MOBILE ELECTRONIC CONFERENCING SYSTEM

by

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Report submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

SYSTEMS ENGINEERING

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February 1995

Blacksburg, VA
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(ABSTRACT)

The confluence of rapid technology developments in microelectronics, telecommunication, computers, networking and displays is making it possible to conceive of systems that offer new ways for people to interact and collaborate. Multi-user networking allows team collaboration for both application development and simulation while hardware and software modularity bring economy of scale. Advances in low power technologies and high energy density storage devices is making it possible to move these technologies off the desk and into the hands of mobile individuals. The human interface to these technologies is still largely unexplored but offers significant potential in applications that have a need for flexibility, improved information flow, and group participation at reduced costs.

This objective of this project is to develop a system that will increase performance and reduce costs associated with the interaction and collaboration of people who are remotely located from each other and who are engaged in team-oriented work. The Mobile Electronic Conferencing
System (MECS) is designed to solve a problem facing a large (fictitious) manufacturing firm, Macropolis, that has a large percentage of mobile and distributedly located employees who need to confer and share data in real time. Macropolis is not unlike other large corporations that need to find new ways to promote more efficient collaborative work.

The concept of MECS is based upon rapidly accelerating trends in microelectronics, displays, telecommunications, computers, information management, etc. that will make it possible to construct an affordable, high value-added system for remote collaboration within the next decade. The approach taken in this project is to design a workable system using technology that is available now. While current technology is limited in bandwidth, resolution, human-computer interfaces, computational speed and energy efficiency for portable equipment, this project shows that a cost effective system can be designed and beneficially used today. The MECS is designed to be modular so that new technologies can be incorporated as they become available. The MECS can also serve as a testbed for evaluating alternatives and to gain a better understanding of human factors issues associated with the efficient use and social acceptability of remote, electronic-based, conferencing in the future.
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1.0 INTRODUCTION

1.1 Project Background

Macropolis is a large corporation that develops and manufactures a wide variety of sophisticated household and industrial systems such as power systems, air conditioning and heating units, and electrical systems. The company, as illustrated in Figure 1, has approximately 90,000 employees; 50,000 are located in 3 manufacturing facilities, 20,000 in 2 research and development centers, 1,000 in the corporate headquarters office, and the rest in numerous warehouses and sales offices. The vast majority of the company's workers can be classified as mobile, meaning that they are not ordinarily located together with a fixed telephone and a computer. Since the corporation has adopted computer aided design (CAD), computer aided logistics support (CALS), and numerous other digital tools, almost all the workers require occasional to frequent access to digitally stored data.

Workers in all parts of the corporation require shared expertise. Whether the worker is a factory floor technician who needs help in identifying the source of a problem, a sales or service consultant who requires technical assistance about a product, or a researcher or design engineer who needs to collaborate on a project; they will be required to communicate
Figure 1. Macropolis' Distributed Network
and share data with a coworker who most often will be mobile or remotely located.

Macropolis estimates that it could save millions in lost productivity by providing nearly every employee with a device that allows them to have real time voice and data interaction from any location at any time. The following examples of the types of productivity savings are illustrated in Figure 2.

- The manufacturing facilities operate 24 hours per day in 3 shifts. Most of the manufacturing workers are located on the factory floor. When there is a problem, they must leave their post to find a process engineer to help with a solution. The process engineer then has to find a computer to look up data about the machine in order to find the right solution. This impacts the amount of time the line is running at its optimal rate. A system is needed that allows the worker to interact with a process engineer and to simultaneously look up information about the machine from the factory floor (see Figure 2a).

Often an employee does not require collaboration or assistance from another employee, but simply wishes to view data. Currently, the mobile employee needs to stop his or her current action in order to locate access to a computer.
Figure 2a. The Factory Floor:

i) A worker views schematics electronically.

ii) A process engineer communicates in real time with factory floor workers through voice and data stored in central computing facility and sent over the wireless local area network.

Figure 2b. The Field Agent:
A mobile field agent with a laptop computer and cellular modem confers and shares data with corporate, sales and technical representatives.

Figure 2c. Collaborative Design Projects:
Multiple system, manufacturing and design engineers confer and simultaneously share data for collaborative design project from various locations.

Figure 2. Conceptual Productivity Savings with MECS
to open a data file. A system is needed where the employee can access data files from his or her current location (see Figure 2a).

- Much of the company's sales and customer support staff are field agents. The field agents try to spend most of their time out of the office where they are the most productive. Often the sales or service representative needs to interact with an engineer at the home office. The representative must return to the home office to effectively confer with a technical expert while viewing supporting documentation. This takes time away from the field and slows the customer support down impacting service quality and efficiency. A system is needed that allows the representative to call remotely and view data while conferring with the technical support person (see Figure 2b).

- New products are designed and produced with corporate, research and development, and manufacturing engineers in collaboration with each other. These types of collaborative efforts require multiple participants who are often mobile or from remote locations to interact with each other and share data. This is currently accomplished through scheduled meetings where conferees must travel from remote locations.
The meetings are then supplemented by telephone calls which limits interaction to voice only. In short, collaboration among the remote employees is either limited by the expense of travel or limited by the effectiveness of phone, mail, and facsimile communications. A system is needed where multiple remotely located employees can interact effectively while viewing and annotating design or planning documentation at any time (see Figure 2c).

Macropolis wants to acquire a system that will give its employees a real-time capability for interacting and sharing data at all times and from any location. The system should support the following:

- Voice conferencing with 2 or more employees.
- Visually interacting with 2 or more employees.
- Data viewing and annotation by 1 or more simultaneous users.

Macropolis wants to use its installed equipment, particularly its current computer equipment and normal telephone links to remote sites and field agents. Macropolis would like a system that can be incrementally upgraded with their equipment in terms of software support capabilities. Macropolis anticipates that as more employees have access to
the system, there will be some increase in telephone traffic. The corporation is, therefore, willing to upgrade service to accommodate the increased volume. The corporation is also willing to add a wireless local area network for its buildings and large factories to accommodate intra-building communications.

Macropolis wants a generic and simple system so that all employees can use with very little training. The overall usage will vary from employee to employee. Macropolis predicts that the maximum usage per employee can be estimated at 5 continuous hours per day, while the average usage will be closer to 3 hours per day. The corporation will outfit a total of approximately 70,000 employees on an incremental basis. The capital equipment budget is restricted to less than $5,000 per employee to pay for the new system and any necessary upgrades required to support it. The total usage volume will increase as approximately 10,000 more employees are outfitted with the system each year. As the volume increases, the supporting network must be designed to accommodate the increased traffic. The network should be designed such that the probability of a blocked call does not exceed 5%.
1.2 Project Objective

The objective of this project is to design a commercial teleconferencing system that will support Macropolis' needs. It will provide a large number of mobile users with voice and visual communications and access to centrally stored data in real time. Voice and visual information will include an icon or character so that the speaker can be visually identified (e.g. machine operator #3, or corporate executive Charlie Jones), information about the state of the user (emotions, feedback, and general attention), and non-verbal cues for turn-taking. The system will also allow file viewing and annotation by a distributed set of users. The system will be limited by the bandwidth available within the company's wireless local area network and phone line connections.

This system will be referred to as the Mobile Electronic Conferencing System (MECS) throughout this paper. It is a paramount objective that MECS be simple to use and require virtually no training. MECS should behave more like an appliance such as a TV or telephone than a computer. MECS will have limited functionality and operate simply. It will have a generic design and be somewhat independent of software updates.
1.3 Project Limitations and Scope

The first version of this system will be designed with a fairly simple dataset. The icons or characters and scene objects will have low resolution. For future systems, the hardware design will remain relatively fixed. The software applications will, however, contain much more data and increase in capability and complexity until the scenes and participants appear realistic. Initially the user will have limited interaction. In the future, high-quality body sensors may become available that will facilitate more user interaction.

The MECS will primarily support three operations, 1) voice connection, 2) visual connection, and 3) file sharing. A voice connection that follows a procedure that is easy and simple to use will be established. The design and operating modes of the voice and visual connections will be structured and analyzed with the voice connection based on the standard telephone. The MECS will allow symbolic figures or animated characters to represent actual participants. The effectiveness of the non-verbal signals relayed by these figures or characters will be established in user testing.

The symbols or characters representing the participants must all be within view of each MECS user. The operating procedures for determining the user's location as well as the location of the other participants in the visual space will be
designed to function automatically so that all the participants will be accommodated within the field of view of MECS display.

Finally, a design will be established that will allow documents, presentation materials, and other electronic files to be viewed with MECS. This feature will allow participants to have access to the materials that they require for collaborative planning and education. The MECS will also have an electronic whiteboard capability which will allow participants to write annotations to files or a blank page and share them with the other participants.

This project is limited to systems engineering the design for MECS based on existing technologies. This paper does not propose to develop any new technologies. Only technology trends will be examined. This paper does not include detailed analyses relating to the development or cost of supporting systems, particularly servers, local area network (LAN) systems, or supporting software. The purpose of this project is simply to evaluate the potential for creating a MECS system.

1.4 Paper Organization

Chapter 2 describes the detailed requirements derived from top level performance, reliability, and maintenance requirements. The necessary functions to be performed will be delineated in the functional flow diagrams. The functional
analysis will highlight human factors issues in the operational sequence diagram.

Chapter 3 describes the allocation of functions to a possible set of system components. A top-level system design is established, followed by an analysis to establish the availability of components. Design tradeoffs will be analyzed to determine the optimum system architecture.

Chapter 4 outlines the system life cycle from development, testing, and evaluation to operation and utilization. Costs for design, development and production are provided. Market research data are used to determine production quantities and cost goals. The overall life-cycle cost (LCC) of the system is determined.

Chapter 5 discusses any conclusions relating to the overall feasibility of the system design and the potential for conducting a manufacturing program.
2.0 FUNCTIONAL ANALYSIS

2.1 Detailed Requirements

2.1.1 Environmental Requirements

MECS will be designed to operate in a home, office or industrial environment with moderate temperature and humidity variations, specifically 50 to 90 degrees F, and normal relative humidity. Because the system is portable, it will be designed to withstand moderate shock and vibration environment. More specifically, MECS will withstand an impact equivalent to a seven foot drop to a hard surface and a vibration equivalent to several thousand hours of residence on a mobile user (see section 2.1.2).

MECS will be required to establish connectivity with a resident computer to support many of its display functions. The system will also have to support reconfigurable data files to store user identification information.

2.1.2 Utilization Requirements

Only one user will be able to operate a single MECS unit at any given time. The typical user will have no training and will not be expected to perform any complicated maintenance procedures. It is assumed that MECS will generally be used
during normal working hours in an office or industrial facility 
or during waking hours in the home or classroom. Assuming a 
limited amount of usage per day allows for some down-time to 
perform simple maintenance procedures. If current televisions 
and telephones provide a reasonable indication, MECS will be 
used a maximum of 5 hours per day and an average of three hours 
per day and require very little maintenance.

Undoubtedly, there will be new technology developments in 
the areas of electronics and communications that periodically 
provide significant increases in capabilities to new MECS 
designs. For example, current personal computers are considered 
to be obsolete within approximately 3 years of purchase. A more 
conservative estimate of 7 years between purchase and 
obsolescence will be assumed. Thus, MECS be designed for a mean 
lifetime of 7 years. This results in the requirement for an 
average operating life of approximately 9100 hours.

2.1.3 Operational Requirements

MECS will be designed to support business or educational 
remote conferencing needs. The following requirements refer to 
the three basic types of functions MECS will perform: voice 
connection, visual connection, and file sharing.

2.1.3.1 Voice Connection.
It would be extremely difficult to generate a market for a system that is in any way inferior to the current telephone. Therefore, the voice must be of equal or better quality from current phone-line services which support signals from 300 Hz to 3100 Hz. The military has a slightly higher standard for acceptable voice quality stating that microphones and associated devices must respond to the that part of the speech spectrum most essential to intelligibility, or 200 Hz to 6100 Hz (ref.29). To put this in perspective, the human audible range is considered to be 20 Hz to 20,000 Hz.

The audio system will operate in a moderate to low ambient noise environment. It must be assumed that the users will be speaking into the microphone in the presence of environmental noise. The microphone must be sensitive enough to pick up signals even in the presence of a noisy background and similarly, the earphones must have a large dynamic range so that they can filter signals in the presence of noise. The audio scale intensity level of various sounds found in the environment is listed in Table 1. The reference audio intensity level on the scale is considered to be the threshold of hearing, and relative power levels are listed in terms of audio decibels (dBA). The maximum ambient noise level expected is somewhere between normal conversation and traffic noise, or about 65 dBA. The minimum ambient noise will be a whisper, or
about 20 dBA. The microphone must be sensitive enough to hear signals that are -45 dBA or lower. The headsets must have a dynamic range of >45 dBA.

Table 1. Sound Levels

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<tr>
<th>Sound</th>
<th>Intensity Level (dBA)</th>
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<tr>
<td>Threshold of hearing</td>
<td>0</td>
</tr>
<tr>
<td>Rustle of leaves</td>
<td>10</td>
</tr>
<tr>
<td>Average whisper (at 1 m)</td>
<td>20</td>
</tr>
<tr>
<td>City street, no traffic</td>
<td>30</td>
</tr>
<tr>
<td>Office, classroom</td>
<td>50</td>
</tr>
<tr>
<td>Normal conversation (at 1 m)</td>
<td>60</td>
</tr>
<tr>
<td>City street, very busy traffic</td>
<td>70</td>
</tr>
<tr>
<td>Nosiest spot at Niagara falls</td>
<td>85</td>
</tr>
<tr>
<td>Pneumatic drill (at 3 m)</td>
<td>90</td>
</tr>
<tr>
<td>Stereo at 10W (at 3 m)</td>
<td>110</td>
</tr>
<tr>
<td>Threshold of pain</td>
<td>120</td>
</tr>
<tr>
<td>Jet engine (at 50 m)</td>
<td>130</td>
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Source: Ref 28

The voice connection will be compatible with normal phone services so that a user with a normal telephone can establish a
voice connection with a MECS and vice versa. The voice
connection system shall operate in a manner similar to a normal
telephone, so that a novice user could operate MECS by making
an association with a telephone.

2.1.3.2 Visual Connection.

Graphics, symbology, and characters should be defined such
that the user can have an immediate, intuitive understanding of
their meaning. Users will be able to relay nonverbal cues to
other users through the visual scene by calling up symbology or
initiating actions of animated figures. For the first system
design, the cues will be limited. The following requirements
are related to the definition of the overall visual format with
which the viewer will be interacting.

- **Virtual Space.** The space in which the virtual conference
takes place should also be simple and intuitively
defined. A three-dimensional space with well-defined
space boundaries that correspond with the real world
should be used (ie. the floor should be below, ceiling
or sky should be above, etc.). The visual space will be
arranged automatically by MECS so that all participants
are within view of one another.
• **Turn-Taking.** Turn-taking cues will be in the form of symbology overlaid near or upon the corresponding character or a character motion. Two signals will be supported initially, a question or a comment. In addition, when the participants begin speaking, a visual cue (such as a highlight on the character) will be used to signify which participant is speaking.

• **Gestures.** Supported gestures will be a speaker pointing to another speaker to encourage a response, and a speaker pointing to a section of the whiteboard (other file sharing capabilities are discussed in section 2.1.3.3)

• **Expressions.** The expression of emotions, feedback, and general attention will take the form of character animation’s. These signals will represent six emotions: attentive, amused, puzzled, concerned, surprised, and distraction.

The visual system will be equipped with a personal display for each user. To make the system mobile while maintaining a comfortable viewing environment, the design solution should incorporate a head-mounted display (HMD). HMDs are a relatively
new industry, and while there is much to be learned about the
human factors requirements for using such systems, some basic
parameters can be used to generate an HMD design that is
acceptable to most users: field of view, binocular/monocular
configuration, resolution, eye relief, magnification,
luminance, color/grayscale display, modulation transfer
function, and latency. Each of these parameters is discussed
below.

2.1.3.2.1 Field Of View. A phenomenon known as simulator
occurs when a person’s visual frame of reference is
offset from his or her physical frame of reference. This
occurs frequently in simulators that provide visual cues
in the user’s peripheral vision and motion cues that do
not exactly correspond to one another. To avoid this
hazard with MECS, the field of view (FOV) of the HMD will
not be extended out into the user’s peripheral vision. A
maximum FOV of 40° will be an established design
parameter for MECS. Large FOVs are more comfortable for
viewing, therefore the maximum FOV obtainable below 40°
is required.

Though not directly related to FOV, the exit pupil is
defined as the area within which the image is visible
when viewing the optics. The pupil of the eye can be up
to 7 mm in diameter. The exit pupil should be designed to be larger than this so that the user can move the eye about without losing imagery. This helps establish a minimum FOV that should be large enough for the user to view the scene while moving the eye slightly.

2.1.3.2.2 Biocular/Monocular. Numerous factors are involved in choosing a binocular or monocular HMD system. Biocular systems are more comfortable than monocular systems because the user does not undergo any eye strain due to the mixture of focus distances and luminance values. Binocular systems provide the user with the opportunity for good depth perception. On the down side, binocular systems will certainly cost more and use more power than monocular systems due to the doubling of the number of displays. For a mobile system, the power usage is a significant issue, since the users would prefer to carry as little battery weight as possible. Another significant issue for mobile users is the relative safety of using a monocular system, which does not obstruct the user's vision of the outside world. A binocular display tends to isolate the user from the outside world which can be hazardous if the user is mobile. The monocular is also less cumbersome and can be made so that it can be
easily pushed out of the user's field of vision when the need arises. Since the graphics in the initial MECS unit will be relatively simple, the requirement for true depth perception does not exist. For this reason, and because of cost, power, safety, and environmental considerations, a monocular is more suitable for the MECS unit.

2.1.3.2.3 Resolution. Headaches and eye discomfort can arise from the user being forced to view a low-resolution display. Resolution can be determined from the number of pixels per inch in the display (a more common measure is line pairs per millimeter) versus the viewing distance of the display. A Snellen visual acuity of 20/20 corresponds to the eye being capable of resolving a minimum of 1 arcminute from a distance of 20 ft. Depending on the task, a lesser visual acuity might go unnoticed. For example, a 13-inch VGA monitor that has 640x480 pixels averages approximately 62 pixels per inch. When viewed from 20 inches, the resolution approximates 2.7 arcminutes, or a 20/50 visual acuity. Analogously, a visual acuity of 20/50 will suffice for several hours at a time if the viewer is watching a graphics display. This is the minimum goal for MECS.
2.1.3.2.4 Eye Relief. Eye relief is a measure of the distance from the rear of the viewing optics to the eye. Comfortable viewing dictates that the eye relief be as large as possible. For example, microscopes have a very small eye relief and are, therefore, uncomfortable to use. A larger eye relief requires larger display optics. Larger display optics add extra weight to the system, which increases the discomfort level. Therefore, it is generally advantageous to select the minimum comfortable eye relief. A common established parameter is the minimum eye relief required for users with glasses which is 25 mm.

2.1.3.2.5 Magnification. Magnification is a parameter used to describe the optics used in the HMD design. Since for an HMD the viewing distance is mere inches from the eye, the optics design becomes very important. Optics are required because the eye cannot focus on an object that is too close to the eye, as is the case with an HMD. The focal distance of the object must be adjusted to be comfortable while maintaining the specified FOV.

For MECS, the eye relief is established at 25 mm. Using the earlier example for resolution, a minimum comfortable viewing distance for the image can be taken as the
typical viewing distance of a computer monitor, 20 inches (50.8 cm). A simple geometrical optics approximation from the Gaussian lens equation yields the following:

\[ \frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} \]

where

\[ s_o = \text{object distance, 2.5 cm} \]
\[ s_i = \text{image distance, 50.8 cm} \]
\[ f = \text{the focal length of the lens} \]
\[ = \frac{1}{(1/2.5 + 1/50.8)} \text{ cm} \]
\[ = 2.38 \text{ cm} \]

It is evident by this formula that, as the image is projected at shorter distances, the focal length decreases, which corresponds to an increased refractive power of the lens. The dioptic power, \( D \), is a unit of measure of the refractive power of a lens. It is computed as follows:

\[ D = \frac{1}{f} = 0.4 \text{ m}^{-1} \]

Thus, the refractive power of the lens must be less than 0.4 diopter for the image to be projected a minimum of 20 inches away.
The required magnification, \( M \), of the lens can be expressed as:

\[
M = \frac{y_i}{y_o}
\]

where \( y_i = \text{image height} \)
\( y_o = \text{object height} \)

or, from similar triangles

\[
M = -\frac{s_i}{s_o}
\]

\[= \frac{-50.8}{2.5} \text{ cm}
\]

\[= 20
\]

The optics portion of MECS will likely require significant design effort.

2.1.3.2.6 Luminance. The display luminance is a measure of the light intensity output of the display system. It is commonly measured in lumens per unit area. The monocular HMD will be occluded, providing better viewability; however, it will be forced to compete with the level of ambient light. Table 2 ambient light levels:
Table 2. Luminance Values

<table>
<thead>
<tr>
<th>Source</th>
<th>mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar surface at midday</td>
<td>$10^5$</td>
</tr>
<tr>
<td>Snow in sunlight</td>
<td>$10^5$</td>
</tr>
<tr>
<td>White paper in sunlight</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Overcast sky</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Light level for reading</td>
<td>10</td>
</tr>
<tr>
<td>White paper in moonlight</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>White paper in starlight</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Overcast night sky</td>
<td>$10^{-5}$</td>
</tr>
<tr>
<td>Absolute threshold</td>
<td>$10^{-6}$</td>
</tr>
</tbody>
</table>

Source: Ref 5

The anticipated MECS environment will be indoors with artificial light mixed with some indirect sunlight. Accordingly, the luminance requirements will fall between 10 mL and $10^3$ mL.

2.1.3.2.7 Color/Greyscale. A color display is required so that the users can more readily distinguish characters and symbols. Full color is not required for the expected
type of graphics that will be used. A multicolor display will be sufficient. A multiple grayscale display is also required to enhance shading of polygons and increase the effect of depth perception.

2.1.3.2.8 Modulation Transfer Function. The modulation transfer function (MTF) is based on linear system theory. It is a characterization of image quality as the image is transferred through the optical system. The optical system will have modulation effects on the display image, including intensity variation, magnification, diffraction, and aberration. Applying linear system theory, the output of the display system can be determined from the input and the systems transfer function. In the case of the MTF, the spatial frequency of the display image is modified. The complete transfer function is the optical transfer function (OTF). The MTF is the magnitude of the OTF. The phase is the phase transfer function (PTF). The PTF is generally of less interest since phase shifts occur offaxis. The MTF has become the widely used means of specifying performance.

Traditional measures of contrast and resolution are contained in the MTF. The MTF, as the spatial frequency approaches zero, is related to contrast ratio as follows:
DC modulation = (contrast ratio - 1) / (contrast ratio + 1)

Resolution is roughly the spatial frequency at which modulation falls to zero. This illustrates a key point in the optical system design; that is, the nominal resolution of the display system is not the maximum displayable pixels per line, but the highest spatial frequency that can be observed through the system. Since the number of display pixels per inch is generally a cost driver, the optics designer will design the system to match the resolution.

Resolution and contrast describe the performance of the system at only two frequencies: zero and the limiting resolution of the display. The MTF describes the response of the display system at all intermediate frequencies, which are also significant to image quality. Good MTF values will vary from 0.9 near DC to 0.3 for a large portion of the spectrum. The MTF will be used as a measure of the overall success of optics system design.

2.1.3.2.9 Latency. From the display industry, we know that latency is noticeable below 20 Hz update rates and flicker is noticeable between 20 Hz and 50 Hz. Thus, the
common RS-170 video standard was developed, which has a 30 Hz frame update rate for no perceptible delay and a 60 Hz field update rate that is interlaced for no perceptible flicker. To the degree possible, the MECS visual connection will be required to adhere to these minimum standards. As an exception, some latency can occur in updating scene changes, visual cues, animation movements, or file-sharing functions. However, the sequence of events should be closely controlled. This will prevent problems such as gesturing to a file that has not been opened or initiating a command unintentionally.

2.1.3.3 File sharing.

Users will be able to retrieve and view documents, presentation materials, and other electronic files that are available over the supporting data network; communicate with written text or sketches through an electronic whiteboard; and annotate portions of viewable files. Cues will be given to indicate which participant is pointing to or annotating the whiteboard or a file. The graphical user interface for viewing and annotating files will be simple and intuitive.
2.1.4 Mechanical Requirements

MECS will be a portable system consisting of two distinct parts: a head-wearable apparatus for audio communications and viewing the display, and a portable handheld apparatus for mounting controls and a function input system. The head-wearable apparatus will be of minimal size and weight, and it will be properly balanced for user comfort over several hours of wear. To minimize weight and maximize comfort, only the those electronics that are absolutely necessary will be worn on the head. Most of the electronics modules will be contained within the hand-held unit.

The handheld apparatus will be light, portable, and rugged so that it may be used in a mobile environment. All system components will be packaged to fit into either of the two parts. Packaging will be optimized for comfort, ease of use, and user preference.

The number of controls will be minimized for reduced complexity. The controls will include a function input pad for dialing a voice connection and implementing gestures and other commands. The head-wearable and handheld portion will be designed so that they can be placed together in a convenient carrying case, when the system is idle.
2.2 Functional Analysis

The basic functions listed below serve as an outline to define the overall system design. The functions may undergo slight adjustments after the product prototype is developed and customer utilization feedback is analyzed. The functional flow overview is illustrated in Figure 3.

Figure 3. Functional Flow Overview
2.2.1 Startup

The system startup procedure shown in Figure 4 will be transparent to the user, who only needs to activate a power-on function. After receiving the power-on signal, the handheld unit and headset will start the initiation procedure.

![Figure 4. Start Up Procedure](image)

2.2.1.1 Initiate Power System. The user initiate the power system by activating a power on switch located on the handheld unit. The power system then attempts to power on the headset.

2.2.1.2 Power-on Headset. When the headset is powered on, it undergoes a series of built in tests (BITs) to check the status of each of its subsystem modules as shown in Figure 5.
2.2.1.2.1 Power system BIT. The power system for the headset must support all the communications components and the display. The power system will be examined for the level of source voltage. If the correct voltage is being received by the headset, an external light emitting diode (LED) indicator light will turn on; otherwise the indicator will remain off. This will alert the user to troubleshoot for a loose connection or dead batteries at the source.

2.2.1.2.2 Display BIT. The BIT for the display system should be to illuminate the display. If the power-on light is operating and the display is not, this will alert the user to a malfunction in the display system.
2.2.1.2.3 Audio Module BIT. The audio module will support an audio receiver system and a microphone audio output system. The audio speakers and microphone systems will undergo separate BITs. If they are completed successfully, the user will hear a positive signal (i.e. a beep). The absence of a beep will alert the user to troubleshoot for an audio system problem.

2.2.1.3 Power-on Handheld System. When the handheld unit is powered on, it undergoes a series of built in tests (BITs) to check the status of each of its main functional component modules shown in Figure 6.

![Diagram of Power on Handheld System](image)

Figure 5. Power on Handheld System
2.2.1.3.1 Power system BIT. The power system for the handheld unit must support the input device, the renderer module, and the wireless LAN (WLAN) transceiver, and supply power to the headset. The power system will be examined for the level of source power. If the correct voltage is being received by the unit, an external LED indicator light will turn on, otherwise the indicator will remain off. This will alert the user to troubleshoot for a loose connection or dead batteries at the source.

Assuming that the power system uses rechargeable batteries, the level of charge left in the battery is an important indicator. This information will be passed on to the renderer and subsequently displayed to the user. The user is expected to maintain proper charging of the batteries.

2.2.1.3.2 WLAN transceiver BIT. The WLAN transceiver will have three functions: it will support two-way audio communications, it will transmit low-rate data from the input device, and it will function as a high-bandwidth receiver for graphics data. The BIT will verify these functions by sending both an initializing audio signal and a data signal to the server via the WLAN. The server is tasked with responding with its own initializing audio and data signal.
MECS will wait a designated amount of time for both an audio and data response. If the audio signal is received, a signal (e.g. two-tone beep) is transmitted through MECS audio system to the user. If the audio signal is not received, an error is sent to the renderer module and displayed. If the correct initializing data message is received, a message is sent to the renderer and displayed. If no data response or an improper data response is received, an error message is sent to the renderer and displayed. Both the audio channel and the data channel will continue to attempt to initialize until MECS is turned off.

2.2.1.3.3 Renderer module BIT. The renderer will be tested by displaying the BIT initialization results from the power module BIT and the communications module BIT. An improper display will be visible to the user.

2.2.1.3.4 Input device BIT. The input device will be tested in operation. The user will either attempt to initiate a command or generate a pointer icon. The input device failure will immediately be visible to the user.

2.2.1.4 Render Options Menu
The options menu shown in Figure 7 is the top-level menu displayed at the startup of MECS. Commands that are activated on this menu are sent directly to the server where program information is stored. From here, the user has three options:

- Initiate the call by activating the Call Menu.
- Activating the Configuration Menu.
- View the file, thus bypassing all MECS communications functions.

![MECS Options Menu](image)

Figure 7. MECS Options Menu

2.2.1.4 Activate Configuration Menu (Optional)

The Configuration Menu will enable the user to change MECS software configuration, such as the user name or other identification parameters. Commands that are activated on this
menu are sent directly to the server where program information is stored. When the user exits this function, the Options Menu returns.

2.2.1.5 Activate Call Menu

The Call Menu is used for the user to input a desired recipient identification number and subsequently to initiate a call. Commands that are activated on this menu are sent directly to the server where program information is stored. This Call Menu is shown in Figure 8.

![MECS INITIATE CALL](image)

Figure 8. MECS Call Menu
2.2.2 User Inputs Desired Addressee(s)

The procedure for selecting a recipient to contact with MECS will have some flexibility, as shown in Figure 9. The Call Menu is used as the input device.

Figure 9. User Inputs Desired Addressee(s)

2.2.2.1 User Enters Recipient Phone Number or Alias

This function is activated by selecting numbers from the keypad shown in the menu. The selected numbers will appear in the selection window. The user will have the option of entering an identification number or predefined alias (starting with \#) for the desired recipient.

2.2.2.2 User Selects to Choose a Name from Stored List

This function is selected by activating the Choose Names button. From here, a list of predefined names that were stored on the central server with corresponding identification numbers
will appear. The list may be updated via a computer or workstation. The user may select one or several names from the list. These names will appear in the select window.

2.2.2.3 User Selects Clear (Optional)

The clear option erases all the information currently in the selection window.

2.2.2.4 User Selects Exit (Optional)

The exit option quits the window and brings the user back to the options menu.

2.2.2.5 User Selects Connect

The connect command sends the selected identification numbers to the central server with the instruction to initiate a MECS call.

2.2.3 Initiate a MECS Call

The procedure for initiating a MECS call via connection through the central server is outlined in Figure 10. The server will be configured with an instruction set for supporting all MECS functions.
Figure 10. Initiate a MECS Call.

2.2.3.1 Render Conferencing Environment

The conferencing environment will be a fixed design for the initial version of MECS. This will enable the scene to be rendered from a limited number of objects that can be previously stored together with a simple set of instructions. The complete set of objects required to render the conferencing scene will be provided to each MECS server. Selected object attributes will be updated in real time.

The initial MECS conferencing environment is depicted in Figure 11. It is designed such that each MECS user will have a direct view of all the participants. The setup will consist of tables and chairs in a room with some degree of geometrical depth to replicate an environment that is familiar to the user. Each of the participants will be represented by a virtual character or symbol. Initially, blank shadows will represent potential participants for which the server is currently trying to establish connections. A large screen above the participants
is will be used for file sharing. The screen will also display current commands that are available to the user at all times.

Figure 11. Initial MECS Conferencing Environment

The rendering process takes place initially at the central server and is then transferred to MECS at some point prior to display. The rendering process is shown in Figure 12.
2.2.3.1.1 Retrieve Objects From Database. MECS database objects required to render the scene will have been recovered by the central server.

2.2.3.1.2 Construct 3-D Objects. Standard software will be used to construct 3-D objects as they are currently defined.

2.2.3.1.3 Add Lighting and Shading. The objects will have texture attributes. Lighting and shading parameters will be predefined and stored in the central database.
2.2.3.1.4 Find 3-D Projection. The conference scene will be constructed from the point of view of the user. This will also be predefined and stored in the central database.

2.2.3.1.5 Clip to View Size. Once the point of view has been constructed, the scene can be reduced to the FOV that is viewable by the user.

2.2.3.1.6 Order Polygons in Depth. The polygons will be placed in the order that they are visible from the point of view of the user.

2.2.3.1.7 Remove Hidden Polygons. All polygons determined not to be visible by the user will be eliminated from the record.

2.2.3.1.8 Transmit Ordered Polygons. All visible polygons will be transmitted over the WLAN to MECS to be displayed.

2.2.3.1.9 Convert Polygons to Raster. Prior to display formatting, the polygons in the scene will be translated into a raster file. To speed the process, the area of the display can be broken down into blocks. Each of the blocks in parallel can construct the polygons to raster format.
2.2.3.1.10 Store Raster Blocks in Frame Buffers. The display area will be reconstructed and put into a frame buffer.

2.2.3.1.11 Convert Frame Buffer Data to Display Format. The entire raster file will be converted into the exact signal format required to drive the display.

2.2.3.1.12 Send Frame Buffer Output to Display. The converted signal will be sent as output to the display drivers.

2.2.3.2 Activate Options Menu

Once the initial conferencing scene is constructed, the options Menu that appears in the overhead screen will be activated.

2.2.3.3 Instruct Server to Connect Addressee(s)

The server will have instructions required to read the recipient's identification number and to distinguish whether it is a telephone number or a MECS number. The server will then attempt to initiate either a voice-only call or a data connection as well. If the server is trying to contact another MECS, it will need the proper identification number to locate it in the recipient's own designated server.
2.2.4 Alert Addressee(s)

A signal attempting to notify the recipient of an incoming call will be sent by MECS server. The various outcomes of the alert signal path are depicted in Figure 13.

Figure 13. Alert Addressee(s)

2.2.4.1 Send Alert Signal to Addressee(s)

The server will attempt to locate the identification number and transmit an intent to initiate a connection.

2.2.4.2 Invalid Address or No Response?

Several outcomes may result when the location is attempted. For both voice and MECS connections, the call must first be received. An error is indicated if the call does not go through or there is no response after a specified amount of time. For a MECS connection, the identification number may not
be recognized by the connected server. This, too, would result in an error.

2.2.4.3 List Connection Status in File Window

While an error condition does not exist, the current status of the connecting call(s) will be displayed.

2.2.4.4 Alert User and Terminate Call

If an error condition arises, MECS will update the status screen to indicate that there was a failed connection along with a brief description of the type of failure that occurred.

2.2.5 Connect Addresssee(s)

Establishing a connection with a recipient requires several actions as is illustrated in Figure 14.

![Diagram](image)

Figure 14. Connect Addresssee(s)
2.2.5.1 Receive Addressee(s) Response

The recipient response that the connection has been opened will be transmitted back to the server for action. The server will then immediately identify the recipient as a MECS call or a voice line via the identification number that was used. At this point, the recipient will become classified as a participant.

2.2.5.2 Identify Addressee(s) as Voice Only

If the participant was identified as a voice-only call, the server will render a 3-D speakerbox icon in place of the animated figure in the conference. The server will then initiate a voice-only connection.

2.2.5.3 Identify Addressee(s) as MECS

If the participant was identified as a MECS, the server will request that an animation file be sent, if one has not been received.

2.2.5.4 Render Speakerbox Icon in Scene

The speakerbox icon will be rendered from a stored object that is standard for MECS scene. The rendering process will occur as was described in section 2.2.3.1.
2.2.5.5 Send Animation File to MECS Addressee(s)

The server will immediately send an animation file to all identified MECS participants. The animation file will consist of a small data file listing attributes such as hair color, eye color, flesh tone, etc., that the user has previously stored as part of the configuration file. The attributes will be part of a standard, limited set of the object attributes associated with the animation character that can be modified.

2.2.6 Retrieve Animation Files From MECS Participants

The animation files make the animation character unique by modifying certain features. This adds a sense of association to the characters that are being rendered in the scene to the actual participant. The functions associated with this are illustrated in Figure 15.

![Diagram](image)

Figure 15. Retrieve Animation Files for MECS Participants

2.2.6.1 Display Pause for MECS Connection
While the animation files are being retrieved and the new object files are being constructed, a pause message will be transmitted to the user's screen.

2.2.6.2 Receive Animation Object File from Addressee(s)

Animation files associated with each MECS participant will be used to update object files, which are the basis for the construction of their animated characters in the scene. The files consist of a list of data attributes described in section 2.2.5.5 above.

2.2.6.3 Server Constructs Characters From Object File

Each participant will have an associated object file that is used to construct the animated character. Following receipt of the animation file, each character will be constructed with the new modified attributes.

2.2.7 Render/Activate Scene

The final MECS conferencing will incorporate all the updates received from the participants. One might appear like the scene depicted in Figure 16. The following final actions required to ready the scene are shown in Figure 17.
Figure 16. MECS Final Conference Scene

Figure 17: Render/Activate Scene
2.2.7.1 Server Reconstructs Conferencing Environment to Adjust for Participants. This function applies to situations where not all of the connection attempts were successful. In this case, the shadow characters in the scene that cannot be associated with participants are removed and the scene is resized to fit the actual number of participants. The resized scene will be constructed and rendered as described in section 2.2.3.1 above.

2.2.7.2 Transmit "OK" Status to Addressee(s)

When all the participants are in place in the scene, an "OK" signal will be transmitted to the participants to indicate that MECS is ready for conferencing.

2.2.7.3 Activate Animation Functions Upon Receipt of "OK" Status. The icons that are used to initiate the animation functions are depicted in Figure 16. They will be displayed at all times on the bottom of the screen. Their activation must be preceded by the "OK" status from the other participants to insure that the activated function is transmitted to the other MECS.

The animation functions operate by initiating a command to the server to send an attribute change associated with the scene environment or the character to all MECS participants. The functions are limited to a small set in the initial MECS
design. The functions and their associated icons are as follows:

- Annotation. The user may initiate a pointer or a cursor display that will be visible to the other participants. The cursor will be capable of highlighting and annotating areas of the whiteboard. Only one MECS participant at a time will be allowed to activate the annotation function.

- Question. The user will be able to indicate that he or she has a question. When this is activated, the user’s animated character will have a question symbol displayed with them.

- Comment. The user will be able to indicate that he or she has a comment. When this is activated, the user’s animated character will have a comment symbol displayed with them.

- Attentive. This function sends a message which is translated by other MECS into attentive animated body language and facial expressions in the user’s rendered character. This is the default character state.
• 🤔 Confused. This function sends a message which is translated by other MECS into confused animated body language and facial expressions in the user's rendered character. This can be used to provide feedback to the speaker.

• 😂 Amused. This function sends a message which is translated by other MECS into amused animated body language and facial expressions in the user's rendered character. This can be used to provide feedback to the speaker.

• 😲 Surprised. This function sends a message which is translated by other MECS into amused animated body language and facial expressions in the user's rendered character. This can be used to provide feedback to the speaker.

• 😳 Distracted. This function sends a message which is translated by other MECS into amused animated body language and facial expressions in the user's rendered character. This can be used to signify that the user has been temporarily disrupted.
2.2.8 Begin Voice Communications

Voice communications will be established after the scene has been completed and activated. The one exception is that for participants with voice-only connections, voice communications will not be delayed for the scene construction. The process for establishing a voice connection is shown in Figure 18.

![Diagram showing the process of establishing voice communications](image)

**Figure 18. Begin Voice Communications**

2.2.8.1 Activate Audio System

The microphone and earphones will be activated to transmit and receive audio signals.

2.2.8.2 Open Voice Connection

The voice connection line through the server will be opened, and all audio signals received into the system will be transmitted.

2.2.9 Open File Sharing.

The functions relating to file sharing are illustrated in Figure 19.
2.2.9.1 User Selects View File

Each MECS participant has the option of initiating a file sharing function. This action calls up an Open File menu to the screen from which files can be searched and selected.

2.2.9.2 User Selects Close File

When a file that has been opened by the user is currently being viewed on the screen, the user will have the option of closing the file.

2.2.9.3 Deactivate View File for Other Participants

When a user has selected a file for sharing, the View File option becomes deactivated for all MECS participants. This is
to prevent multiple files from being overlaid on the screen, which would cause almost certain confusion among participants.

2.2.9.4 Activate View File for Other Participants

When the file has been closed by the user, the View File option automatically becomes enabled for the other participants.

2.2.9.5 Obtain File From Server in View-Only Mode

When a file is selected from the open file menu, the server searches for the file. If the search is successful, the file is opened into a view-only mode and displayed on MECS screen.

2.2.9.6 Close File

This command activates a Close File function. This will initiate a request to all MECS participants to save the current view. If any annotations have been made, the user will also be requested to save the view under a file name prior to exiting.

2.2.9.7 Activate Browse

When a file is displayed on the screen, all of MECS participants will have the option of browsing through it.
2.2.9.8 Deactivate Browse

When any MECS participant highlights a portion of the file with a pointer, the browse option is disabled for the other participants. This is to ensure that the effect of the highlighted portions is transmitted to all the participants.

2.2.10 Shutdown

A shutdown option will be available to all participants. It will be the method for exiting a conference. The shutdown process is shown in Figure 20.

![Shutdown Process Diagram]

Figure 20. Shutdown Process

2.2.10.1 Close File

If a file remains open on the display, a command to close the file will be activated. Subsequently, a request for the user to save the changes made to the file under a default file name will be activated.
2.2.10.2 Close Connections

A disconnect option can be activated during a MECS call or at shutdown. Both the voice and data connections will be closed and the options menu will return to the display.

2.2.10.3 Render Options Menu

After the connections have been terminated, the Options Menu will reappear on the screen.

2.2.10.4 Disconnect Headset

The user can disconnect the headset manually. This will result in a shutdown in power to the headset subsystems while leaving the MECS active in anticipation of an incoming call.

2.2.10.5 Initiate Power Off

The user can initiate a power off sequence by manually disengaging the power switch located on the handheld unit.

2.2.10.6 Power Off Headset

Powering-off the headset unit will automatically result with the initiation of a power-off sequence. Upon completion of the sequence, the LED indicator light will go off indicating that power is off.

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2.2.10.7 Power Off Handheld System

The user must select the power-off function on the handheld unit for a complete shutdown. The power-off sequence which will be transparent to the user. Upon completion of the sequence, the LED indicator light will go off indicating that power is off.

2.3 Operational Sequence Diagram

The operational sequence diagram shown in Figure 21 illustrates the sequence of events in the operation of the MECS as they are currently defined.
Figure 21. Operational Sequence Diagram
<table>
<thead>
<tr>
<th>Operator</th>
<th>MECS 1</th>
<th>Server 1</th>
<th>Server N</th>
<th>MECS N</th>
<th>Operator N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 Press Change Configuration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User Press OK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fig. 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change Parameter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fig. 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6 Activate Call Menu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fig. 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.0 USER INPUTS DESIRED ADDRESSEE(S)

2.1 Enter #s From Keypad
| Display #s In Enter Window |
| Fig. 5 |
| Select Name(s) From List |
| Display Name(s) In Enter Window |

2.3 Select Clear

2.4 Select Exit

2.5 Select Connect
| Send Select Connect |
| Fig. 9 |

3.0 INITIATE A MECS CALL

3.1.1 Retrieve Scene Objects from Memory
| 3.1.2 & 3.1.3 Connect 3-D Scene |
| 3.1.4 Convert to 2-D View |
| 3.2 Render Options Menu in Scene |
| 3.3 Send Connect Address(es) |
| 4.0 ALERT ADDRESSEE(S) |

Figure 21 Cont. Operational Sequence Diagram
Figure 21 Cont. Operational Sequence Diagram
Figure 21 Cont. Operational Sequence Diagram
Figure 21 Cont. Operational Sequence Diagram
3.0 SYSTEM DESIGN

3.1 Top-Level System Design

The top-level system design is shown in Figure 22. It is envisioned that MECS will have two main subsystems: the headset and the handheld unit. It will require a supporting infrastructure designated as the server system.

The headset will be small, lightweight, and comfortable. It will consist of a monocular display, a microphone, earphones, and supporting electronics. The packaging will be sleek with careful attention to balancing weight for the most comfort. The fit and display adjustments will be designed for large variations in head sizes and user preference.

The handheld unit will also be small and hand-portable. The handheld unit will house much of the supporting electronics to minimize weight on the headset. It is envisioned to be a single integrated unit consisting of a pen-input tablet, a WLAN transceiver, two electronics subsystems that will support the display generation (a renderer and scan converter), and a power subsystem. The pen input tablet will cover the top portion of the unit; the electronics will be housed in the base.

The required supporting infrastructure will consist of a central computer server that can be accessed through a WLAN network, and a standard analog phone line with a modem.
MOBILE ELECTRONIC CONFERENCING SYSTEM
TOP LEVEL SYSTEM DESIGN

SERVER SYSTEM
- WLAN TRANSCEIVER
- SERVER
- MCDEM

HEADSET
- DISPLAY OPTICS
- AUDIO SYSTEM
- DISPLAY
- DISPLAY ELECTRONICS
- POWER DISTRIBUTION SYSTEM

HANDHELD UNIT
- WLAN TRANSCEIVER
- PEN INPUT DEVICE
- SCAN CONVERTER
- RENDERER
- POWER SYSTEM

Telephone Line
- Wireless DataLink
- Audio signal
- Data signal
- AC Power
- External charging port

Figure 22. Top Level System Design
3.2 Requirements Allocation

The mechanical and functional requirements described in section 2.0 are allocated to various systems and subsystems as is shown in Figures 23 and 24. The system will be designed to meet the goals outlined in this preliminary system configuration.

Figure 23. Mechanical Requirements Allocation
3.3 Maintenance Concept

Three levels of maintenance will be planned for MECS, an organizational level maintenance, an intermediate level maintenance, and depot level maintenance activity. The actions
performed at each of these activities are outlined in Figures 25, 26, and 27.

The organizational maintenance activity will be performed by the MECS consumer. The consumer will have no training in maintenance. The consumer will have access to a users guide which when combined with MECS BIT capabilities, will allow him or her to isolate the fault to the subsystem level. The troubleshooting procedure will be simple and straightforward so that someone with a remedial education can perform the tasks.

Figure 25. Organizational-Level Maintenance Concept
The intermediate level maintenance activity will be performed by the MECS retailer. Like the consumer, the retailer will have no training in maintenance but will be required to understand the users guide and an additional repair manual. The retailer will repeat the troubleshooting procedure to isolate the fault to the subsystem level as is outlined in the users guide. The repair manual will explain the troubleshooting procedure in greater detail as well as describe how to remove the subsystems. The retailer can then ship the faulty headset or handheld unit to the manufacturer or can attempt to remove the faulty subsystem for shipping as outlined in the repair manual.

**INTERMEDIATE LEVEL MAINTENANCE CONCEPT**

![Diagram of headset and handheld unit with subsystems]

Figure 26. Intermediate-Level Maintenance Concept

Depot maintenance will be performed by the manufacturer. The manufacturer will employ trained technicians to perform
diagnostic testing on the faulty subsystems. They will isolate the fault to the component level. The faulty component will then either be shipped back to the component manufacturer for repair or disposed of. The new or repaired component will be placed into the subsystem and diagnostics repeated until it is operating properly.

DEPOT LEVEL MAINTENANCE CONCEPT

![Diagram of maintenance concept]

Figure 27. Depot-Level Maintenance Concept

3.4 Design Tradeoffs

There are tradeoffs that must be evaluated prior to specifying a final system design. Each subsystem will have tradeoffs that impact the overall cost, performance, and availability of the system. These tradeoffs are highlighted in section 3.5. As part of the development effort, these tradeoffs should be analyzed carefully. It is recommended that several alternative designs be analyzed and costed using the methodology in sections 3.5 and 3.6. The designs may be further optimized through modeling of overall performance factors.
3.5 Subsystem Specification

Each of the subsystems will be defined as part of a preliminary overall design. Requirements for more detailed component definition will be addressed.

3.5.1 Display

The display selection is a critical decision since it has a tremendous impact on most of the other subsystems and greatly affects overall cost and performance. The display constrains the optical solutions, driving electronics configurations, bandwidth requirements, and subsequently power and weight requirements.

The FOV and resolution requirements strictly limit the choice of display. Although it is stated that the FOV should be less than 40 degrees, it is desirable to have the widest FOV possible within that limit. The number of pixels is related to FOV and resolution as follows:

\[
\text{FOV/resolution} = \text{pixels}
\]

This relationship is plotted in Figure 28.
The plot is significant because it highlights standard pixel counts for displays. Using a standard display will be an important tradeoff for MECS given that the electronics required to drive standard displays will be more available. A standard display will also simplify software development. Starting with the 2.7 arcmin resolution requirement we see from the graph that a 1,000-pixel display will provide more than 40 deg FOV or greater than 2.7 arcmin resolution. This actually exceeds the requirement at the expense of higher bandwidth, overhead, etc. A 750-pixel display will provide a 30 deg FOV at 2.7 arcmin. This might be a good option; however, there are currently no...
flat panel displays available at this resolution. CRT displays require a large optical chain, adding orders of magnitude more weight than a flat panel; therefore, a flat panel display is imperative. VGA resolution (640 x 480 pixels) is currently coming available for small, color flat panel displays. A 640 x 480 display will approximate a 30 x 23 FOV. This is a very good option given that 640 x 480 resolution conforms to a widely used display standard. This appears to be the best choice for now.

Three technologies are available for a 640 x 480 resolution color flat panel display. A transmissive active matrix liquid crystal display (AMLCD) which uses a single backlight and three stacked color filters, a reflective liquid crystal display (LCD) reflects light off of three color LEDs; and an active matrix electroluminescent (AMEL) display, which starts with a 1280 x 1024 display and uses spatial filters to achieve color with a 640 x 512 display.

LCD technology has the advantage of being a relatively mature technology. LCD technology is based on the fact that liquid crystals can be aligned by an electric field. When polarized light is shone on them, they are transmissive or reflective depending on their alignment. Backlit LCDs operate by shining a backlight through a layer of liquid crystal inside a transparent glass. Reflective LCDs rely on a mirror-like
coating behind the liquid crystals to reflect ambient light
back that penetrates the display. This makes them much more
efficient than transmissive LCDs. Ferroelectric LCDs are
bistable, which means that they can be driven to a stable on or
off state. They require lower threshold voltages and have a
longer memory. As a result, the liquid crystals remain aligned
longer after the voltage has been removed. Ferroelectric LCDs
have a tendency to be more power efficient than conventional
LCDs.

Electroluminescent (EL) technology is defined as the non-
thermal conversion of electrical energy into luminous energy.
LEDs are a common application of EL technology. LEDs have a
high brightness capability and can be extremely efficient
depending on the source material. Gallium arsenide (GaAs) is
very efficient for red light emission, and gallium phosphide
(GaP) is also efficient for green light emission; however, an
efficient blue source material is not yet available, reducing
the overall efficiency of a color LED display. AMEL displays
operate by placing a thin phosphor layer between electrodes,
creating a phenomenon whereby light is emitted when high-energy
electrons impact the phosphor. This process is extremely
efficient, with virtually all of the energy being converted
into light. Unfortunately, this requires a large field to be
maintained between the electrodes. Again, the phosphor has a large effect on the overall efficiency of the display.

Assuming that further analysis determines that the cost and quality of the three displays to be nearly equivalent, Table 3 shows a preliminary comparison based on the overall efficiency and complexity of the supporting electronics. The reflective LCD technology will be selected for our prototype design based on this preliminary comparison. It appears to have the most potential for operating with reduced power requirements and simplifying the electronics design, which has the added benefit of further reducing power requirements.

The overall power requirements to drive the display can be determined from the luminous efficiency, 0.2 L/W. The illuminance requirement was stated earlier as 0.01 L to 1 L. This translates into the following power requirements:

Minimum power: 50 mW
Maximum power: 5,000 mW
Average power: 250 mW
Table 3. Comparison of Display Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Typical Luminous Efficiency (Lumens/Watt)</th>
<th>Power Supplies</th>
<th>Frame Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color AMEL*</td>
<td>0.2</td>
<td>-3V, 5V, 7V, GND, (high voltage 180V to 250V)</td>
<td>&lt;70</td>
</tr>
<tr>
<td>Color AMLCD with backlightb</td>
<td>0.1</td>
<td>20V, 10V, 5V, GND</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Reflective LCD with LEDsc</td>
<td>0.2</td>
<td>5V, GND</td>
<td>72</td>
</tr>
</tbody>
</table>

aSource: Ref.19
bPreliminary data, source: Ref.20
cPreliminary data, source: Ref.21

The maximum power of 5 W might not be acceptable to the overall system. This should be analyzed further; for the interim, the maximum brightness requirement will be compromised and reduced to a more acceptable 0.2 L, which yields a maximum power requirement of 1 W.
3.5.2 Display Optics

The display optics design will be analyzed based on the initial requirements and the two new display parameters, namely the display size and configuration. The display requires an optical configuration to support a reflective display and LED placement. A possible configuration is shown in Figure 29. The optics will be designed to support the reflective display size which is approximately 0.5 inches on a side.

![Optics Diagram](source: Ref.23)

**Figure 29. Reflective Display Configuration**

The FOV requirements of 30 deg x 23 deg were determined earlier in this section after selecting a 640 x 480 display. It is important to determine what impact the FOV will have on the overall optics. Optics diameter is directly related to the FOV.
and eye relief, as is shown in Figure 30. To satisfy the requirement for a 25 mm eye relief, the optics diameter is close to 20 mm, which is suitable for incorporation into an HMD.

![Graph showing optics diameter vs. field of view](image)

Source: Ref. 8

Figure 30. Optics Diameter vs. Field of View

3.5.3 Display Electronics

The display electronics subsystem will control power and data inputs to the display. Each display has unique power and data control requirements; thus, the driving electronics can vary widely. For the selected display, electronics will be
required to control the display data inputs and the LED light source. The selected display is built into a complementary metal oxide semiconductor (CMOS) circuit, which greatly simplifies the electronics.

In most cases for displays, data is read from memory and then travels over a CPU bus to a separate display controller, which writes the data to the display drivers. The display drivers deliver high-voltage power to the rows or columns. The logic section of the driver operates at low voltage, whereas switching the display requires significantly higher voltages. Display drivers technically consist of shift registers, latches, level shifters, and drivers. The shift register receives data from the controller and then passes the data to the latch circuit. The latches hold the data until they receive a controller signal to pass the data on to the drivers. Level shifters raise the voltage of the output to the required level. The drivers finally connect the rows and columns.

The CMOS display greatly simplifies this process. With no high voltage power requirements, data can be read directly from memory and written to the display. The LED light source, which is essentially a low-voltage, high-current device, will also operate off standard CMOS logic.

A controller will be required to manage the frame sequence and to synchronize the color LEDs. The display operates by
writing each of the three color fields separately; one with the red LED, one with the green LED, and one with the blue LED. This will require a processing element to separate the data into three separate frames. The field rate must operate at >216 Hz to maintain a frame update rate of 72 Hz, which is specified in the preliminary display information.

Although the electronics have not been specified, CMOS circuitry is very power efficient. It is assumed that the total power consumption for this circuit running at approximately 216 MHz will be continuous at 1 W.

3.5.4 Audio System

The audio system must be small, low power, and lightweight. The performance requirements for operation in a low moderate ambient noise environment are a microphone sensitivity of < -45 dBA and a speaker dynamic range of > 45 dBA. The entire system must operate within the 200 Hz to 6100 Hz frequency range. Tables 4 and 5 list some commercially available speakers and microphones that meet these requirements.
Table 4. Audian Speakers

<table>
<thead>
<tr>
<th>Model</th>
<th>Diameter (mm)</th>
<th>Height (mm)</th>
<th>Frequency Range (Hz)</th>
<th>Dynamic Range (dBA)</th>
<th>Power Input (mW)</th>
<th>Power Input (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JP-130C</td>
<td>13.5</td>
<td>6.5</td>
<td>150-16k</td>
<td>108</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>JP-15C</td>
<td>15.5</td>
<td>5.5</td>
<td>130-18k</td>
<td>110</td>
<td>10</td>
<td>30</td>
</tr>
</tbody>
</table>

Source: Ref.32

Table 5. Audian Microphones

<table>
<thead>
<tr>
<th>Model</th>
<th>Frequency Range (Hz)</th>
<th>Sensitivity (dBA)</th>
<th>Average Power (mW)</th>
<th>Maximum Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JMS-70</td>
<td>50-12k</td>
<td>-70</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>JMP-70</td>
<td>30-16k</td>
<td>-70</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: Ref.33

Both the speakers and microphones are analog systems, therefore an analog-to-digital conversion must take place. The data bandwidth will be 5900 Hz. The minimum allowable sampling rate is 11.8 kbps. The signal should be sampled at a somewhat higher rate to minimize noise corruption. A comfortable margin will be 14 kbps. The signal must be quantized to generate...
amplitude modulations. Assuming eight levels, the data rate becomes 112 kbps. A compander can be used to minimize the signal to noise ratio degradation caused by quantization. In anticipation of the requirement that the data be transmitted over a standard modem (< 32 kbps), the 112 kbps can be reduced by adapting an encoding scheme such as Adaptive Delta Modulation (ADM) which can reduce the data rate by a factor of 4. A voice coder (vocoder) could also be used to reduce the data rate. A linear predictive coder which separates the signal into passbands and then encodes it can reduce the bandwidth significantly (e.g. a system with 30 filters will yield: 30 filters x 40 samples/sec x 8 bits/sample = 9.6 kbps). This type of encoder would most likely be a custom design although lesser quality vocoders are commercially available.

The digital voice will be coupled with data files. These files will consist of participant command statements and some object file transfers at startup. These files are expected to be small (i.e. on the order of < 1 kB). It can therefore be assumed that the overall data transmittal rate will safely remain less than 32 kbps. Table 6 lists some capabilities of commercially standard modems when used with standard modem compression schemes set by the International Consultative Committee for Telegraphy and Telephony (CCITT).
Table 6. Standard Modem Data Rates

<table>
<thead>
<tr>
<th>Modem Speed (kbps)</th>
<th>Compression Standard</th>
<th>Full Speed (kbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.4</td>
<td>V.32bis</td>
<td>38.4</td>
</tr>
<tr>
<td>14.4</td>
<td>V.42bis</td>
<td>56</td>
</tr>
<tr>
<td>28.8</td>
<td>V.32bis</td>
<td>76.8</td>
</tr>
<tr>
<td>28.8</td>
<td>V.42bis</td>
<td>112</td>
</tr>
</tbody>
</table>

Source: Ref. 14

3.5.5 Power Distribution System

The power distribution system for the headset will carry power to each subsystem. The power and voltage requirements for all the subsystems are summarized in Table 7.

Table 7. Headset Subsystem Power Requirements

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Maximum Power (mW)</th>
<th>Average Power (mW)</th>
<th>Voltage Level (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display Optics</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Display</td>
<td>1000</td>
<td>250</td>
<td>5</td>
</tr>
<tr>
<td>Display Electronics</td>
<td>1000</td>
<td>1000</td>
<td>5</td>
</tr>
<tr>
<td>Audio System</td>
<td>30</td>
<td>11</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>

83
Since all the subsystems operate at 5 V, the power distribution system will not require any conversion. Varying impedance loads will be managed.

### 3.5.6 Hardwire Transmission Link

The hardwire transmission link will consist of adatalink cable for two-way data transmission and a shielded power cord to direct power from the handheld unit to the headset. The maximum total power requirement for the headset is approximately 2 W at 5 V. Assuming some leakage, the power cable should be rated at somewhere near 2.5 W. The largest current required is approximately 200 mA. The cable will need to be long enough to connect the handheld unit to the headset (ie. <1 m).

The data transmission link will also be less than 1 m and will support a data rate of up to 32 kbps for voice in one direction and a large data bandwidth to support a raster display in another. The data bandwidth for the display computes to the following:

\[
\text{bandwidth} = (640 \times 480 \text{ pixels}) \times (8 \text{ grayshades}) \times \\
(3 \text{ colors}) \times (72 \text{ Hz}) \\
= 530 \text{ Mbps}
\]
This requirement exceeds the RS-422 standard capacity which can carry up to 10 Mbps with 5 V logic over a distance of <15 m. A copper coax cable, which can support data transmittals in the hundreds of megahertz, will be adequate. However, a multimode fiber optic link, which will support data transmittals up to 1-2 Ghz, may be a more elegant solution for two-way transmittal. Finally, a tradeoff between cost, bulk, and weight will be analyzed to determine if the optimum solution is to integrate the renderer subsystem module into the headset. Finally, a data compression scheme may be used. For the current decision, it is assumed that the low-cost solution will work. A coax cable hookup will be used for the high bandwidth transmission, and an RS-422 link will be used for the audio transmittal.

3.5.7 Renderer

The renderer subsystem module will convert 2-D graphics primitives into a raster file. The graphics primitives will be uniquely constructed at the central server to match the requirements of the renderer. An ASIC has been designed and tested at Stanford University that can accomplish this function (Ref.12). Each chip is a self-contained system with its own processors and frame buffer. The chip as designed is capable of rendering 210,000 2-D polygons/second; at maximum throughput,
the standard rate is 30,000 polygons/second. The polygons are
Gouraud shaded, which is very high quality. The chips are
designed to work in parallel. The chips are addressed in an
array configuration with each chip assigned a block on the
display to render. Data is passed from the host graphics
processor to the rendering chipset with location information.
In this way, it is automatically sent to the correct chip for
rendering and subsequently stored in a buffer. The data is
reconstructed into a complete frame at the output. A single
clock synchronizes the process.

Assuming that the average size of a polygon is 10 x 10
pixels, the 640 x 480 display will require 3072 polygons to be
rendered at each frame. Using the frame rate of 72 Hz yields a
rendering speed of 221,184 polygons/second. This translates
comfortably to over seven chips. The design tradeoff is how
many chips need to be used. Assuming that in the initial system
the graphics will be quite simple and will not require complex
shading, some lesser number of chips will likely suffice. It
may also be assumed that, although the display may be updated
at 72 Hz, the graphics frame may be updated at only 20 Hz. For
the current design, it is assumed that two chips will be
capable of performing the function. This will essentially
eliminate any redesign of the system.
The renderer ASIC was tested as part of an overall rendering scheme setup, including a packaged chip set, a separate host graphics processor, and display. Sixteen chips were packaged together for that configuration. The host processor that constructed the 2-D polygons for rendering was demonstrated to transmit the polygons over a wireless implementation with a bandwidth varying from 1 to 7 Mbps averaging 4 Mbps. The chipset consumed 17 mW to 133 mW total power at 1.5 V operation. Assuming a packaged chipset of 2 chips, these parameters would translate as follows:

Server-to-chipset transmittal rate: 0.1-0.9 Mbps
Total power consumption: 2 to 17 mW at 1.5 V

3.5.8 Scan Converter

The requirement for the scan converter assumes that the data received from the renderer subsystem is not in a suitable format for the display input. For example, some commercial displays require a specific or specialized data format such as inverted rows or columns or analog input. In the case of the reflective LCD that has been selected, the data output from the renderer buffer will most likely be in a correct format to input directly into the display data RAM.
3.5.9 Pen Input Device

The pen input device should be small, portable, and rugged. It is envisioned as a touch-sensitive device that will be used for inputting user menu commands. The basic requirements are for acceptable response times for commands to be received: < 1 second and an absolute position accuracy of < 1/2 pixel. Thus, the pen tablet to be used with the display must have approximately 1280 x 960 pixels.

Several technologies are currently available on the market:

- **Resistive front-surface film.** This technology uses a resistive film on the front surface that acts as a potentiometer. The pen touches the surface and measures the voltage. This technology is inexpensive, but may not hold up to wear.

- **Electrostatic film.** This technology uses a resistive film on the rear surface of a glass that acts as a potentiometer. The pen acts as a capacitive probe. These devices can be made to be very accurate and moderately inexpensive; however, a glass surface may not be suitable for a portable device such as the MECS.
- **Electrostatic grid.** This technology uses a grid of unterminated wires in X and Y. Wires are pulsed in sequence in X. The pen measures the strongest pulse to determine the closest location. These devices can be rugged, inexpensive, and fairly accurate.

- **Electromagnetic grid.** This technology uses a grid of loops in X and Y that transmit an AC signal. The pen again determines proximity from the strongest signal.

Other touch input technologies are available but are not suitable for this type of pen input due to poor performance. Tradeoff studies will be performed to determine the optimal system.

An acceptable solution may be the GlidePoint manufactured by Alps Electric, which sells for $99.00. The GlidePoint is a resistive front-film device. It has a resolution of 400 dpi and measures 2.5 x 1.9 inches. The device uses a MacIntosh Apple Desktop Bus (ADB) interface, which is essentially a 5 V serial port that also provides the device with a maximum of 80 mW and has immediate response times. The GlidePoint uses significantly less than 80 mW of power. A custom input device may be the optimal solution, but for now it is assumed that the GlidePoint solution can be repackaged and integrated with MECS.
3.5.10 WLAN Transceiver

The WLAN transceiver will be required to transmit audio, user commands, and graphics data simultaneously. The total bandwidth requirements are as follows:

Audio: < 32 kbps
User commands: < 10 bps
Graphics: 0.1-0.9 Mbps
Total approximately: 0.13-0.93 Mbps

WLANs are a relatively new industry, and standards are currently being created. In 1985 the Federal Communications Commission (FCC) allocated industrial, scientific, and medical bands for LANs using spread-spectrum technique. These bands are 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz. New bands in the 17 GHz and 61 GHz range are under consideration. No license is needed provided no more than 1 W is transmitted. The Institute of Electrical and Electronic Engineers (IEEE) is creating the IEEE 802.11 standard for WLANS. The standard will dictate shared space protocols for both infrared and radio LANS.

The choice between a radio WLAN and an infrared WLAN depends on the application. For instance, infrared WLANs are
cheaper, but more nodes are required for large areas. Table 8 is a comparison between the two technologies:

Table 8. Radio and Infrared WLANS

<table>
<thead>
<tr>
<th>Technology</th>
<th>Radio</th>
<th>Infrared (quasi-diffuse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>Good</td>
<td>Medium</td>
</tr>
<tr>
<td>Speed</td>
<td>64 kbps-1 Mbps</td>
<td>1-20 Mbps</td>
</tr>
<tr>
<td>No. of channels</td>
<td>Large</td>
<td>One</td>
</tr>
<tr>
<td>Interference</td>
<td>Possible</td>
<td>No</td>
</tr>
<tr>
<td>Price</td>
<td>Medium to High</td>
<td>Medium to Low</td>
</tr>
</tbody>
</table>

Source: Ref.18

A radio LAN can penetrate walls and buildings, and does not require line-of-sight to a receiver. Therefore, a radio LAN may be more suitable for MECS application, where the user might wish to roam more freely in the office or campus. The choice of WLAN will be made after further analysis of user markets. Possibly the optimal tradeoff option will be to integrate a single Personal Computer Memory Card Interface Architecture (PCMCIA) slot into the handheld unit. This will allow the user to adapt MECS to whatever LAN system he or she is currently using. A PCMCIA card adapter was developed as a standard bus
interface architecture for portable computer products. The host system contains an expansion slot that allows the user to plug in PCMCIA compatible products. The basic categories of PCMCIA configurations are memory devices (Type I), communications devices (Type II), and miniature hard disks (Type III).

Proxim currently makes a PCMCIA-compatible WLAN called RangeLAN. RangeLAN has a data rate of 242 kbps, has a range of less than 1,000 ft, and operates with 100 mW average and 250 mW maximum input power (Ref.16). This solution falls in the range of the WLAN data requirements. Although it does not meet the maximum data rate of 900 kbps, it will suffice for average data rates. RangeLAN is a candidate for testing the initial MECS.

3.5.11 Power System

The power system in the handheld unit will provide power distribution for all the handheld components as well as providing the power source to all subsystems. The power and voltage requirements for all the subsystems in the handheld unit are summarized in Table 9.
Table 9. Handheld Subsystem Power Requirements

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Maximum Power (mW)</th>
<th>Average Power (mW)</th>
<th>Voltage Level (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WLAN Transceiver</td>
<td>250</td>
<td>100</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Scan Converter</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Renderer</td>
<td>17</td>
<td>9.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Pen Input Device</td>
<td>80</td>
<td>&lt;80</td>
<td>5</td>
</tr>
</tbody>
</table>

The total power requirements for the handheld unit are approximately 350 mW maximum and 190 mW. The highest current supported is 50 mA. Recalling section 3.5.6, the maximum power requirement for the headset is 2.5 W at 200 mA. This indicates that the power supply must support a total of approximately 3 W and a maximum current of 400 mA.

In selecting a battery, it will be necessary to review the system requirements in terms of power usage, voltage and current drains. Weight and volume are also significant factors. Figure 31 shows how current technologies compare in terms of energy per unit weight and volume. The maximum required current sink should closely match what is rated as optimal for the battery. Batteries can be used in series to increase voltage output. Batteries come in a large variety of shapes and
sizes, and many manufacturers can custom package a battery to conform to specific dimensions, which may be desirable if MECS is using a rechargeable battery configuration.

![Image of battery technology comparison](image)

Source: Ref. 31

Figure 31. Battery Technology Comparison

There are two general categories for batteries: primary and secondary. Primary batteries are of the disposable type and generally have longer charge retention (shelf life), are always in a state of readiness, and have a higher energy density. Secondary batteries are rechargeable, and have longer lifetimes and higher rate capabilities.
Primary batteries generally have a higher energy density than secondary batteries; however, require replacement. Some typical performance characteristics of small-volume, high-capacity primary batteries are listed in Table 10. The primary batteries in this chart will not meet the MECS operating power demands, namely 3 W peak power, 400 mA peak current, and maximum usage of 5 hours per day.

**Table 10. Primary Battery Characteristics**

<table>
<thead>
<tr>
<th>Type</th>
<th>Voltage (V)</th>
<th>Capacity (mAh)</th>
<th>Drain (mA)</th>
<th>Power (W)</th>
<th>Volume (cm³)</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline D</td>
<td>1.5</td>
<td>14,000</td>
<td>245</td>
<td>0.37</td>
<td>53</td>
<td>132</td>
</tr>
<tr>
<td>Alkaline C</td>
<td>1.5</td>
<td>7,000</td>
<td>120</td>
<td>0.18</td>
<td>26</td>
<td>64</td>
</tr>
<tr>
<td>Lithium</td>
<td>3.5</td>
<td>1500</td>
<td>4.3</td>
<td>0.015</td>
<td>9.8</td>
<td>19</td>
</tr>
</tbody>
</table>

Source: Refs. 25,30

For high discharge rates, high-rate secondary batteries will be the choice. Table 11 presents some typical characteristics of small, high-capacity rechargeables that can support the required current load. Rechargeable batteries often come in custom-design battery packs.
## Table 11. Secondary Battery Characteristics

<table>
<thead>
<tr>
<th>Type</th>
<th>Nom. Voltage</th>
<th>Capacity (mAh)</th>
<th>Drain (mA)</th>
<th>Power (W)</th>
<th>Wt (g)</th>
<th># for 3W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-MH (AA size)</td>
<td>1.2</td>
<td>1100</td>
<td>220</td>
<td>0.264</td>
<td>25</td>
<td>11.4</td>
</tr>
<tr>
<td>Ni-MH (D size)*</td>
<td>1.2</td>
<td>2500</td>
<td>500</td>
<td>0.6</td>
<td>46</td>
<td>5</td>
</tr>
<tr>
<td>Li+ (D size)*</td>
<td>3.0</td>
<td>1200</td>
<td>220</td>
<td>0.67</td>
<td>38</td>
<td>4.5</td>
</tr>
</tbody>
</table>

* largest available

Source: Refs. 30,31

It is apparent from Table 11 that the best choice is a lithium-ion (Li+) battery pack. Additional advantages to choosing Li+ batteries are that they are chemically stable, safe to use, and environmentally sound (they contain no harmful substances such as cadmium, mercury, or lead). Li+ batteries are new on the market and are currently being incorporated into Japanese products. Their availability in the large size is questionable; therefore, a Nickel-Metal Hydride (Ni-MH) battery pack must be planned for as well. Both Li+ and Ni-MH batteries can be fully recharged within a period of 1 to 2 hours. Four batteries will probably be sufficient. The total weight of the batteries will be 128 grams or 4.6 ounces. The batteries will be arranged in series to maintain the specified voltage. A voltage regulator will be used to control voltage output.
4.0 LIFE-CYCLE COST

The overall lifecycle of MECS is planned to follow the steps outlined in Figure 32. It is anticipated that the design, development, and consumer evaluation phases will take 2 years. Product utilization is expected to be a total of 7 years. The costs associated with the various stages in the lifecycle are illustrated in Figure 33. All costs are estimated to the nearest $50 and are computed in 1995 dollars.
Figure 32. Life Cycle Flow Diagram
4.1 Design and Development Costs

Preliminary estimates of the costs associated with design and development are:

$650,000 + program management costs = $715,000.
These costs are broken out in the following sections. A technician’s rate can be estimated at $15.00 per hour and a design engineer’s rate at $35.00 per hour. A man-year is defined as 2,000 hours.

4.1.1 Program Management

Program management costs are estimated to be 10 percent of the total design and development costs incurred.

4.1.2 Engineering Design

The engineering design costs associated with each system are estimated as follows.

4.1.2.1 Server System.

Configuration tradeoffs, WLAN network design, and server selection are the major tasks related to this effort. These tasks will require the following efforts:

1 technician-year (TY) = $15 \times 2,000 = $30,000
1/2 engineer-years (EY) = $35 \times 1,000 = $35,000
$65,000
4.1.2.2 Equipment Development and Test

Significant development remains to be done on the headset and handheld unit subsystems. The costs associated with subsystem development efforts are as follows.

4.1.2.2.1 Display. The display will be purchased off the shelf.

4.1.2.2.2 Display Optics. The display optics design will require 1 EY = $70,000.

4.1.2.2.3 Display Electronics. The display electronics will require 1/2 EY = $35,000.

4.1.2.2.4 Audio System. The audio system electronics will be purchased off-the-shelf.

4.1.2.2.5 Power Distribution System. The power distribution system design and peripheral integration will require 1/2 EY = $35,000

4.1.2.2.6 WLAN Transceiver. The WLAN transceiver will be purchased off the shelf. Integration will be require 1/2 EY = $35,000
4.1.2.2.7 Scan Converter. The scan converter is not currently applicable to design costs.

4.1.2.2.8 Pen Input Device. The pen input device will be purchased off the shelf. Integration costs should be insignificant.

4.1.2.2.9 Renderer. The renderer ASIC design is complete, however, the chipset integration will require 1/2 EY = $35,000.

4.1.2.2.10 Power System. The power system will utilize standard batteries. Addition power system design will require 1/2 EY = $35,000

4.1.2.3 Mechanical Design

Several prototypes will be developed requiring 1 EY = $70,000.

4.1.2.4 Systems Engineering

Systems engineering efforts will require 1 EY = $70,000.
4.1.2.5 Software development

Software development will be a significant portion of the overall system design. This will require 3 EY = $210,000.

4.1.2.6 Engineering Test

Testing will be conducted at the development facility by the allocated design personnel. It will be assumed that the facility has existing electronics test equipment but will need to purchase some supporting hardware to demonstrate equipment. The server is estimated to cost $25,000, and the WLAN is estimated at $100,000, for a total of $125,000.

4.2 Production Costs

Preliminary estimates of the costs associated with production are $1,100,000 investment costs, $1000 per unit assembly costs, and $2.75 per unit support costs. These estimates are discussed below.

4.2.1 Display

The display will cost an estimated $250 per unit.

4.2.1 Display Optics

The display optics will cost an estimated $50 per unit.
4.2.3 Display Electronics

Assuming standard components, the display electronics will cost an estimated $100 per unit.

4.2.4 Audio System

The audio system will cost an estimated $50 per unit.

4.2.5 Power Distribution System

With standard components, the power distribution system will cost an estimated $50 per unit.

4.2.6 WLAN Transceiver

The WLAN transceiver will be sold separately from the unit. The PCMCIA cardslot will cost an estimated $100 per unit.

4.2.7 Scan Converter

The scan converter is not currently applicable to production costs.

4.2.8 Pen Input Device

The pen input device will cost $100.
4.2.9 Renderer

The renderer ASIC will be implemented in a design with less than 100,000 gates. The initial fabrication of such a circuit will cost $15,000. The unit cost is estimated as $50 per unit for a total of $200 per module.

4.2.10 Power System

The power system will use standard batteries and components which will cost an estimated $50.

4.2.11 Mechanical Design

The initial startup cost to fabricate the mechanical housing is estimated at $100,000. Unit costs are insignificant (i.e. $50.)

4.2.12 System Assembly

Fabrication costs for the overall system is dependent on new requirements for tooling and facilities. Tooling is estimated at $1,000,000 and facilities costs at $50 per unit.

4.2.13 Logistics Support

Logistics support costs will require several assembly technicians and program management, which is computed as 10 percent of the support and facilities costs. The logistics
support costs are 10 TY per 100,000 units = $1.5 per unit. Shipping is estimated at $1 per unit, and program management at $0.25 per unit. This gives a total cost of $2.75 per unit.

4.3 Operations and Maintenance Costs

Preliminary estimates associated with operations and maintenance are estimated to be $35,000 investment cost plus $0.0476 per unit cost. These estimates are computed as follows.

4.3.1 Organizational User’s Guide

A presentable user’s guide will be developed for organizational level (consumer) uses at an estimated cost of $20,000.

4.3.2 Intermediate-Level Repair Guide

A detailed repair guide for intermediate-level maintenance will be developed at a cost of $15,000.

4.3.3 Depot-Level Repair

A trained technician will perform most depot level maintenance. The following are estimated cost requirements per 500,000 units sold: 1 TY = $15,000 per 500,000 units, 0.25 EY = $8,750 per 500,000 units, and shipping = $50 per 500,000 units, for a total cost of $0.0476 per unit.
4.4 Life-Cycle Cost Analysis

The total life-cycle costs are estimated in Table 12. The design and development phase will occur in the initial 2 years. The following 7 years will consist of production, operations and maintenance. The costs will be computed in then-year dollars. Finally, to complete the cost model, the expected number of sales was estimated. A fixed selling price of $1,300 per unit was assumed to be a reasonable cost. Finally, it was assumed that sales would start at 1,000 the first year and increase to 10,000 units in the following years.
### Table 12. Total Life Cycle Costs

<table>
<thead>
<tr>
<th>COST</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE</td>
<td>Design &amp; Development</td>
<td>Design &amp; Development</td>
<td>Production / O &amp; M 1,000 units</td>
<td>Production / O &amp; M 10,000 units</td>
<td>Production / O &amp; M 10,000 units</td>
<td>Production / O &amp; M 10,000 units</td>
<td>Production / O &amp; M 10,000 units</td>
<td>Production / O &amp; M 10,000 units</td>
<td>Production / O &amp; M 10,000 units</td>
</tr>
<tr>
<td>Cd</td>
<td>$357,500</td>
<td>$357,500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cp</td>
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<td></td>
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<tr>
<td>Ci</td>
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<td></td>
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<td>Co</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cm</td>
<td>$476</td>
<td>$476</td>
<td>$476</td>
<td>$476</td>
<td>$476</td>
<td>$476</td>
<td>$476</td>
<td>$476</td>
<td>$476</td>
</tr>
<tr>
<td>Total Costs</td>
<td>$357,500</td>
<td>$357,500</td>
<td>$2,037,796</td>
<td>$10,027,976</td>
<td>$10,027,976</td>
<td>$10,027,976</td>
<td>$10,027,976</td>
<td>$10,027,976</td>
<td>$10,027,976</td>
</tr>
<tr>
<td>*Total (then year)</td>
<td>$370,013</td>
<td></td>
<td>$2,182,480</td>
<td>$11,123,018</td>
<td>$11,512,116</td>
<td>$11,931,235</td>
<td>$12,324,382</td>
<td>$12,755,585</td>
<td>$13,206,844</td>
</tr>
<tr>
<td>**Income (then year)</td>
<td>$1,300,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
<td>$13,000,000</td>
</tr>
<tr>
<td>Income</td>
<td>$1,392,000</td>
<td>$14,417,000</td>
<td>$14,924,000</td>
<td>$15,444,000</td>
<td>$15,977,000</td>
<td>$16,536,000</td>
<td>$17,123,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profit</td>
<td>-$357,500</td>
<td>-$370,013</td>
<td>-$790,480</td>
<td>$3,975,992</td>
<td>$3,411,894</td>
<td>$3,530,785</td>
<td>$3,652,618</td>
<td>$3,780,415</td>
<td>$3,914,156</td>
</tr>
</tbody>
</table>

*Costs calculated at 3.5% inflation

**Unit price = $1,300
The goal of this project was to demonstrate a new paradigm in conferencing -- mobile voice and data combined in real-time. This project represents an initial system design of a MECS using currently available components and a standard communications infrastructure. There does not appear to be any major technical, infrastructure, organizational or cost barriers to implementation of the system as designed. Life cycle cost estimates indicate that the use of MECS could be beneficial to a large corporation like Macropolis.

The requirement to use currently available components and an existing infrastructure resulted in limitations in the final design over those that were originally envisioned. The primary limitations are bandwidth required to transmit graphic information in real-time and power requirements that limit the processing capability of the portable unit. This results in a system that has less graphical capability than would be desired for a widespread commercial product and potentially less mobility than would be desired for other applications, such as a military system.

Because this is a new paradigm for performing remote collaborative work, little empirical data exists to allow quantitative measurement of the effectiveness of the system.
design. Video teleconferencing and systems that transmit data on computer screens or whiteboards to remote locations experience some of the same bandwidth deficiencies as the MECS. The MECS, however, addresses a major deficiency of those systems by introducing the ability to interact, in real-time, with data and people. To measure the full impact of a MECS, it will be necessary to perform experiments with people interacting in real-time and performing useful work.

While life cycle cost projections are supportive of the MECS, the lack of empirical data coupled with the high initial capitalization cost will tend to discourage rapid industrial adoption of the system. A MECS research and development program could construct a testbed that would serve as a mechanism for collecting data through experimentation, identifying and analyzing alternative technologies, and fostering mature system level solutions that will promote and accelerate the evolution of mobile electronic conferencing in the future.
REFERENCES


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Ms. Harkin has been employed by System Planning Corp. since July 1992. She works as a Senior Project Engineer for the Electronic Systems Technology Office of the Advanced Research Projects Agency. There she assists in the definition and management of research and development programs relating to head-mounted display systems, and tactical information assistants.

Prior to 1992 she was employed at Pacific-Sierra Research (PSR) Corp. Her experience at PSR includes noise cancellation software development for the Office of Naval Research and sensor and avionics analyses for the Aircraft Research and Technology Office of the US Naval Air Systems Command.

Kathleen A. Harkin