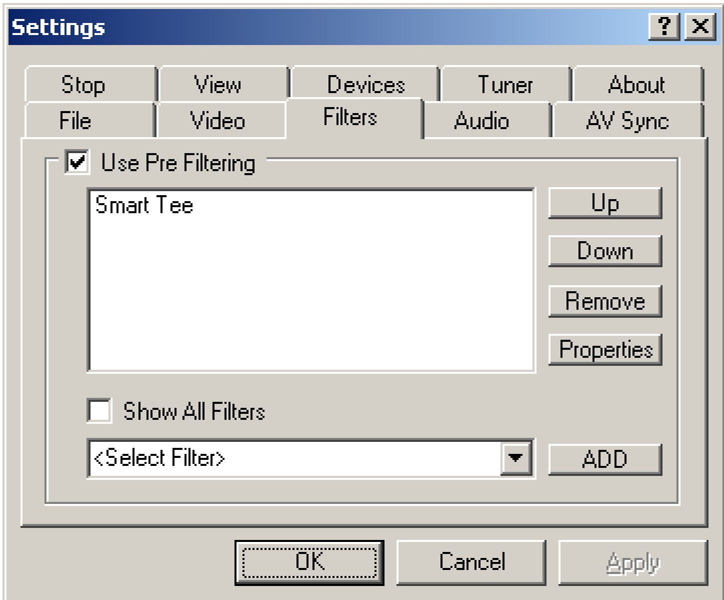
This is assuming you have already run the installation files for VirtualVCR and DivX5.02
Follow the Diagrams:
(All settings shown are Kyle Wood's default values for recording traffic video w/o audio.



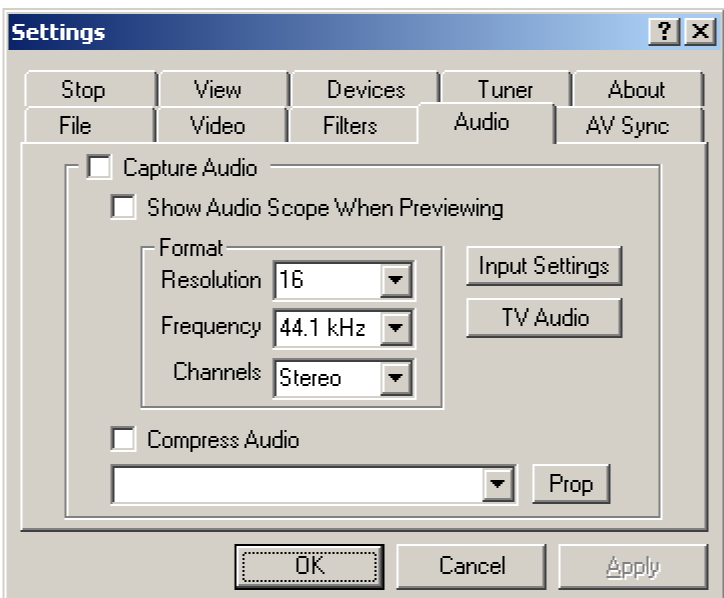
Here is the whole string...
"C:\Video_Encoding\Encoded_Video\VirtualVCR\VirtualVCR_capture.avi"
Or wherever you want to store the files. The time stamp is for logging the files and the compatibility index is for searching within the video.



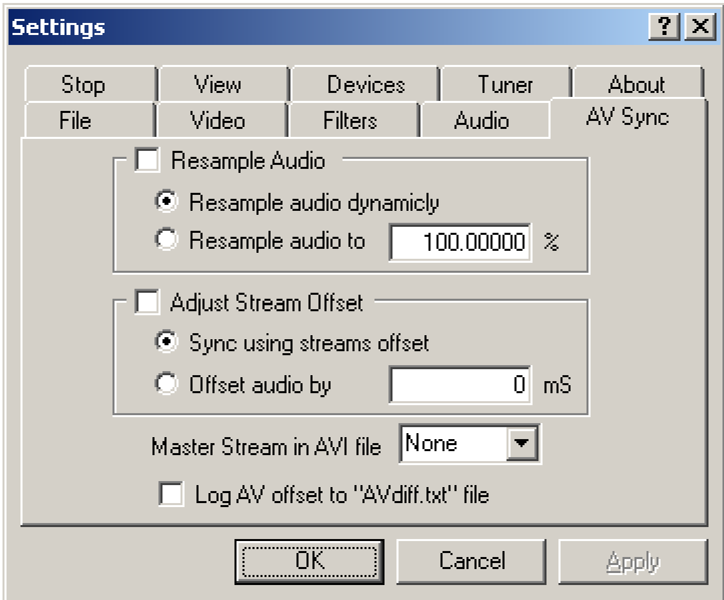
Or whatever formats/fps you want. If you choose to use Divx, my settings are listed on step ten. You can adjust these by clicking the "Prop" button.

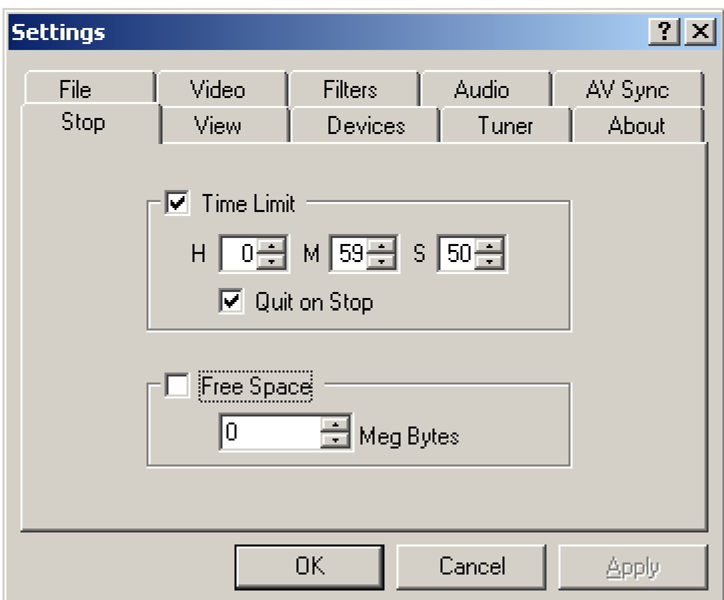


Select this if you want to see the video while it's recording

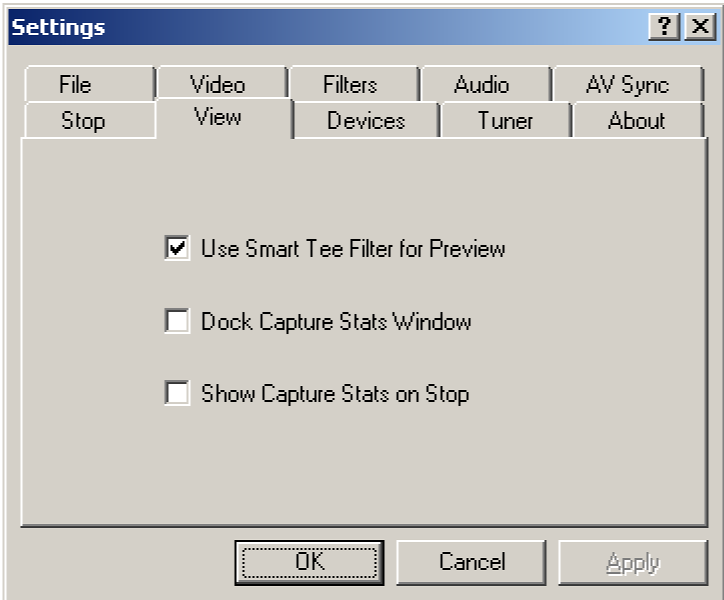


Choose this if you want to capture/compress audio

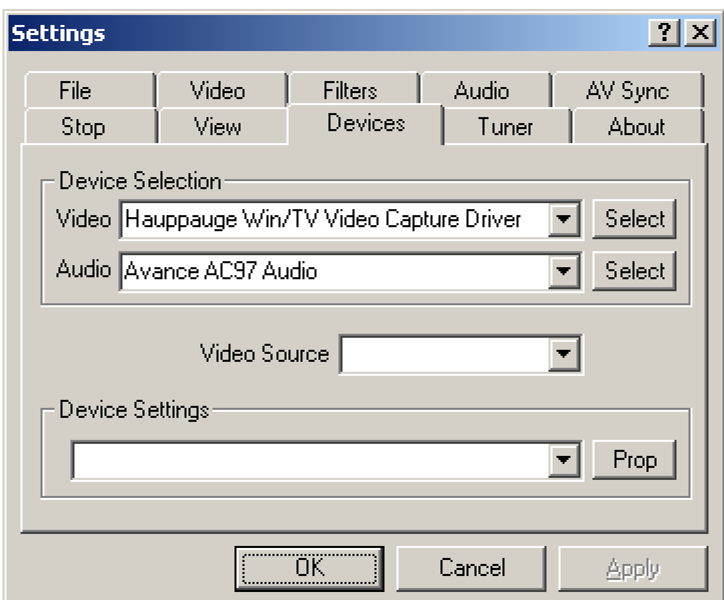




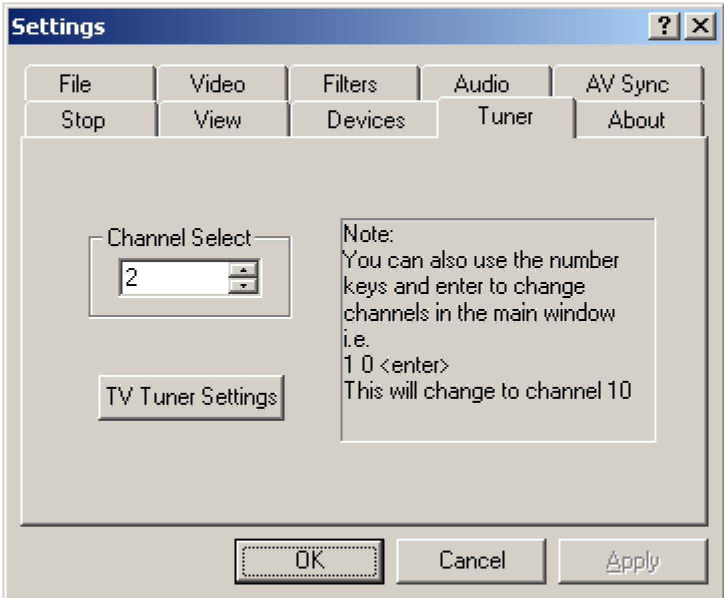
Here you can select the stop time...I have chosen 59min 50sec so that the files are chopped up into approx. 1 hr segments. The reason that it's not 59:50 and not 1hr is because the program must shutdown and restart each new file recorded, this way there is a ten second window for closing and initializing.



Again select this if you want to view the file as it's encoding

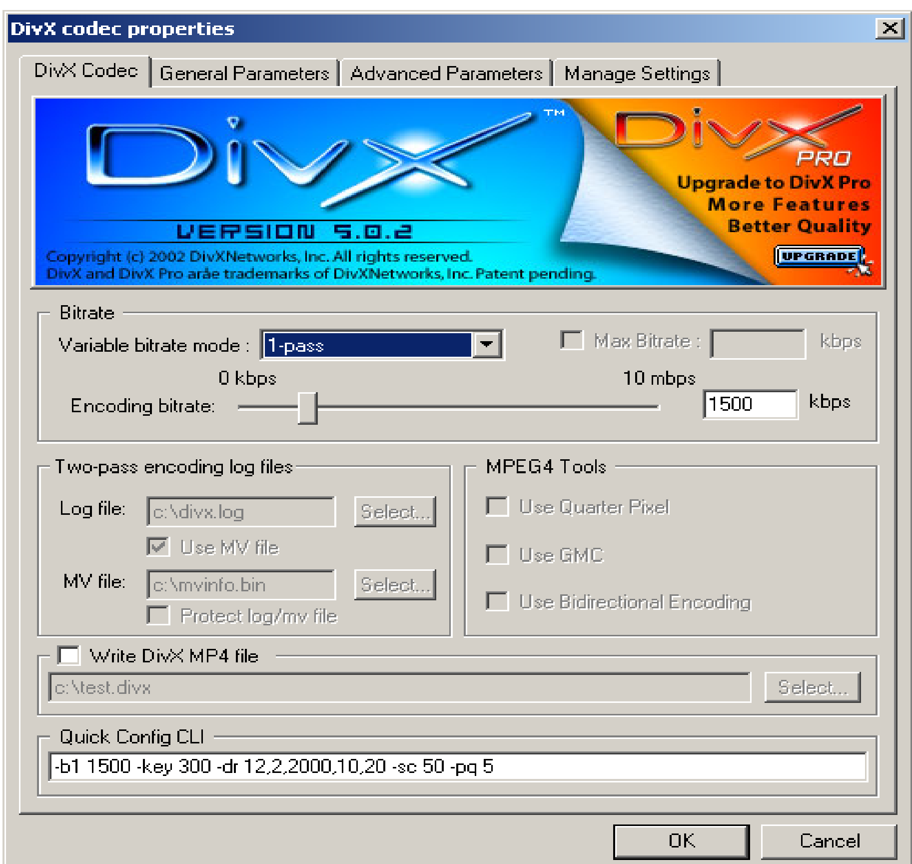


Choose your capture devices



This doesn't matter unless you're capturing from television channels

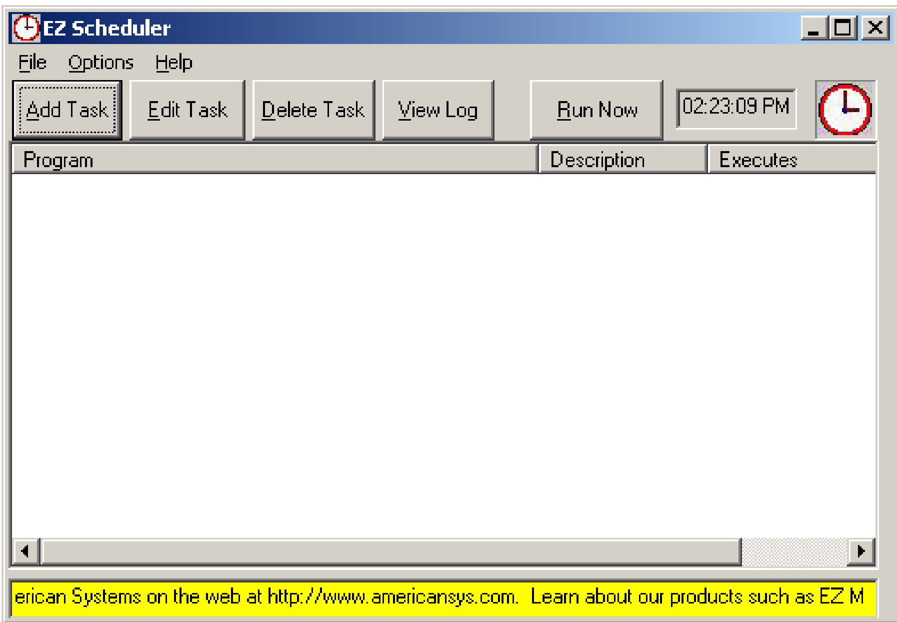
***Make sure to "Store Defaults" in the Options Menu!**



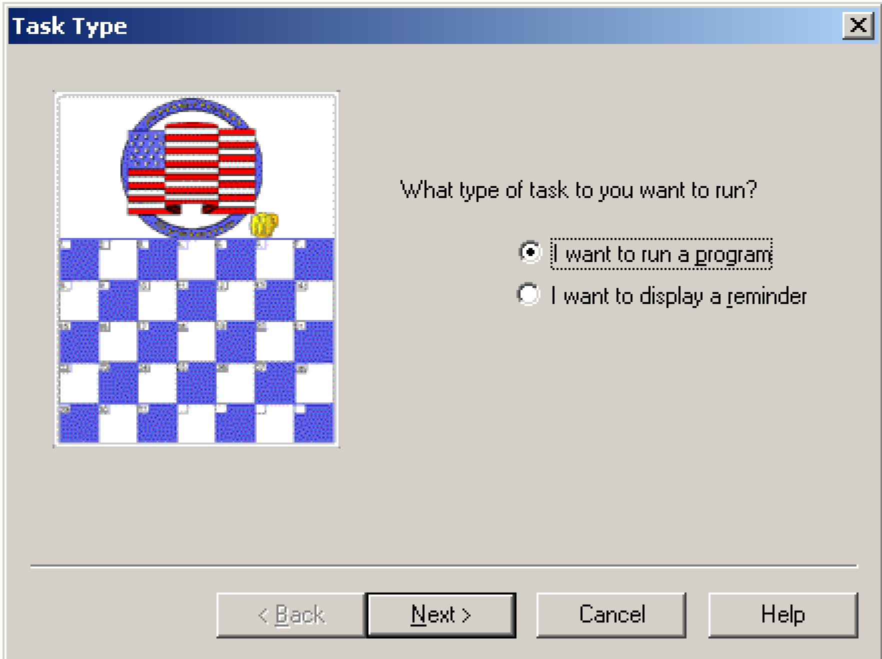
Leave all other setting at their default unless you are experience with DivX.
The 1500kbts setting will give a 1hr encoded video at 15 fps, 640x480 a file size of approximately 350MB. You can adjust the file size according to what file size/quality you want.

EZ Scheduler Setup

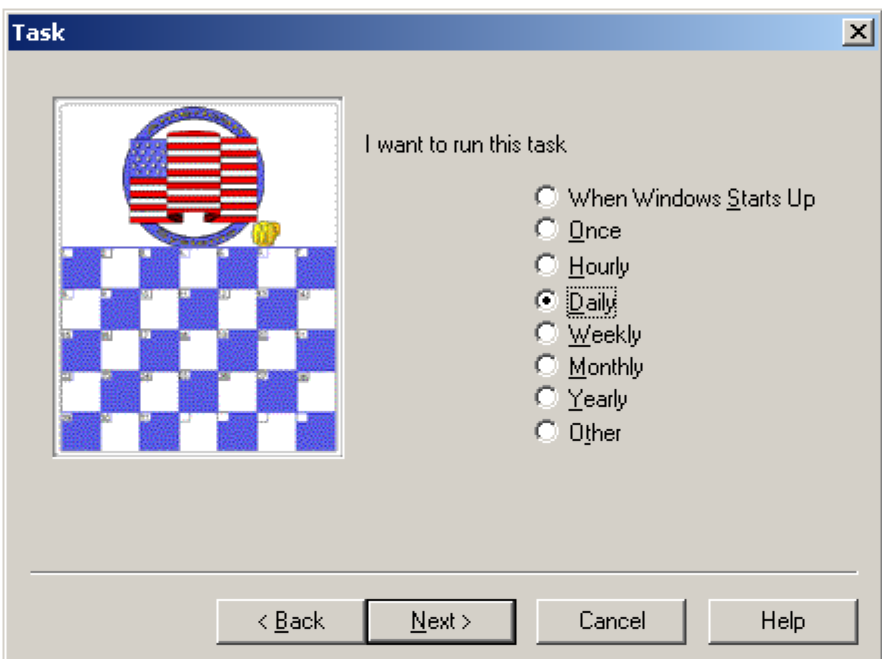
(You can also use Windows Scheduler or any other scheduling software you like)
First open up the interface and it should look like this:



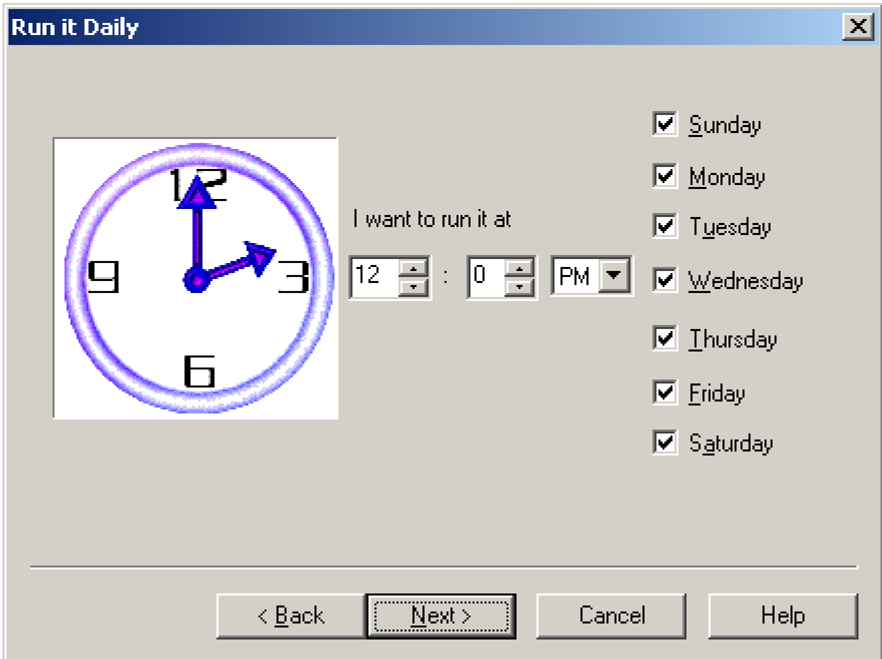
Click "Add Task" and Choose "I want to run a program"



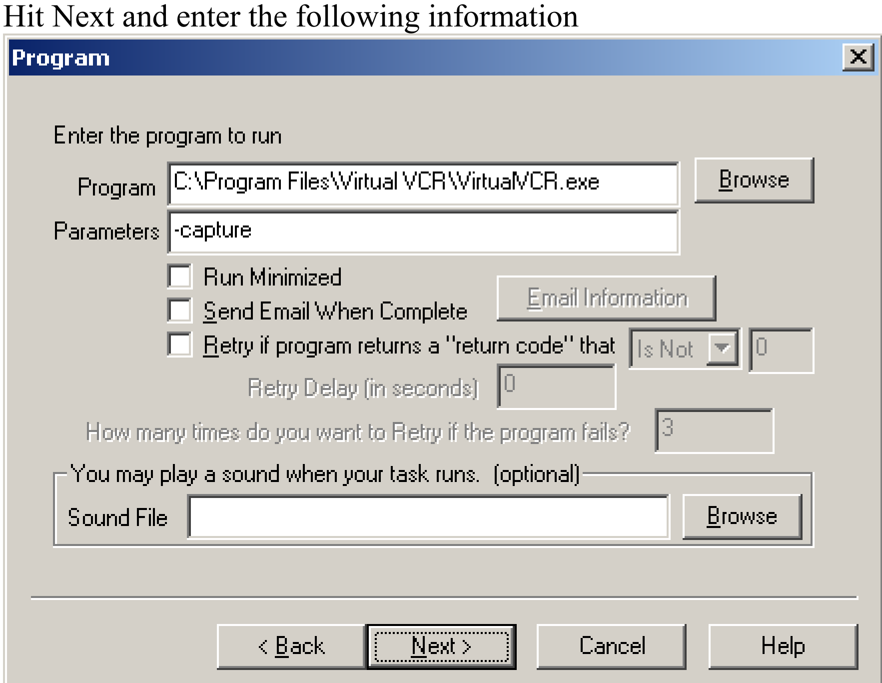
Hit "Next" and then choose "Daily or what ever kind of schedule you want.



Again hit next and choose more scheduling options.

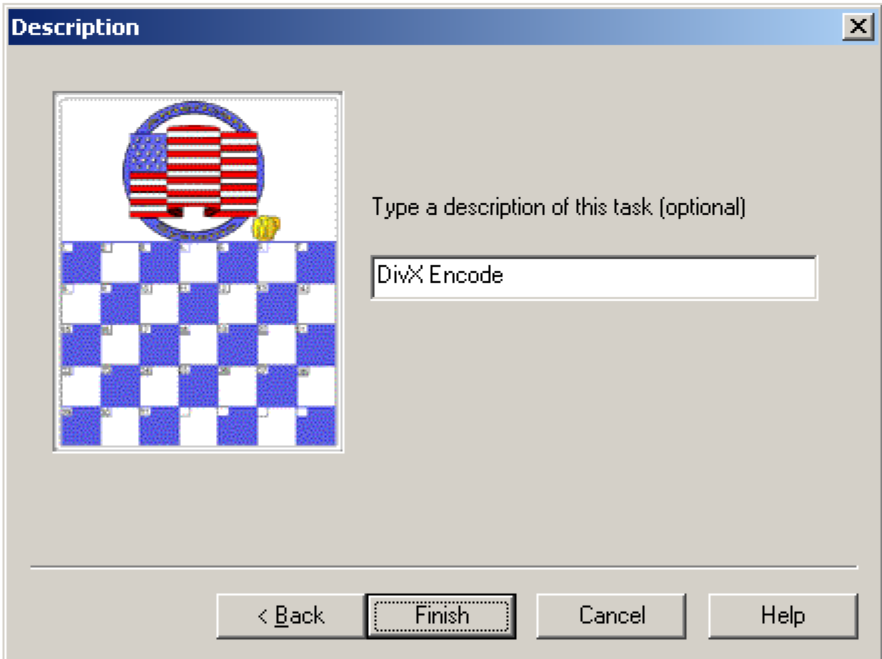


Hit Next and enter the following information

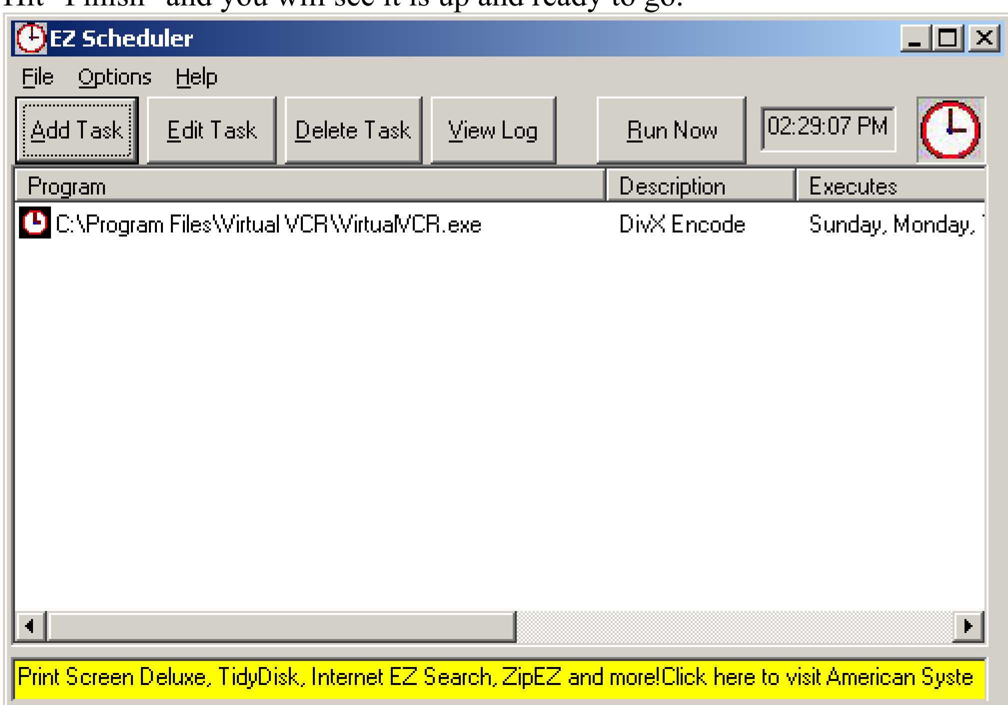


You can choose "Run Minimized" if you don't want to see the interface on the desktop while encoding

Again hit next and give it a description.



Hit "Finish" and you will see it is up and ready to go.



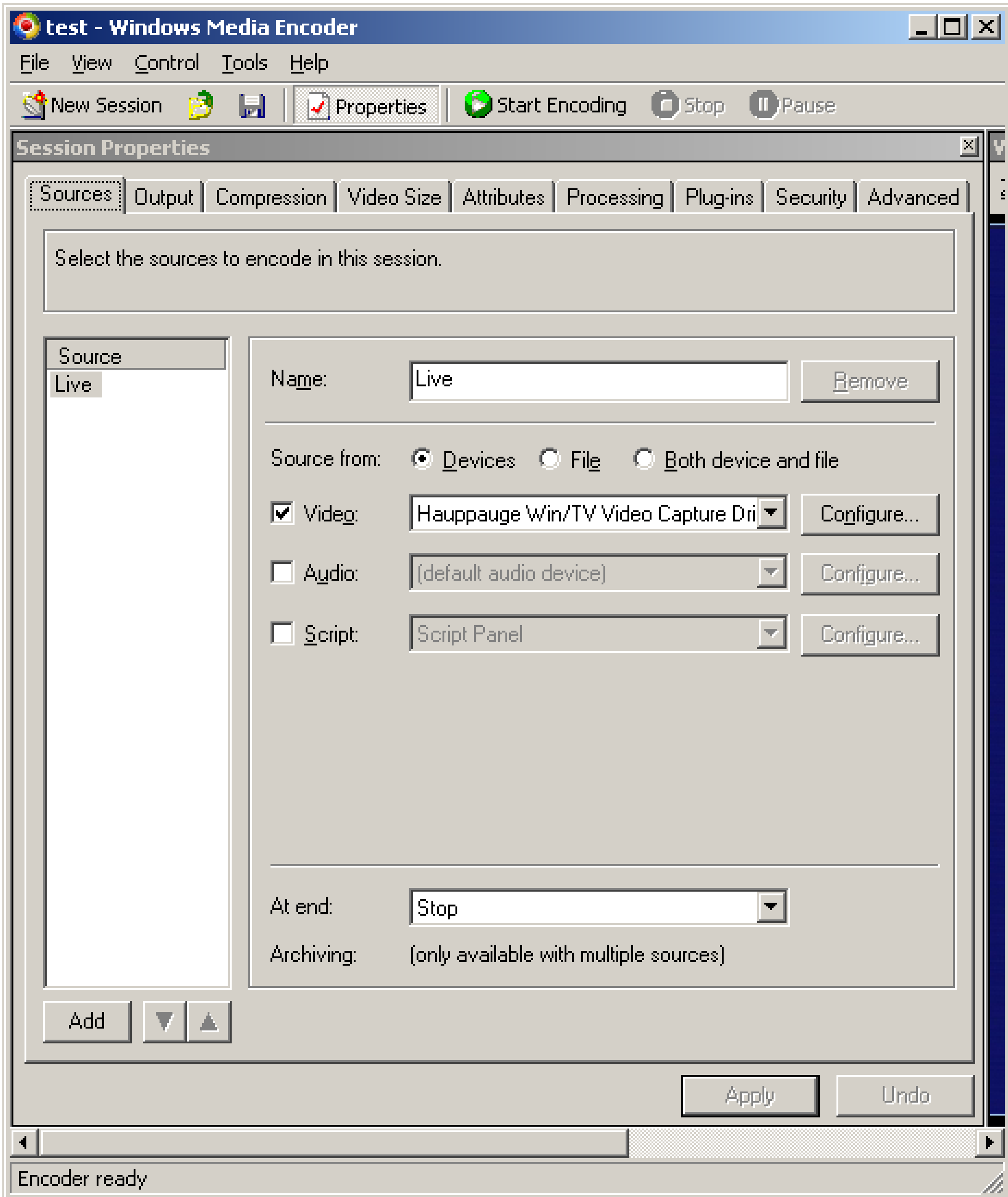
Repeat this for as many schedules as you like

Make sure that the "Auto Start" under Options is selected if you want your computer to start up and encode without any human intervention

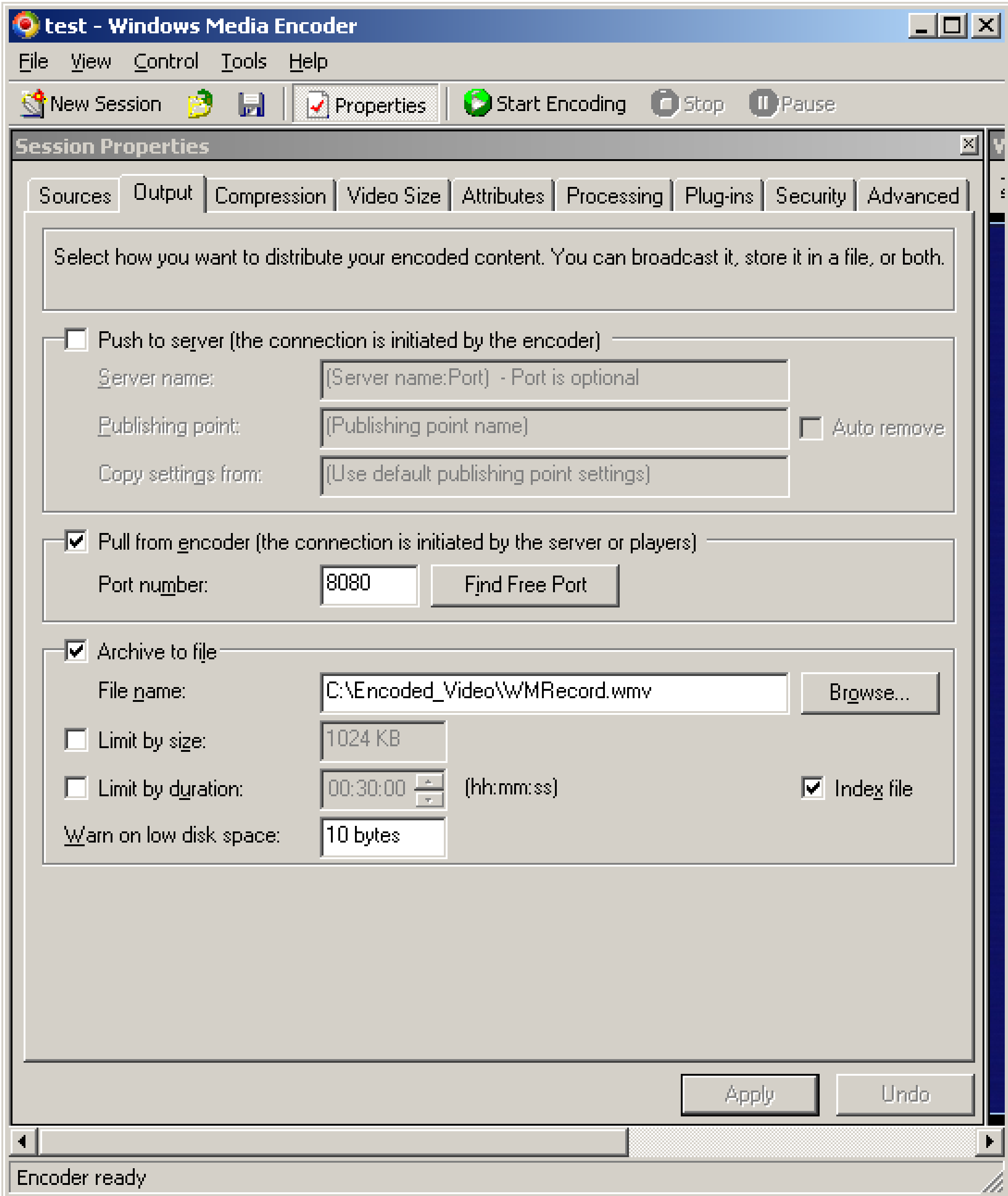
Appendix C:

Windows Media Encoder 9 Install Settings

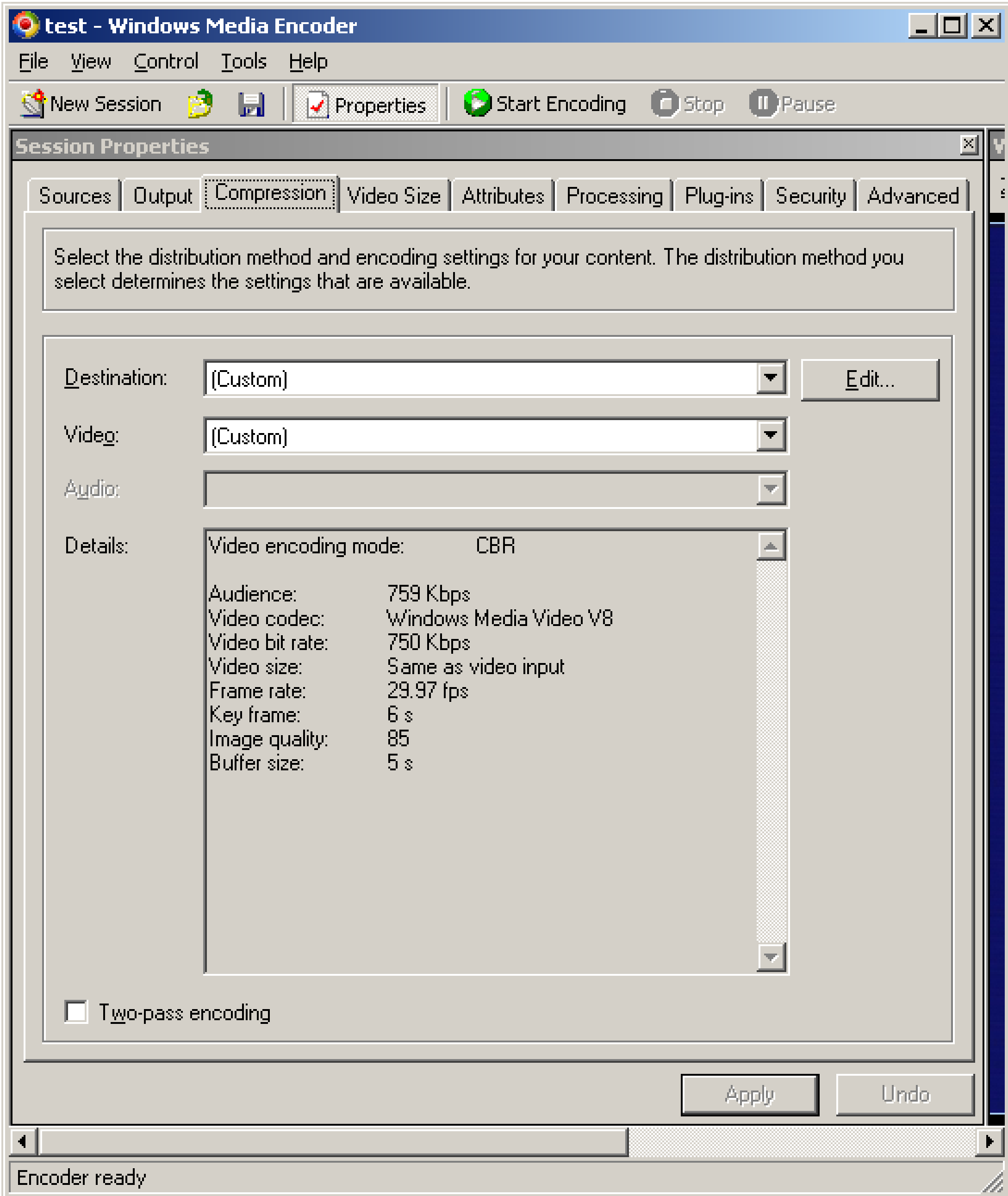
This is assuming you have already run the installation files for WME9 and the WME9SDK
Open WMEncoder 9 and click File=>Open and choose the included file with the install files i.e. "C:\video_encoding\install_files\test.wme"
Here is what you will see:



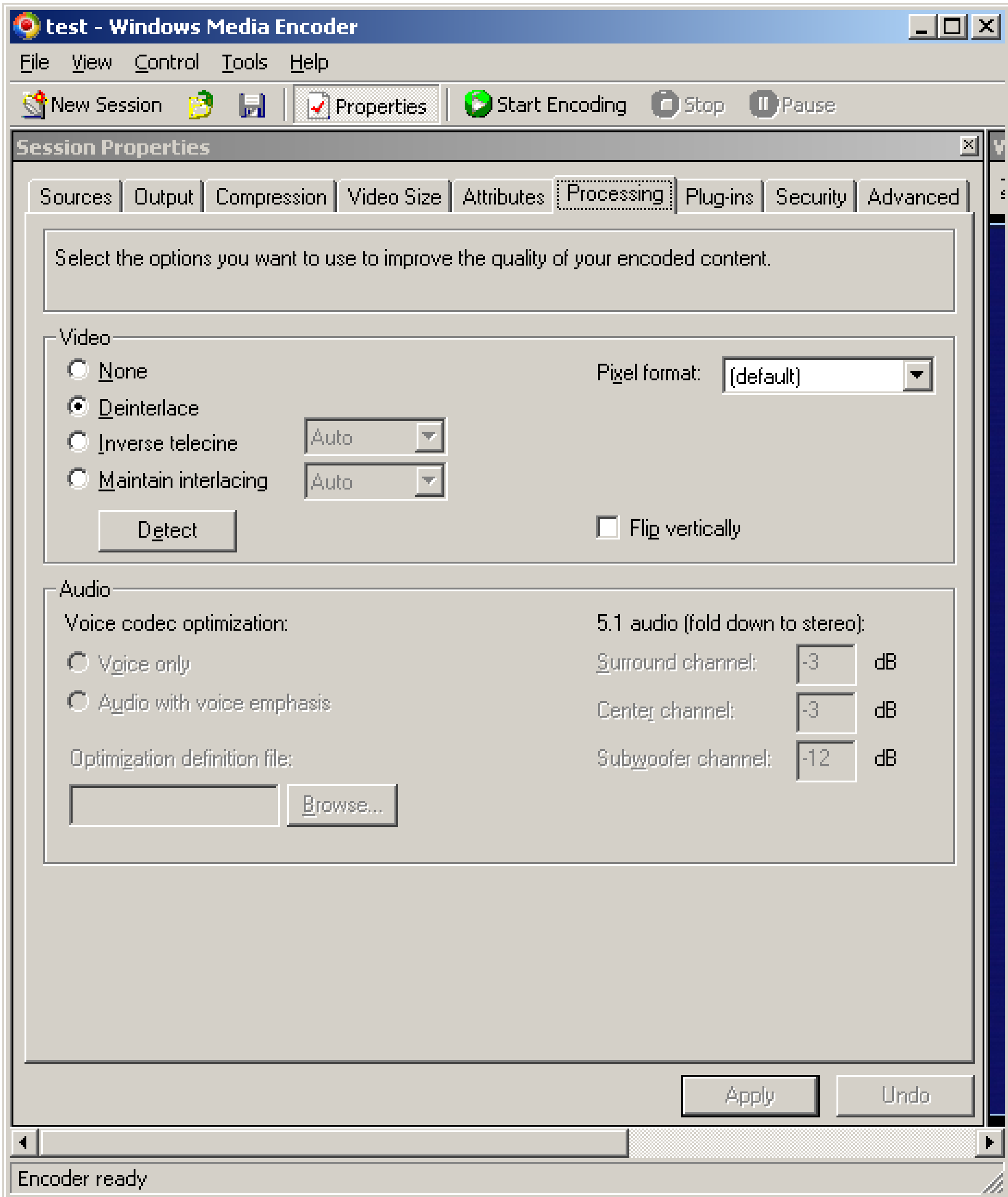
Here you can choose your capture devices.



The "Pull from encoder" feature broadcasts the video from you PC via this address: http:\\(your_ip_address):8080



These are my default settings; you can change these by clicking the edit button.



The de-interlace feature cleans up the picture quality a little, it is not necessary though.

Save you session as the same file and continue on to the next step

You now can edit the file "C:\Video_Encoding\install_files\encoder_start.bat"
The only thing you should have to change is the duration of the recording which is in seconds.
To edit this file just right click on it and select edit.

Here is what the file looks like:

encoder_start - Notepad

File Edit Format Help

```
CALL "C:\encoding_install_files\get_time.bat" set

C:\WINNT\system32\cscript.exe C:\encoding_install_files\wmcmd.vbs -wme
"C:\encoding_install_files\test.wme" -duration 3590 -output
"C:\Encoded_Video\WME9\%_lldate%%_lltime%__%_ldate%"
```

Note that this file records for 3590seconds or 59min and 50seconds. This is so the encoder has time to stop and start between files.

Here is the “get_time.bat” file that is called:

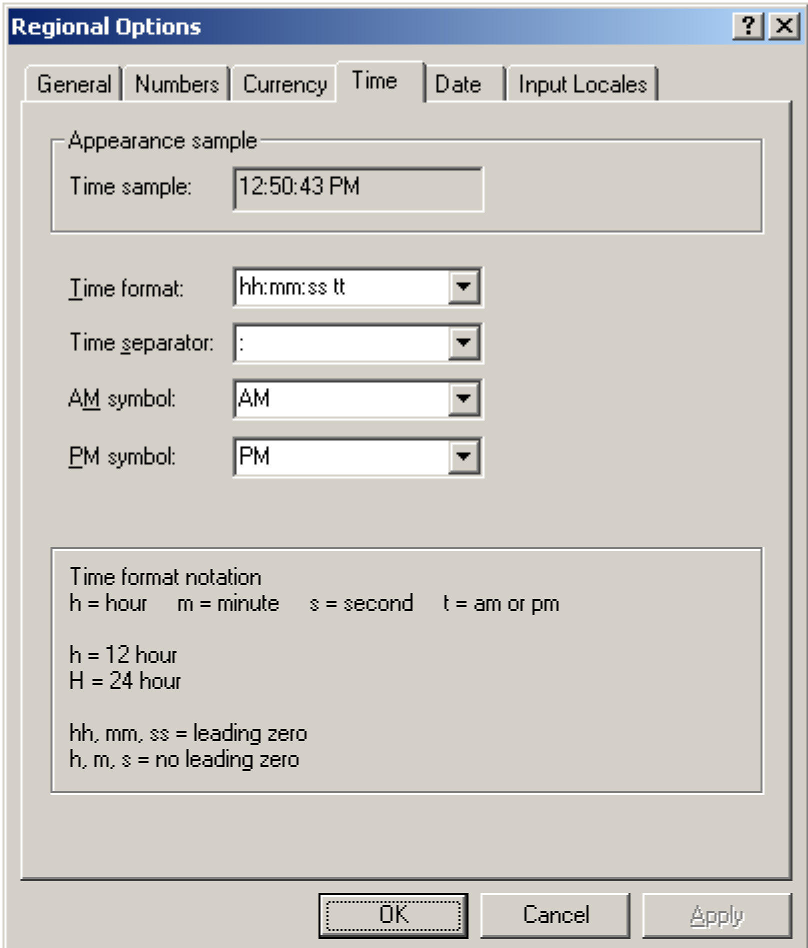
get_time - Notepad

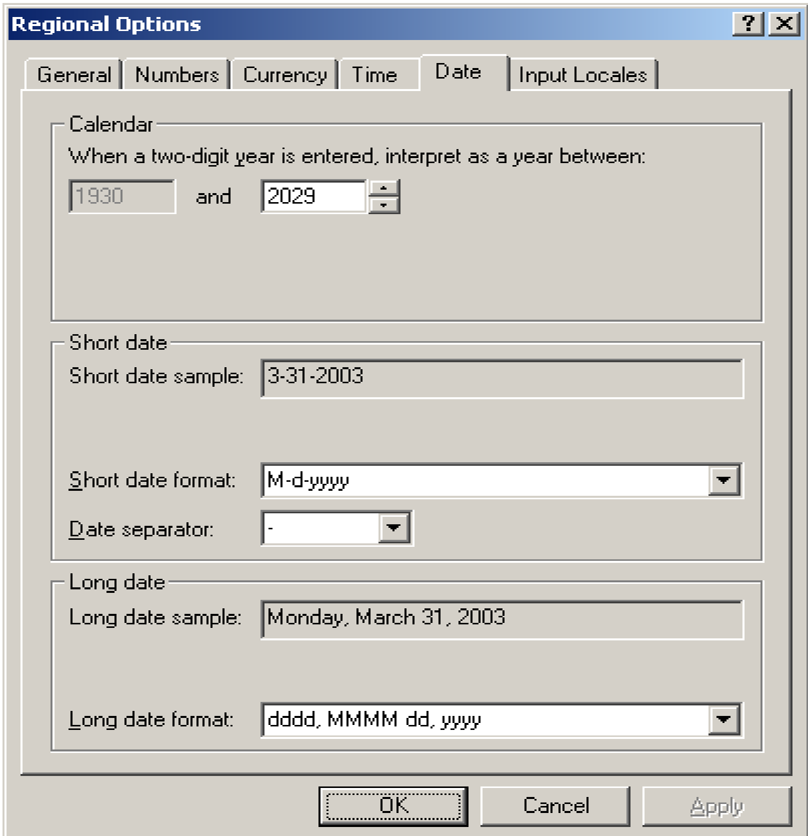
File Edit Format Help

```
@if not "%test%"=="y" echo off
goto s_%1

:s_
echo.
echo use:
echo    %0 set
echo or:
echo    %0 clean
echo or:
echo    %0 clear
echo.
goto end


:s_set
for /f "tokens=2,3,4 delims=/ " %%i in ('date /t') do call %0 date %%i %%k
for /f "tokens=1,2 delims=.: " %%i in ('time /t') do call %0 time %%i %%k %%j
goto end

:s_clear
set _ldate=
:s_clean
set _dt=
set _lusdate=
set _lldate=
set _lltime=
set _ltime=
set _lhour=
goto end

:s_date
set _lusdate=%2/%3/%4
set _lldate=%4/%2/%3
set _ldate=%4%2%3
goto end

:s_time
set _lhour=%2
set _lmin=%4
set _lap=%_lmin:~2%

set _lmin=%_lmin:~0,2%
if "%_lhour%%_lap%"=="12a" set _lhour=00


if "%_lhour:~1%"=="" set _lhour=0%_lhour%
set _lltime="%_lhour%-%_lmin%-%_lap%m"
set _ltime=%_lhour%-%_lmin%
set _lmin=
set _lap=
goto end

:end
```

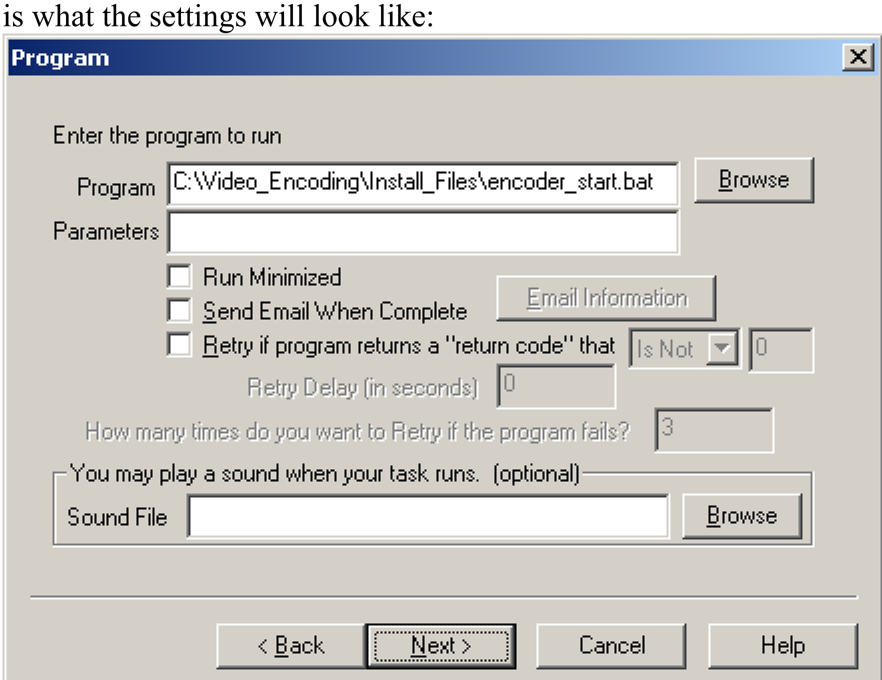
Now you MUST change the DATE and TIME format in Windows so that the logging of

files occurs correctly.
To do this, go to Control Panel then Regional Options. Change your formats so they look like this:





Now simply add this program to the EZ Scheduler as shown in the set up for Virtual VCR. Here is what the settings will look like:



Now you can schedule that however you like.