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Advances in Display Technology VI

Elliott Schlam
Chairman/Editor

Presented in cooperation with
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Center for Laser Studies/University of Southern California • Georgia Institute of Technology
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ADVANCES IN DISPLAY TECHNOLOGY VI

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INTRODUCTION

Progress continues in the development and production of flat panel displays and in the understanding and implementation of displays in systems. Plasma, liquid crystal, and electroluminescent displays are becoming larger, with higher resolution. Addressing and interfacing techniques have been developed to enable each of the display technologies to operate at video rates and function as if they were CRT monitors. It is clear that on many applications, these flat panel technologies are readying themselves as CRT replacements. In other cases, they will find use in new applications where CRTs have not been previously used. Displays are finding use in a greater variety of systems applications, underlining the trend to provide more diversified electronically generated information to the user. These applications vary from small hand-held computers to large stereoscopic and projection systems. In regard to the user, new and greater insights are being generated as to how people view and assess displayed information. These insights are coming from both a better understanding of the psychophysical process of display viewing and more sophisticated human factors testing. The results include techniques to improve display viewability and enhance information content.

This 1986 conference was divided into four sessions. Session I, Display Perception, presented a selection of papers relating to the ergonomic and psychophysical aspects of displays, and papers on color selection and visual aspects of display use in particular system applications. In Session 2, Electroluminescence, an announcement of a fully IBM-compatible TFEL display was presented. In addition, papers on power reduction, addressing considerations, and the fabrication of large TFEL displays were presented. Session 3, Display Systems, discussed a variety of specific systems applications for CRT displays. Papers on stereoscopic displays, display simulation, and 3-CRT color projection system were presented. In Session 4, Plasma and Liquid Crystal Displays, papers covered developments in multicolor approaches to ac plasma panels, high speed addressing of a 60cm x 80cm plasma display, and an analysis of active matrix liquid crystal addressing.

Elliott Schlam
U.S. Army Electronics R&D Command

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Chairman
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Ergonomics testing of new technologies

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Abstract

Although engineers profess to have a working knowledge of testing methods, ergonomics is an area of testing with which engineers are only beginning to grapple. Testing for such human factors as personal goals, requirements, limitations and comfort is necessary to evaluate the human consequences of new technologies. While engineers are concerned with performance of the technology and its components, ergonomists assume working machinery and test for human performance and preference effects. Examples from the literature illustrate the approach to ergonomics research. Despite the problems and tradeoffs inherent in arriving at human factors solutions, ergonomics must be included in the design of new technologies so that they not only enhance human productivity, but also are accepted by users.

Introduction

Engineers who design computers and other systems currently test the equipment for many properties such as compatibility with other components, design and programming errors, reliability, response time, functionality and safety. In general, these tests are conducted to determine that the system works according to its specifications and that it doesn't injure anyone. However, even when a design passes all of these tests, it is still possible that the finished product will be a failure from the users' perspective.

While engineering tests are performed to determine whether the system works, ergonomics testing is conducted with functional equipment to determine human performance and preference effects. Testing for these human factors is necessary to evaluate the human consequences of the introduction of new technologies.

Usability and adaptation

In addition to hardware and software, the areas of interest to human factors engineers include installation, documentation, procedures, training, task performance, maintenance, and the environment. They are concerned with human performance, attitudes, health and safety, usability and comfort. Human engineering aims to maximize usability and to minimize human adaptation to products. Usability is the ability of people to make the technology work for them. Regardless of how well it works, if people cannot operate the equipment, then it is essentially useless. Adaptation occurs when people must change their behavior or thought patterns to match those required by the equipment. Although people can successfully adapt to technology, potential benefits can be reduced by tradeoffs in training time, productivity, comfort or well-being.

Since most people view technology as a means to an end (as tools for accomplishing tasks), rather than as an end in itself, products are accepted by people to the degree that the equipment is secondary to the task. For example, when making a telephone call, people are most likely to be thinking about the number they are dialing, the person they are calling or the reason for the call. The telephone set itself is largely ignored, except on occasions when something goes wrong (e.g., the call is cut off or a wrong number is reached). At these times, the telephone equipment or service intrudes on the caller's consciousness.

Types of ergonomics tests

Testing for human factors generally takes one of two forms: 1) comparisons of multiple designs, and 2) single design evaluations. Comparisons of two or more designs are conducted to determine which alternative is best. The criteria for comparison most often are measures of human performance and preferences. For example, several designs of antiglare filters for VDT screens have been compared to determine which filter is preferred by users and which filter results in better performance under different glare conditions.[1, 2]

Testing of a single design is done to find areas in which the product can be improved. Errors, questions, hesitations, task completion and quality of output are commonly used as indicators of ineffective designs. An example of this type of test is the revision of a user manual for a text editor.[3] Several steps were performed to evaluate and refine the user manual. The final step was to compare the new and old versions to determine whether the changes actually improved the manual.

These two types of testing are usually integrated into the design process to answer different questions at various stages of development. For instance, product comparisons may be conducted to narrow the number of potential designs, while product improvement tests are performed to refine the chosen design. Other circumstances may require only one or the other type of test.

Three elements

As L.M. Branscomb, Vice President and Chief Scientist of the International Business Machines Corporation (IBM), so aptly put it, "you can't evaluate ease of use without use."[4] Testing for usability requires a minimum of three components: 1) real users, 2) real equipment, and 3) real tasks. The users in the test should be recruited from the actual population of people for whom the product is being designed (i.e., the "target population"). The equipment should be as similar as possible to the proposed design. Although it can be a prototype, mock up, or partially simulated, it must be something that people can actually use. Imaginary or photographed equipment is not sufficient. The tasks for the test should represent things that people will actually do with the technology, rather than artificial activities or games (unless the product is designed to be a game).

Problems of testing with people

Because ergonomics tests are performed with real users, there are many potential problems which can bias the test results or make it impossible to interpret the data. These problems are inherent in any research with people because of the nature of human beings. Many of these factors are difficult to measure and control. Some important variables are described below.

Individual differences

Because each person is different, individual characteristics can affect the way people behave. Age, sex, experience, personality, handedness, vision, mood, intelligence, and size are just a few of the ways people differ. For instance, if all of the test participants are female secretaries in the age range of twenty to thirty years old, who are employed as secretaries, the results of the test may not apply to male managers who perform different tasks.

Change

During the course of an evaluation, many changes can take place which could influence the outcome of the test. Equipment may show signs of wear over time and may even be damaged or changed by the nature of the test procedure. Computer response times can vary according to the time of day because of the number of other users on the system. People learn, have new experiences, change moods and become fatigued. They can adapt to the testing procedure so that earlier results are inconsistent with later data. Lighting, temperature, humidity and other environmental conditions change within days, from day to day and from season to season. Even current events can affect the way people behave. For example, test results from the day President Kennedy was shot could certainly have been affected by people's knowledge of the event.

Because so many changes can occur and most of them cannot be controlled, the consistency from one test session to another can be severely compromised. Experimental control is much more difficult, but no less important, with human participants than with most of the objects engineers normally test.

Memory

Human memory has limitations which can bias the things that people remember. Information can be changed at the time of input, storage, processing or recall. Because people are exposed to such large amounts of information, they cannot pay attention to all of it. Selective attention limits the amount of information that can be input. Different types of memory have different persistences. Information in short term memory can be lost if it is not subsequently stored in long term memory. Memory processes can alter the way things are remembered over time. People also are not very good at processing complex or intricate interactions. Finally, even if information is stored in long term memory, it may be difficult to recall. Recognition of previously stored items generally is found to be much easier than memory recall.

Because of these (and other) limitations of human memory and cognitive processing, data reported by the test participants themselves are not always reliable. More objective measures can be collected automatically by computer, by videotaping, by observers who are not test participants, or by other methods of recording data.

Interpersonal interactions

Behavior of one person can be affected by the behavior of others. If users are tested as a group, the performance of some people may affect others. Peer pressure can be a strong influence on behavior. Even if people are tested individually, the person who conducts the test can selectively influence the behavior of different participants. For instance, clothing, personality, gender, personal hygiene and tone of voice can affect the way researchers and users interact.

Expectations and attitudes

Participants in a test have certain expectations of the purpose of the investigation. Depending on their attitudes toward the test, they can influence its outcome. Some participants are hostile and may try to "sabotage" the results. Volunteers may be only too willing to behave in unusual ways to help the investigator. If users have a vested interest in the outcome of the test, their responses may be biased. For example, if they think that the results could affect an employer's purchasing decision, they may report stronger preferences than if they know the outcome will not have any effect on their own working coditions. Also, some participants may experience anxiety in the belief that their own performance, rather than the equipment's, is being evaluated.

Measurement

Methods of measurement generally include both objective (e.g., number of errors) and subjective (e.g., attitude) assessments. However, results often rely on subjective data. Comfort, fatigue and preferences are subjective by their very nature, but more reliable objective measurements of these properties are possible. Sitting time in different chairs can be inferred to be a measure of comfort or preference. Grasping strength can be an indicator of muscle fatigue. Of course, these types of measures require some inference on the part of the researcher, but objective data tend to be more reliable and convincing than subjective measures. For example, one investigation found that office workers were less accurate at giving quantitative reports of their own activities than observers were at recording workers' activities as they occurred.[5]

Generalizability

There is a tradeoff between realism and experimental control which affects the generalizability of test results. To make the most precise measurements of behavior, it may be necessary to conduct the test in a laboratory setting where extraneous variables can be controlled. To measure behavior under naturally occurring conditions, a field study is more realistic. Because of this tradeoff, results of research with new technologies may suffer from being inconclusive, artificial, too specific to generalize to other circumstances, or influenced by too many irrelevant factors to be evaluated.

Experimental tools

Because test participants introduce many potential biases into ergonomics research, investigators have adopted many of the procedures from the social sciences for obtaining more reliable data.

Experimental control

Rigorous experimental methodologies cannot eliminate bias, but they can reduce its influence on the outcome of the test. One of the best rules is to conduct the experimental procedure exactly the same for each user. While this is impossible to achieve entirely, control can be exercised over the presentation of instructions (e.g., have someone read them to the user or, better yet, record them on tape) and the collection of data (e.g., have a computer collect performance measures and use pretested questionnaires to collect attitude information).

Another method is to counterbalance the order in which participants use the test equipment. For example, in a comparison of two designs, half of the users should begin with design A and the other half should begin with design B. This will allow the investigator to determine whether there are any effects due to the order in which designs were presented to users. If all users try the equipment in the same order, it cannot be determined if the second one really is better or if it was chosen as better only because it was presented second. People may have learned the task better by the second session or they may be able to recall information about the second session better.

There are many other experimental procedures which can be used to reduce bias and its effects. The importance of these methods cannot be underestimated because without them the data from even the simplest of studies may be impossible to interpret.

Objectivity

As discussed above, objective measures are generally more reliable than subjective measures. Objectivity also refers to the attitude with which a researcher approches the study. If the aim is to "prove" that a design is good, then it would not be surprising if the results supported that contention. In fact, that objective makes it easy to ignore or reinterpret data that is contrary to the expectation.

The purpose of ergonomics research should be to find out what is wrong with a design and how it can be improved. This goal requires that the designer take an objective approach to the technology even though there may be a strong personal commitment to the design. From this point of view, the behavior of users is never really "wrong." When the user performs an action the designer did not intend, it is because there is something wrong with the design, not because there is something wrong with the user. Users sometimes press buttons at random just to see what happens, they are not always good typists, and they almost never read instructions. The designer of new technologies should take these characteristics into consideration, rather than blame or punish users for being human.

Statistical methods

Just as designs are planned before they are implemented, ergonomics tests and statistical analyses should be planned. Even apparently simple experimental designs can require complex statistical procedures. For example, unequal numbers of users in each experimental group can make the analyses very tedious. Contingencies should be developed in advance for circumstances such as the loss of data, cancellation by participants, and damaged or inoperable equipment. Pretesting the study procedure can identify many other potential disasters before they become real problems.

One caution about analyzing and interpreting human factors data is that statistical methods should be applied properly. If the statistic requires that people be selected at random from the target population, then a procedure for doing so should be used. If the criterion for a statistically significant result is set at 0.05, then a finding with a probability of 0.054 is <u>not</u> significant. With the zeal to "prove" a new design, it is not uncommon to find that such leniency is used to place the results in a more favorable light (for an example, see reference 6).

Some testing methods

Because it is sometimes necessary to test a design idea before a finished product is available, some specialized methods have been developed. Some of these are discussed below.

Task analyses

This class of methods is most commonly used to determine the activities of users so that the technology satisfies users' needs. Many types of analyses are possible and some have been given specialized names, such as job analysis, activity sampling, memomotion study, process analysis, link analysis, and micromotion analysis.[7] For the purposes of this paper, "task analysis" is used as the general term for all of these methods, although, technically, they are distinctly different methods.

One way the methods differ is in the level of detail that is required. Activity sampling is done at a finer level of detail than job analysis. Data are gathered on the specific activities that make up the tasks which, in turn, are units of work that make up the job. For example, if the task is "make telephone call", the activities might be "lift receiver", "dial number", "talk on phone", "put caller on hold", and "replace receiver." Job analysis looks at the larger picture and the units of interest might be classes of tasks. The job of manager, for instance, might involve such responsibilities as "plan budget", "oversee projects", "allocate resources", and "hire and fire employees."

Along with the task or activity data, other information might also be collected such as the length of time each action is performed, the number of times each action takes place, the location of the behavior, the order in which tasks are performed, the co-workers involved in the task, and the materials used in the job.

Task analyses are generally performed early in the conceptual phase of the design. The data are gathered to determine functionality requirements, space limitations, equipment usage, interpersonal behavior or flow of activities.

Prototyping

If a design has not yet been finalized, it may be possible to conduct testing on prototypes of the design as long as they are functional. It is never a good practice to present users with a prototype and ask them to imagine that it really works. Requiring users to play act with useless equipment is liable to create findings that are as imaginary as the equipment itself. At best, the results will have to be validated at a later stage when operable equipment is available.

Of course, prototypes do not have to be fully functional to be useful testing tools. As long as the user can experience all of the functions that are being tested, the data will be worth collecting. However, the test should not involve interruptions and coaching by the researcher because of "holes" in the design that have not been completed. Users should be able to operate the equipment in ways that are as realistic as possible. If only some of the functions have been implemented, they should enable the user to perform a self-sufficient, natural grouping of tasks. For example, if the on-line help has not been developed, then all references to the availability of help should be eliminated to avoid confusion during the test.

Simulation

When it is not possible to build a functioning prototype, new technology can sometimes be simulated. For example, a "perfect" speech recognition system can be devised by including a human operator as part of the interface. Kelley[8] used this method to develop a natural language program for keeping a personal calendar. After each user interacted with the simulated system, the software was revised to process the inputs that were previously interpreted by the researcher. Eventually, the researcher was able to extricate himself from the loop between the user and the system and the program performed on its own.

Iterative testing

Another method that has gained in popularity over the past few years is iterative testing. The process begins with a prototype or simulation. Tests are conducted to find flaws in the design. The results are then used to refine and improve the design. After changes have been implemented, the design is again evaluated. The process of testing and redesign continues until some predetermined criterion is achieved. Al-Awar, Chapanis and Ford[9] used this method to develop a tutorial for teaching first time users how to operate an IBM 3277 terminal. Their criterion for discontinuing the test-revise-retest process was that "95 percent of first-time users should be able to complete the program without any serious problems. The five percent of the subjects who experience difficulties should be able eventually to extricate themselves and to complete the program."

The design process

Regardless of the complexities inherent in ergonomics research, the process of turning a new technology into something that people can and will use requires ergonomics testing. This testing should be viewed as an ongoing evaluation, rather than a one-time proof. Different tests can be conducted at various stages of design development. The successful implementation of new technologies depends on the ability of designers to predict the effects of their inventions on people. Without ergonomics testing, there is always the risk of failure.

Here is a simple example. Five models of a prototype public telephone were installed in Penn Station in New York. Instead of a handset, the new phones included a microphone placed in front of the caller and a loudspeaker in the ceiling of the phone booth. While the equipment components probably worked very well, the system posed a real human problem: callers were observed speaking to the ceiling rather than to the microphone![10]

Of course, it is always better to know the shortcomings and benefits of new technology before it is implemented on a large scale. But by the final stage of product development it is usually too late to discover that people are "talking into the wrong end of the equipment."

Experience with ergonomics testing has demonstrated increases in usability and user satisfaction. Although it is sometimes difficult to show that these benefits outweigh the additional costs, it is easy to find technological innovations that were complete failures because they did not conform to human needs and limitations. If a choice must be made between usable products on the one hand, and useful products that people cannot or will not use on the other hand, then the benefits of these methods cannot be underestimated. With the growing use of computers and information technology in our society, engineers would be wise to include human factors testing among their current methods of design and testing.

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Approaches to Fnhancing VDT Viewability and Methods of Assessing the Improvements

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ABSTRACT

Various approaches can be used to improve the viewability of VDT screens. These function by reducing glare and improving contrast. Both OEM and retrofit solutions are discussed and compared. The use of the MTF methodology is applicable to the evaluation of reflected glare and the viewed image. This metric is used to evaluate the reflected glare from screens.

Optimum filters are recommended.

INTRODUCTION

Video display terminals (VDT) are remarkably versatile and useful devices. On the other hand, operators of these devices frequently complain about a number of problems that they experience as a result of working with VDT's all day long. By far the largest category of these complaints are eye-related. Studies[1,2] reveal that typically 55 to 85 percent of the people using VDT's experience eye strain, burning or irritated eyes, blurred vision, and visual fatigue.

There are several possible contributing factors to the operator vision symptoms. These include poor workstation layout, VDT screen image clarity, and background lighting. Specifically, glare is a particularly annoying distraction, and can be one of the contributing factors to VDT vision problems.

In this paper, we discuss the types of glare and methods of optimizing the VDT screen viewability by reducing or controlling reflected glare. We also discuss the modulation transfer function (MTF) methodology for quantifying the screen resolution under various ambient lighting conditions. This metric is incorporated into the proposed ANSI VDT workstation standard.[3]

DISCUSSION OF CRT PERFORMANCE

Ambient illumination can cause two distinct types of screen viewability problems when using an untreated CRT (cathode ray tube): 1. contrast reduction, and, 2. glare. These are illustrated in Fig. 1. In both cases, the viewed image is degraded. In the case of contrast reduction, there is little dependence of the performance on either the angle of incidence of the ambient light nor on the viewing angle. In the case of glare, this is primarily a reflection phenomenon, and so it has a definite dependence on the angle of incidence of the ambient light and the viewing angle. As will be seen, both phenomena can be evaluated with the same methodology, and filters placed between the observer and the phosphor screen can have an effect on both degradation mechanisms.

Contrast:

Contrast is a measure of the range of intensities available to display an image. It is generally defined as

$$C = (I_{max} - I_{min}) / (I_{max} + I_{min})$$

where I_{max} and I_{min} are the maximum and the minimum intensities, respectively. When the background illumination is zero; i.e., $I_{min} = 0$, then the contrast is unity. When the background is as bright as the displayed bright spots in the image, C = 0 and no image is seen.

Contrast reduction occurs in a VDT system when the ambient light illuminates the microscopic particles in the phosphor screen and the light is subsequently scattered back towards the observer. This establishes the light intensity level for the black areas of the image. In other words, this is as "black" as the black areas of the image can be. This limits the contrast (1) attainable (assuming that there is a fixed upper limit on the intensity of the brightest areas in the image).

The contrast available in a display can be improved by installing an absorbing filter between the observer and the phosphor image. The filter may be a. an integral part of the faceplate, b. optically bonded to it, or c. separate from it (free standing). In the latter configuration, the filter should be close enough to the screen so that all of the ambient light that must pass through the filter before reaching the screen. Thus, the light reaching the phosphor particles and subsequently scattered by them must pass through the absorbing filter twice, while the light from the image only goes through the filter once. The improvement in the contrast ratio produced by this type of filter is inversely proportional to the light transmission of the filter.

Glare

We define glare as specularly reflected ambient light which interferes with the user's view of the display. The problem of glare is complex in that the human eye perceives light differently depending on whether there is structure to the reflected image or not. The sharper the structure in the reflected image, the more distracting it is. A uniformly illuminated (diffuse) glare image is much less noticeable than a distinct image with the same total intensity level.

Reflected glare can exist and be annoying to an observer of a CRT display when the following conditions are present: 1. There has to be a source of extraneous light which is reflected by a surface between the observer and the image on the CRT phosphor. 2. The source, the reflector, and the observer need proper alignment so that the glare light reaches the eye of the observer. Since the entire environment in a typical well-lighted office may be illuminated, there is usually some bright or light-colored object with the proper alignment to produce an undesired reflected image.

The source of the glare can be a reflection from either of the two surfaces of the faceplate of the CRT since the two surfaces will have approximately the same reflection coefficient. A contrast enhancing filter placed in front of the CRT may also have one or two reflecting surfaces that can give rise to reflected glare. It should be noted that the reflectances of both surfaces of the faceplate need to be considered when designing a solution to glare.

Glare and contrast reduction are separate problems in that one can occur without the other, and, of course, both may be present at the same time.

SOLUTIONS TO THE GLARE PROBLEM

There are a number of approaches to reducing the amount of ambient light striking the CRT screen and improving the legibility of a CRT display.

1. Eliminate the Ambient Light.
The basic problem is caused by the bright surroundings' being reflected from the screen. The obvious and simplest, though usually not very practical solution is to eliminate or reduce the ambient light level. On the other hand, not very many computer terminal operators care to work in a darkened room, so this solution is not acceptable. A common solution that one finds is that individual operators fashion hoods with available materials and these are placed over the terminal. These hoods block out the most undesirable glare sources for the particular operator/location. This solution to the glare problem is bulky, frequently ugly, in need of constant adjustment, and may be only marginally effective.

Another approach is to control the ambient light more directly by the use of special task lighting. Light fixtures can have integral baffles to reduce high angle illumination, and windows with venetian blinds can reduce the entering light.

2. Redirect the Reflected Light
The reflected light can be redirected away from the observer. By tilting and/or swiveling the screen to a different angle or by positioning the operator differently, it is sometimes possible to reduce the glare. This is not always successful since the entire surroundings are illuminated in a typical office so that if one reflection is eliminated, then another may become objectionable. Thus, if there are many light sources in the surrounding area, tilting may not be a workable approach.

3. Stand Alone Filters
Depending on the index of refraction of the glass, an air- or vacuum-to-glass interface can reflect between 4 and 7 percent of the normally incident light (and as the angle of incidence increases, so does the average reflectance). In a CRT, this can amount to 8 to 14 percent of the normally incident light's being returned by the two interfaces of a polished faceplate. The use of an absorbing filter placed between the observer and the faceplate can reduce the reflected light and increase the contrast by a factor which is proportional to the transmission of the added filter.

It should be noted that if a standalone filter is used, then at least one additional air-to-glass or plastic interface is added (the front surface of the filter), and this interface must not have a reflectance which is greater than that which is intrinsic in the CRT faceplate.

There are three common types of filters used for this purpose:

1. Stretched black mesh;
2. Circular polarizers; and,
3. Neutral density filters with antireflection coatings.

We now characterize each of these and consider their general advantages and disadvantages prior to considering their viewability attributes.

Mesh

In a this type of filter, a black mesh is stretched in a frame and placed in front of the CRT. The mesh is absorbing, but some light can be reflected by it. This filter functions as a contrast enhancing filter, but nothing directly to reduce the reflection coefficients. Mesh filters are relatively fragile and cannot be cleaned easily. In addition, the mesh can interfere with the viewability of some monochrome CRT's when high spatial frequency patterns are displayed because Moire fringes may be produced. This same effect is normally accentuated when a mesh filter is used with a color CRT.

Circular Polarizers

A circular polarizer is very good at eliminating the specular reflectance from polished surfaces by absorbing ambient light reflected from the faceplate. The light emanating from the phosphor is attenuated as it passes through the filter. The result is a greater improvement in the glare reduction than is obtained with simple gray glass. The attentuation of the reflected glare depends to a great extent on the antireflection coating which is applied to the front surface of the circular polarizing filter. Another issue is the durability of the antireflection coating and its effectiveness, since the manufacturing processes may require that a less durable AR coating be used.

Neutral Density Glass and Antireflection Coatings

This approach improves the display contrast and reduces the glare. The substrate is glass upon which a very high performance, high durability antireflection coating can be applied. This essentially eliminates the reflectance from the front surface of the filter. Depending on the transmission value of the gray glass, it may be necessary to apply an AR coating to the second surface of the filter for highest performance applications. Most currently available filters have an average transmission level of approximately 30%; this value optimizes the contrast and the reflected glare attenuation consistent with an acceptable image brightness.

4. Solutions Available to CRT Manufacturers

In contrast to the retrofit types of measures discussed in the previous section, an original equipment manufacturer (OEM) has available to him permanent solutions not available to the aftermarket user. The OEM can treat both the inside and outside surfaces of the faceplate. The common specular reflection reducing treatments are etching, stippling, and thin film antireflection coatings.

The etch level has to be selected carefully lest the resolution of the tube be degraded too much. Stippling is a low amplitude undulation in the glass surface which tends to break up the reflected image. The difference between stippling and etching is that in etching there is little or no short range smoothness, while with stippling, on a microscopic scale, the glass surface is smooth. A stippled surface is formed by pressing the pattern into the glass surface. The amplitude and spatial frequency of a pattern in a glass surface for use in CRT faceplates has been recently discussed in detail by Haisma.[4]

The interior surface of a faceplate may receive an etch or have a stippled pattern pressed into it. It is not a common occurrence to find antireflection coatings on the interior surface of a faceplate, though evidence shows that this may improve the performance of a display system significantly. Many AR coating designs include one or more fluorine containing compounds. These are undesirable elements to have inside a CRT. Fortunately, some very good AR coating designs are available which do not contain fluorine compounds, and these can be utilized to treat the inner surface of a faceplate.

The outer surface of the faceplate is generally coated with an antireflection coating (see Fig. 2). This coating may be applied directly to the front of the faceplate. The most common commercial approach, however, is to place the AR coating on an implosion panel which is bonded to the front of the faceplate. A light etch may be used on this surface (see Fig. 3).

MEASUREMENTS

Measuring the intensity of the light reflected at normal incidence from a faceplate is generally not sufficient to characterize completely the reflected glare from a CRT faceplate. If the reflectance is zero, then indeed this single number may be adequate, but this is generally not the case. As we previously indicated, the sharpness of a reflected image is important.

Modulation transfer theory is well known in the world of precision optics, in which diffraction effects are frequently the limiting factor on the quality of an image (see for example the SPIE Seminar Proceedings on the "Modulation Transfer Function," Vol. 13, 1968). This methodology is applicable under rigorously specified conditions. Its fundamental principle is that an image can be decomposed into spatial frequency components using Fourier theory. These spatial frequencies are analogous to the temporal frequencies so widely used in electronics, where a waveform is decomposed into its frequency spectrum and then analyzed or processed frequency by frequency. In the analysis of an optical system, the wavefront distortion introduced by the system with its finite aperture is converted to an optical transfer function (OTF). The OTF is used to evaluate the extent of the degradation caused by the optical system. The spatial frequencies in the object scene are analyzed to determine how much contrast loss each suffers as it is transferred to the image space by the optical system.

The MTF methodology can be useful in situations where not all of the theoretical criteria are met exactly. In the case of CRT displays, there are many criteria that are not met at all, but the methodology is still useful.

One method for determining the modulation transfer function of an optical system uses a sharp line or an illuminated slit as the object. The image formed by the system is measured to determine how much degradation has taken place. The Fourier spectrum of a line or a slit contains very high frequency components. A measurement of the image and the calculation of its frequency components allows us to evaluate the MTF by taking the ratio of the image power spectrum to the object power spectrum.

In practice the aerial image is scanned with a microscope and the intensity is recorded as a function of position. A Fourier transform of the line spread function yields the OTF. The OTF consists of real and imaginary components, and the MTF is the modulus of the OTF. In the case of CRT displays, we can ignore the phase portion and only consider the modulus of the function.

The optical MTF in general is a two dimensional function. The MTF for a perfect optical system is shown in Fig. 4. Occasionally, symmetries can be found which reduce the MTF to a one dimensional form. In CRT displays, the MTF is a two dimensional function. This becomes very apparent when one considers the difference in the appearance of horizontal and vertical lines in a video display. The spatial frequency response is not the same in the two orthogonal directions (in a monochrome CRT display, a line in the vertical direction consists of a series of dots corresponding to the scan line spacing, while a line in the horizontal direction is continuous, though limited in response by the amplifier bandwidth). This fundamental difference in character will influence the resolution in the two directions, and this will be reflected in a difference in the MTF curve in these two orthogonal directions. For simplicity, this asymmetry is ignored, and the MTF is limited to a single direction.

The evaluation of the effect of these optical interfaces can be difficult if no standard way of measuring the performance of the display is available. For example, one way of eliminating specularly reflected glare is to frost or etch the front of the CRT faceplate. While such a treatment eliminates the specular image very well, it has two undesirable side effects: 1. the reflected light is not eliminated, it is simply redistributed in angular extent, and 2. the etch treatment degrades the viewed image.

MEASUREMENT RESULTS

There are two types of quantities that need to be measured. The first consists of the magnitude of the reflected glare. The second is the sharpness of the glare image.

Glare

The magnitude of the reflected glare was evaluated for the previously mentioned treatments of reflected glare. Figure 5 shows the various reflectances that need to be considered. Only first order terms were used in the evaluation since they are accurate enough for these purposes where the reflectances are low.

Table I summarizes the results of specular glare calculations for five major types of display arrangement: 1. bare CRT; 2. mesh filter; 3. circular polarizer; 4. standalone filter; and, 5. integral (bonded) filter or treated faceplate. The overall transmission (OAT) was calculated using