THE INFLUENCE OF SURFACE PROPERTIES ON IMAGE INTERPRETATION

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Abstract: Surface reflections affect the appearance of images in a variety of ways, depending on viewing conditions and the types of media used.

Light projected to the eye from surface reflections does not carry information about the image; therefore, the reflections can be regarded as noise which interferes with the interpretation of the image.

Different media are characterized in part by surface reflection properties. Ink on paper, for example, provides a complete range of surface properties from glossy to mat. Since it must be viewed by reflected light, as it becomes less glossy there is a desirable decrease in sensitivity to viewing angle at the cost of a loss of image contrast. A CRT surface is rarely flat and never completely mat; therefore, it will allow directional reflections to interfere with the viewed image. Internal reflections and light reflected from the surround will also produce noise.

Such surface properties combine with other factors to affect significantly the appearance of images. To enable the images to be directly compared, conditions affecting visible surface properties must be controlled. Some simple models of surface interaction with light are presented here to help in understanding their causes, their effects on the image, and how to control them.

Viewing of images involves several elements and an infinite set of conditions. Three elements necessary in all viewing situations are: illumination, imaging media distributed in two dimensions on a carrier, and the observer. Some conditions of each element are included among definable models.

This discussion is arranged first by media, then by applicable illumination conditions, then by viewing at the best and worst angles in light and in dark surround. Final sections include typical conditions and measures for control of image appearance.

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INTRODUCTION

Following the development of computer generated interactive displays in prepress preparation for color image printing, the immediate need arose to compare the printed result with the image composed on the CRT. This is one important example of a need for direct comparison of images presented for observation by media differing in almost every respect. Highly significant in the difficulties arising from attempts to make critical comparisons of this type are the surface characteristics of the media and their interactions not only with the light which is so necessary to view the image, but also with light from the surrounding area.

Surface reflections are present in all media. They are characterized by two salient features: by direction with respect to the incident light onto the plane of the imaging medium, and by the relatively uniform performance regarding wavelength.

Directionality—Where the plane of the medium from a micron scale on up can be defined, as with a flat, glass-like surface, and where light impinges onto the surface predominantly from one direction, directionality is a strong factor in image appearance. Conversely, in cases where the surface is mat or the illumination is diffuse or from a broad area, directionality effects can be nearly absent.

A print having half of its surface with a mat finish and the other half somewhat glossy illustrates these effects. Figure 1 shows how bright reflections from a glossy surface are softened by the mat finish. In a more subtle illustration (Figure 2), the mat half (bottom) of the same print shows no reflection of the sidepanel (right) having a black/white boundary visible in the glossy surface. Even identical images as with two prints side by side can be affected by slightly different viewing angles and appear different. Figure 3 illustrates a single mat black print having a line image of glossy varnish overprinted. A simple change in lighting angle reverses the image sign.

A video display exhibits similar effects. Figure 4 shows the very commonly seen reflection of a room light in the surface of the screen. This can completely obscure part of the image. It is hard to avoid because of the curved, glossy surface frequently used on CRTs.

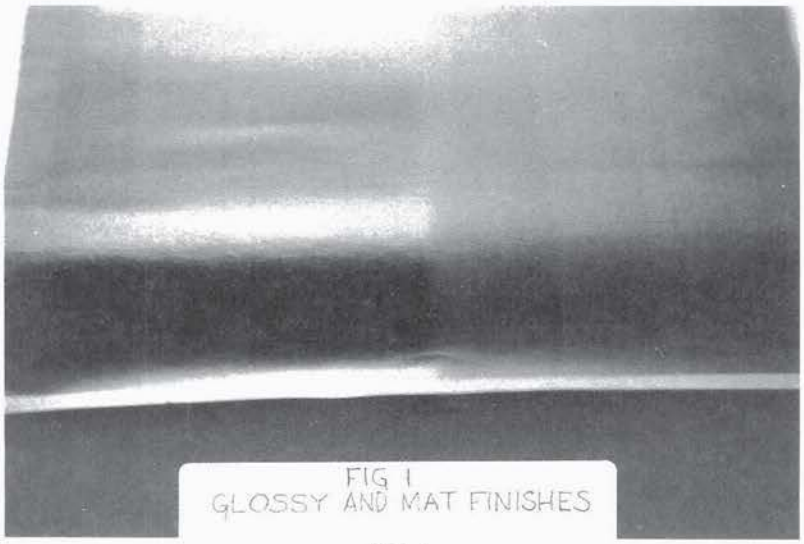


FIG. 1
GLOSSY AND MAT FINISHES

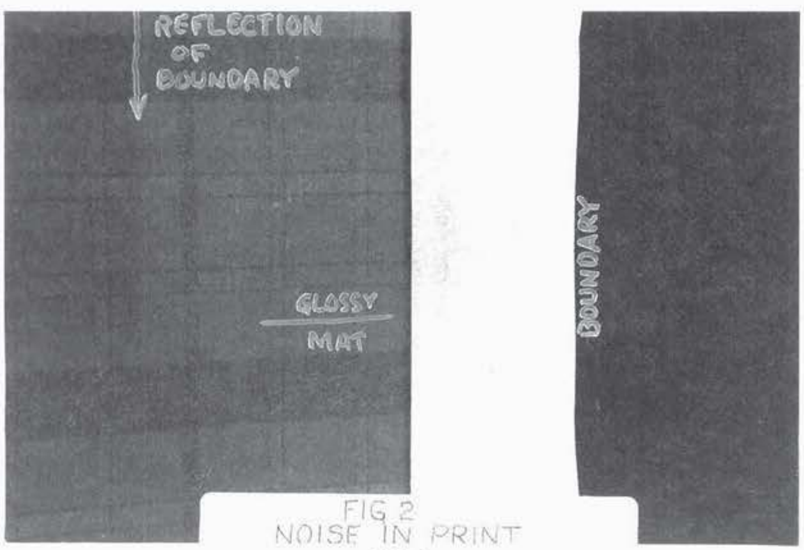


FIG. 2
NOISE IN PRINT

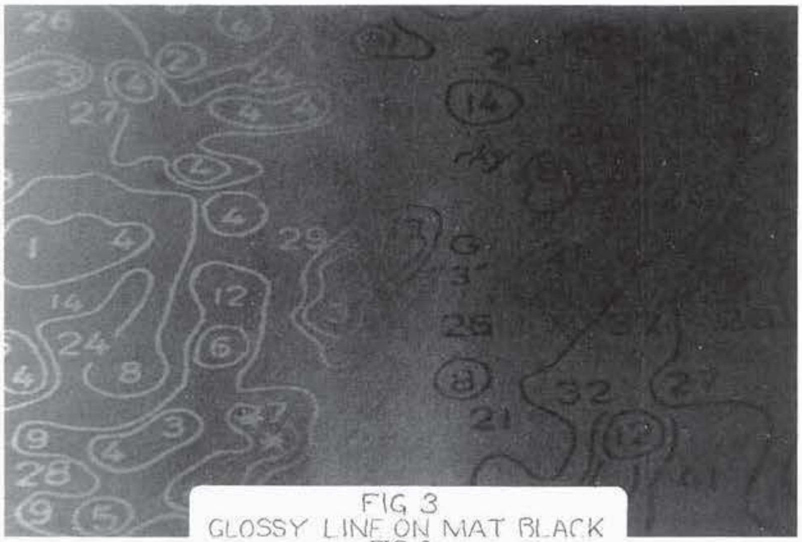


FIG. 3
GLOSSY LINE ON MAT BLACK

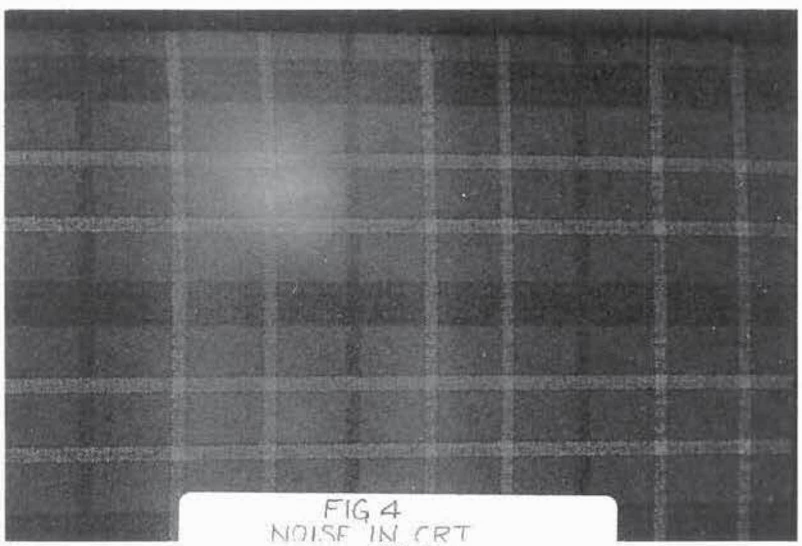


FIG. 4
NOISE IN CRT

A transparent film having clear and mat finishes placed in front of the screen in Figure 5 illustrates that a mat finish would reduce the severity of the surface reflections as with a print.

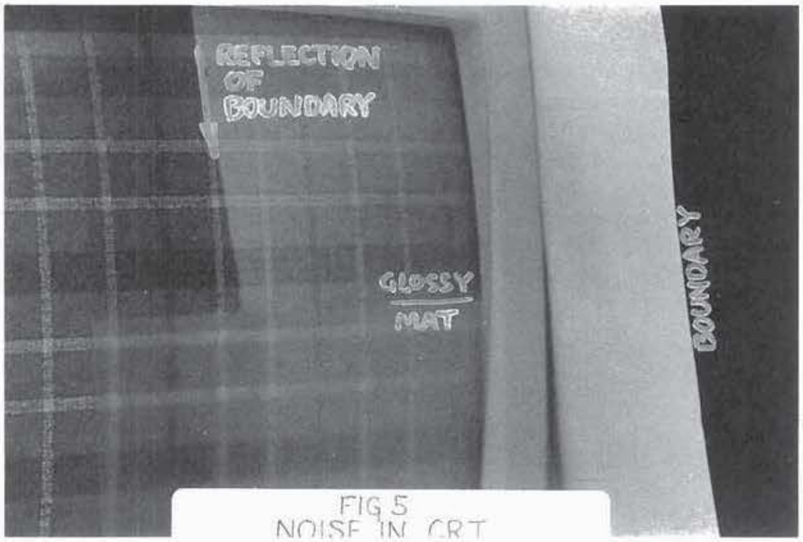


FIG. 5
NOISE IN CRT

Spectral Dilution—As is often true in life, efforts to reduce interfering reflections by use of diffuse sources or mat surfaces result in an increase in the contrast-leveling effects of the surface reflections. When viewing color images, surface reflections project some light to the eye without wavelength modification, and thereby alter the relative wavelength intensity mixture from that due to pigment and carrier alone. When the illuminant is white, as is usually the case, this effect tends to reduce saturation and increase lightness in perceived image color. In viewing monochrome images, the same effects reduce the image contrast. Different surface properties can produce significant alterations in the appearance of otherwise similar images. The examples of a print shown in Figures 1 and 2 illustrate the loss of contrast and color saturation in the mat areas and in the area reflecting a large bright surface. These losses may be inherent in the conditions used for viewing the print. In Figures 4 and 5, the CRT image suffers similarly from incidental room lighting.

Modeling—The important effects can be isolated and individually modeled to aid in understanding and controlling them. The models usually illustrate the extreme conditions of the effect. In the real world, all of the effects interplay simultaneously to varying degrees and very rarely operate at the extremes.

In this discussion, seven conditions are modeled, labeled A through G. A through D describe prints viewed by reflected light, E and F describe transparencies viewed by transmitted light, and G models conditions pertaining to viewing of video monitors. Varying conditions of illumination, surface finishes and effects of lighting in the surrounding room are illustrated.

Theory of Light Interaction with a Surface

Reflection—In Figure 6, the interaction of a pencil of light rays at a surface is diagramed. At the first surface, the light typically encounters a non-metallic microscopically thin transparent medium with a higher index of refraction than air. A portion of the light is reflected at the surface as predicted by the Fresnel equations which depends on the index of the two media and the angle of incidence. The reflected light is polarized to a degree also determined by the angle of incidence. Since the index of refraction is slightly dependent on wavelength, there is a small variation in the ratio of transmitted to reflected light across the spectrum, but you will note that there is no influence on that ratio by the image pigmentation.

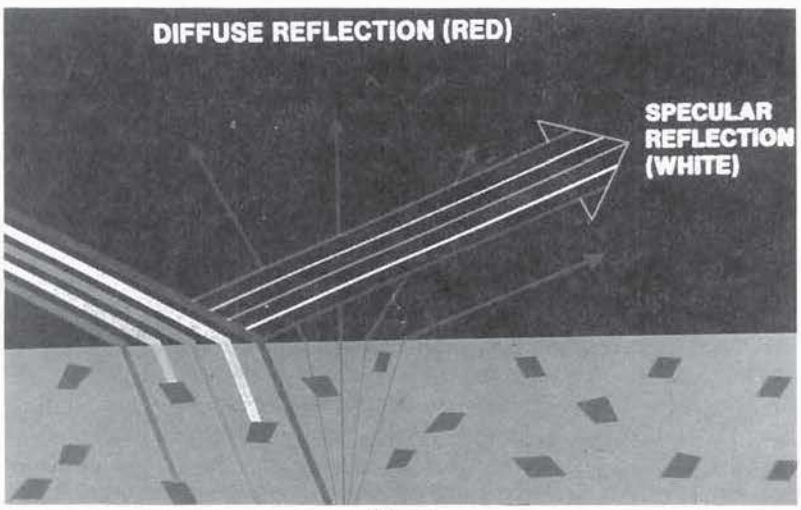


FIG. 6
SURFACE REFLECTION

The light entering the medium is refracted in accordance with Snell's Law and encounters the embedded particles of pigment. Usually the refractive index of the pigment particles and the medium are close in value and little surface reflection takes place at that interface. Light passing through the ink film then reaches the granular texture of the substrate. The irregular shape and small size of the particles in the medium causes light to be scattered in all directions, most of it going back through the ink film. The pigment particles absorb selected wavelengths of light encountering them, so the scattered light is spectrally modulated by the characteristics of the pigment. It is this optical property that pigment manufacturers work so hard to achieve while maintaining the other physical properties needed for inks or paints to perform.

The light thus scattered by the substrate and modulated by the pigment passes outward toward the surface in all directions. Most passes through and becomes the diffusely reflected light that carries the information content of the image. Some is returned by surface reflection and internal refraction to add to the incoming light, only to be recycled.

Gloss—The surface reflection from a smooth surface is called the specular reflection and its appearance imparts the surface quality referred to as gloss. The visual classification, scaling and measurement of gloss is a field of its own. The reader is referred to the listed references for more information on the subject of gloss. For the purpose of this paper, the term is used to designate an optically smooth surface having a high degree of specular reflectance, such as polished glass. Gloss measurements at specific angles to the surface normal are used to classify materials and finishes in a wide variety of applications (Figure 7.)

The term mat (or matte) is used here to denote an optically rough surface in which no increase in reflectance is measured at the angle to the normal equal and opposite to that of the source. Such a surface would have no gloss—for example, ground glass.The surface roughness would be sufficiently small in mean dimension to cause no visible degradation of the spatial detail of the image.

Light Distribution from Different Surfaces—Figures 8, 9, and 10 are rough illustrations of light distribution from different types of surfaces. The relative magnitude of these diffuse and directional components is critical to the appearance of images. Figures 11 & 12 review the proportions of the incident light distributed in different ways by the image and its medium.

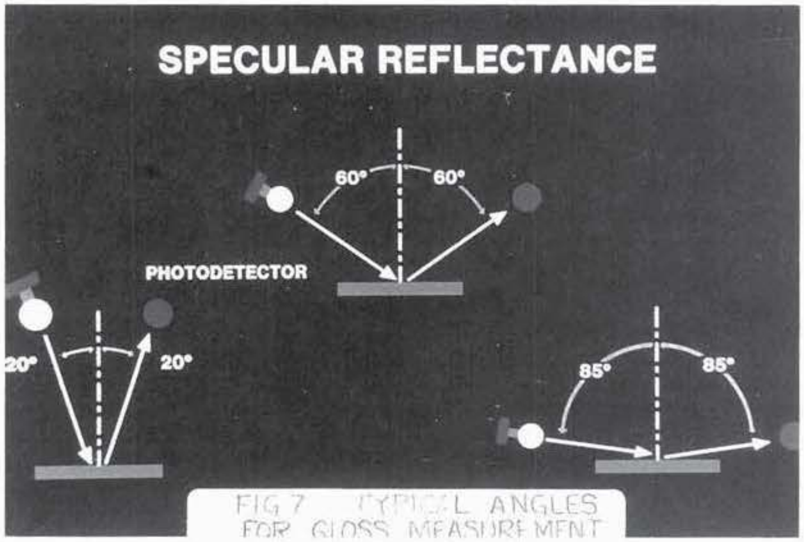


FIG. 7 TYPICAL ANGLES
FOR GLOSS MEASUREMENT

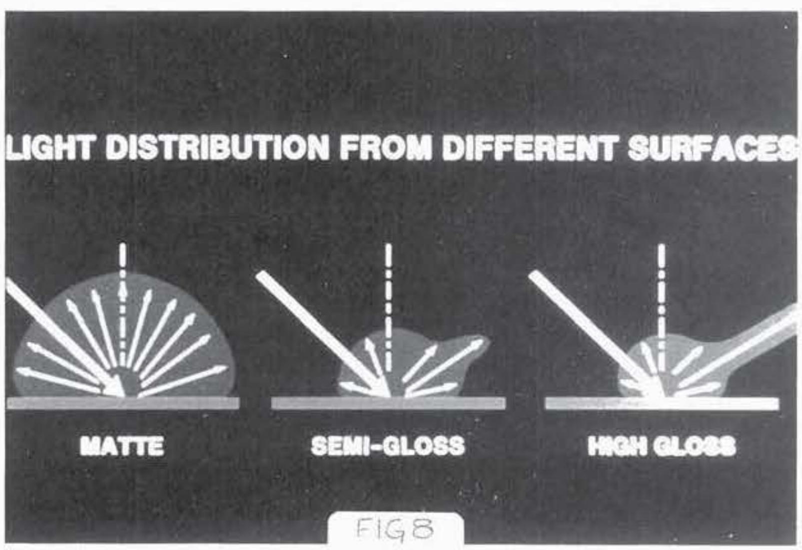


FIG. 8

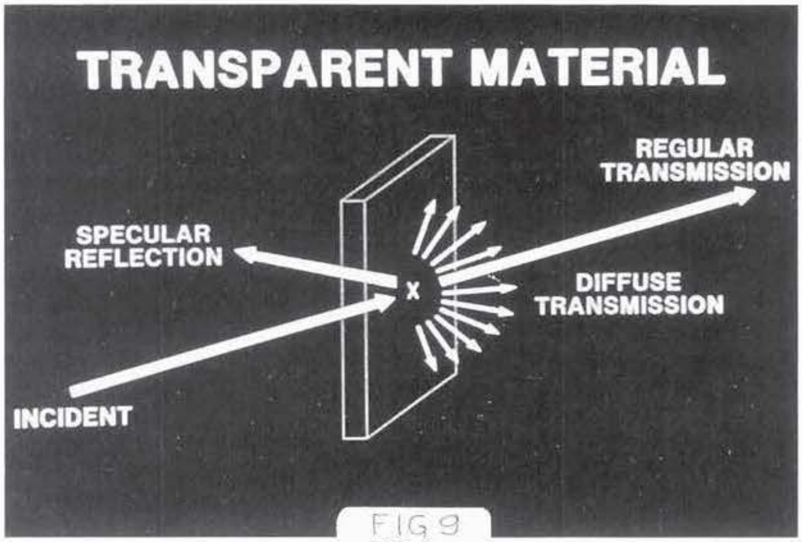

TRANSPARENT MATERIAL
REGULAR TRANSMISSION
SPECULAR REFLECTION
X
DIFFUSE TRANSMISSION
INCIDENT
FIG 9

FIG. 9

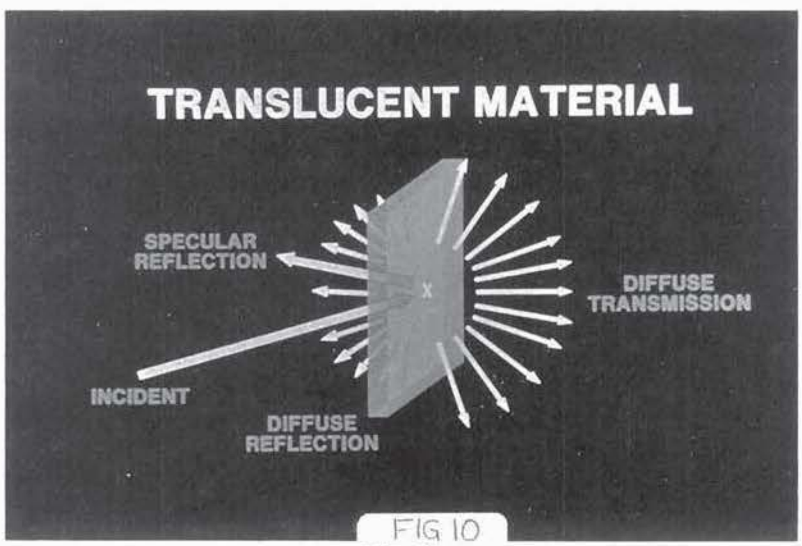

TRANSLUCENT MATERIAL
SPECULAR REFLECTION
X
DIFFUSE TRANSMISSION
INCIDENT
DIFFUSE REFLECTION
FIG 10

FIG. 10

About 4% of the incident light is reflected at the surface of typical materials having an index of refraction around 1.5. In Figure 11, of 100% of the incident light impinging onto a white glossy print medium from a confined source which subtends, say, 20 degrees, about 4% is reflected at the mirror angle into an equivalent cone angle. Of the scattered light which is returned through the surface in all directions, less than 2% will be collected in a 20 degree solid angle.

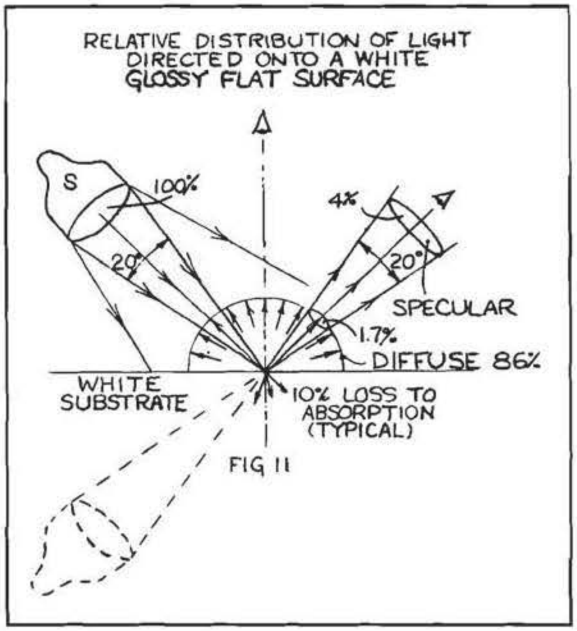
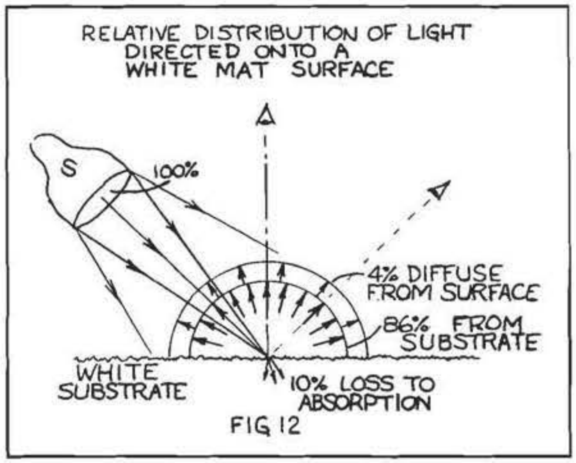


FIG 11

These surface reflections for the pure white are more than double the scattered light from the imaging medium. The source is seen as a reflection superimposed on the image. This severely interferes with interpretation of the image and constitutes noise in the information transfer. Parts of the image seen outside the source image are not contaminated with noise. This is an important clue to preferred viewing conditions.

In Figure 12, the first surface is made rough so that no direction for reflected light is favored. At each tiny facet, the same conditions previously shown exist, but the overall surface does not define a plane. In this case, the surface reflection becomes about 4% of the light reaching the eye from any position, and therefore a small amount of noise is always present.

Transmission—Transmitting media frequently possess a clear transparent carrier and a dye-impregnated coating with the image formed by the spatial distribution of the dyes. Since these are viewed by transmitted light, the first surface at which Fresnel reflection occurs is at the carrier on the back side of the image. The light entering the carrier passes through and is spectrally modified by the selective absorption of the transparent dyes. Reflections again occur at the exit surface of the medium. These rays rereflected from the first surface and scattered from within the coating can reach the eye causing some noise. Most of the noise in this type of viewing occurs from light reflected from the surround from the viewed side of the image, such as room walls and incidental light sources. This is diagrammed in Figure 19.



Viewing of Prints

A. A flat glossy print illuminated by a concentrated source.

The diagram in Figure 13 shows the simplest relationship between the elements of image viewing. This condition is also the most intuitively obvious. The image and carrier are in a plane surface. The source of illumination is remote and aligned at an angle of 45 degrees from the normal to the plane of the image. We have already learned that the imaging medium, the ink pigment, modifies the scattered light reaching it with selective spectral absorption. The colors thus perceived, together with the observed spatial distribution, comprise the information content of the image. Having a flat, glossy surface, the surface reflections are directed as by a mirror along a 45 degrees line opposite the source.

This represents the most effective condition for separating the surface reflections from the image. When viewed from any direction except that of mirror reflection of the source, the noise, or unwanted light, is effectively channelled elsewhere.

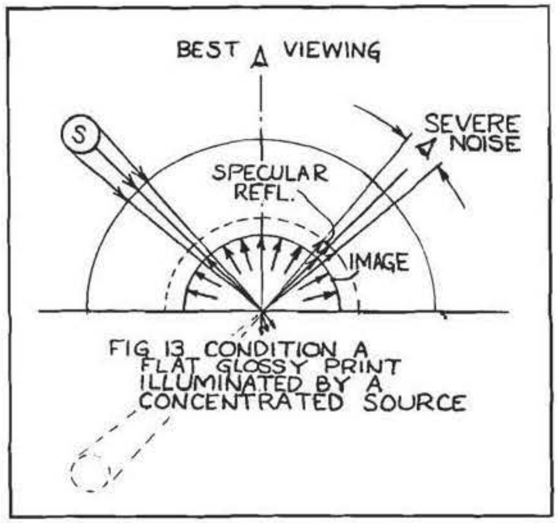
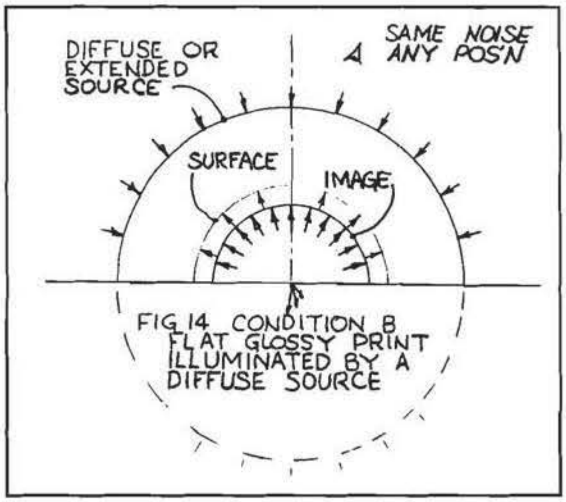


FIG 13 CONDITION A
FLAT GLOSSY PRINT
ILLUMINATED BY A
CONCENTRATED SOURCE

So, why not always use glossy prints and view them in this manner? The reason is that the real world does not conform to this simple model. The print is not always flat, and the surround is very often bright enough to be seen in the surface reflections, and many times the primary source is extended and hard to isolate. Some of the sources of noise are inherent, since they are generated by the light necessary to view the image. Others are determined by the conditions under which viewing takes place. These are termed conditional.

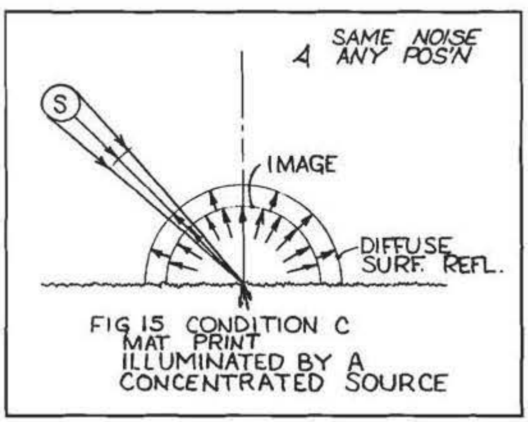
B. Flat, glossy print illuminated by an extended or diffuse source.

In Figure 14, the same object is illuminated from an extended source as in a light colored room with a high level of general lighting, or outdoors on a cloudy day. In this case, a bright object is seen reflected from the surface superimposed on the image from almost any viewing direction. The reflection is noise, affecting the interpretation of the image. Lack of image flatness is not illustrated, but obviously uncontrolled reflections are added to the image when the surface is not flat. In a glossy surface, the mirror-like reflections are sharply defined and are very bright, and often completely obscure the image from visual interpretation.

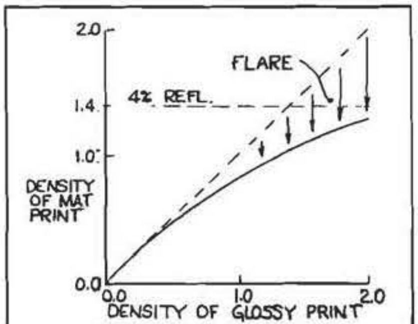


C. Mat surfaced print illuminated from a concentrated source.

In Figure 15, the same configuration of the elements is illustrated as shown in Figure 13. In this case, the surface finish of the print is mat and will diffuse the incident light equally in all directions. The light which is transmitted to the imaging pigment is again scattered as before, and is essentially unaffected by the mat surface. This print can be viewed from any angle, even that of the mirrored source without change in appearance.



Flare—While this set of conditions eliminates the strong, masking reflections associated with the glossy surface, the noise associated with the unwanted light is ever-present. All of the incident light from any direction contributes to this veiling flare when the surface is mat. The result is a reduction in the achievable dynamic range of the intensity of reflected light. No changes or increases in the absorption levels of the pigments can compensate for this flare. The curves in Figure 16 illustrate how flare limits the absorption at the high density end of the tonal scale.



LOSS OF TONAL RANGE
FIG 16

A constant percentage of the incident illumination needed to view the image is superimposed on the image at all wavelengths, diluting the absorption effects so dearly achieved in developing the pigments. Figure 17 illustrates how the flare reduces absorption at the wavelengths where it is highest, having the most damaging effect.

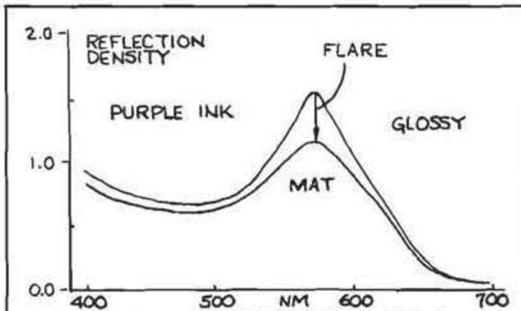


FIG 17 SPECTRAL DILUTION

D. Flat mat print illuminated by an extended or diffuse source.

Figure 18 illustrates an arrangement of the elements similar to that in Figure 14. Since the surface finish of the print is mat, light from any direction is scattered in all directions. Therefore viewing in a bright surround has little effect on the appearance of the image as compared with viewing under directional illumination in a darkened room. Remember, however, that the scattered surface reflection still retains the spectral characteristics of the source, and can affect the color of the image by adding light reflected from colored walls in the room.

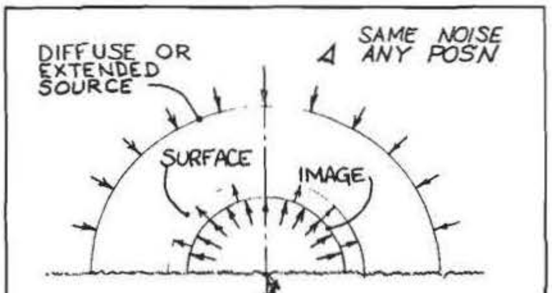


FIG 18 CONDITION D
MAT PRINT
ILLUMINATED BY
DIFFUSE SOURCE

Summarizing the effects of surface finish in viewing prints, use of a smooth glossy surface permits viewing the imaging media at their best, but only under viewing conditions that are specifically arranged for the optimum. The viewing conditions are highly sensitive to viewing direction.

Use of a mat surface finish levels out much of the troubling noise, but significantly reduces the information content of the image. The resulting flare is inherent with prints because it is caused by the light necessary for viewing. Most real life prints have surface finishes that fall somewhere between the two extremes illustrated, and can be characterized by summing the two conditions in suitable proportions.

VIEWING OF TRANSPARENCIES

E. Viewing glossy transparencies with a directional source.

The set of conditions illustrated in Figure 19 is included not only for completeness of the range of possibilities, but also because it offers the best possible viewing conditions for images on any medium. The unwanted reflections from glossy surfaces can be controlled to the highest degree in this arrangement. All light from the source can be collected and directed optically straight through the transparency directly into the eye. The possibility for rays from surface reflections are held to a minimum. This is also analogous to an instrument design in which all three elements are confined by design criteria to repeatable, predictable inputs to the receptor, be it the eye as here, or the detector of the instrument.

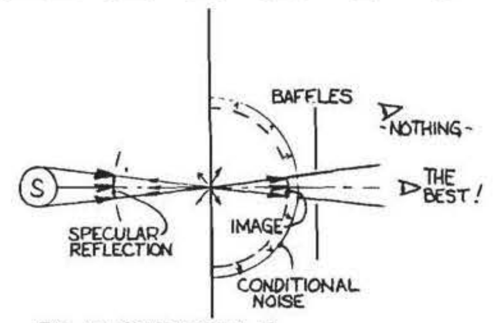


FIG 19 CONDITION E
GLOSSY TRANSPARENCY
ILLUMINATED BY A
CONCENTRATED SOURCE

The incident light angle and quality is controlled onto the transparency. The viewing angle is controlled. The surround is controlled, and consequently its effects can be minimized. Image brightness can be adjusted by the observer for a comfortable white level. The sources of noise are not inherent. They depend on conditions such as back illumination of the transparency from the observer's eye and from the inside of the viewing hood. The dynamic range of the brightness is limited only by the properties of the dye layers and the light scattering within the eye.

Glare—As an aside, the dynamic range of the eye is limited by glare, in which the brightest areas within the viewing field cause scattering of light into the shadow areas inside the eye. This is often controlled by shading the eye from the brightest image parts in order to see into the darker image areas. For example, one lowers the visor when driving toward the setting sun to reduce the glare caused by direct sunlight entering the eye. Glare can result from bright surface reflections, from a bright surround and from highlight areas in images with a very long tonal scale.

The drawback to directional illumination for viewing transparencies is that it is very confining to observer position. Typically one must peer into an eyepiece or an eyeshaded hood. The freedom to compare and discuss image features with others is limited. Furthermore, no other reproduction method can match the tonal scale and color saturation achievable with it.

Image projection—As a final comment regarding this arrangement of source and transparency, it is used to project an image onto a screen, either on the front of a diffusely reflecting surface or on the rear of a diffusely transmitting screen. The delivered image usually has all the good qualities just mentioned, but the screened image is subject to severe degradation from incidental sources and secondary reflections of light.

Rear projection systems are subject to similar surface finish effects as CRTs which will be addressed shortly. Front projection screens are so severely affected by incident illumination from the surround that they can be of no value for critical comparison except in a completely darkened room, where complete control of incidental light can be achieved.

F. Diffusely illuminated viewing of a transparency. (Figure 20)

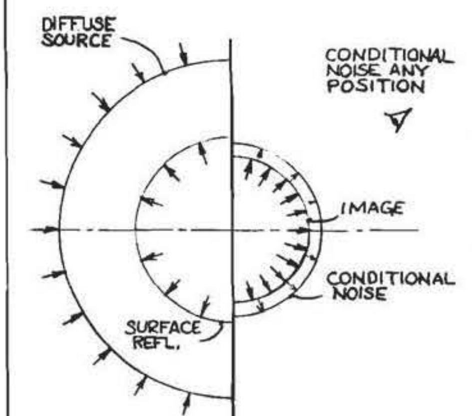


FIG 20 CONDITION F TRANSPARENCY ILLUMINATED BY A DIFFUSE SOURCE

Transparencies are frequently viewed by placing them on a light table. Since transparencies are usually glossy on both surfaces, there is little control of the appearance available in that property. The main distinction of this type of illumination is that each image element receives light from a wide solid angle and transmits the light into a wide angular space. This illumination is therefore uncontrolled and will impinge on surrounding objects. Light reflected back onto the transparency from these objects will reflect light from the surface of the transparency and degrade the image. Often, the light table is larger than the transparency and illumination around its edges reaches the eye and other nearby objects. This combination of glare and secondary reflections adds to degradation of the perceived image quality.

Since the viewing conditions are not confined, another likely source of noise is from incidental sources of light behind the observer, such as a window or overhead lighting fixture.

Mat surfaced transparencies viewed in this manner would eliminate the sharply defined reflections from the surface, but would scatter light, causing flare, thus reducing contrast, color saturation, and introduce colors associated with the sources in the same manner as with the mat print.

Real transparencies often have some haziness or scattering associated with the emulsion layer. This will introduce to a small extent the properties of a mat surface.

Viewing of CRTs

Video monitors are produced in a wide variety of sizes and quality levels. Certain features characterize a cathode ray tube (CRT), making the surface finish a vital part of the observed image. Most CRTs have a curved face which greatly reduces the opportunity to control and thus avoid surface reflections. The glass face of the video display tube has considerable thickness to withstand pressure associated with its interior vacuum. This thickness severely limits the amount of surface texture which can be used for reflection control without loss of image resolution.

G. CRT with a glossy face. (Figure 21)

The CRT has the advantage that it is not dependent on outside illumination for image viewing. There are still a number of ways noise can creep into the observer's view. The curved face of the tube will reflect light from a much wider range of angles into the observer's eye than would a flat face. Therefore, lighted objects in the surround are very likely to be superimposed on the image—for example, the walls or a window. Since the CRT is a light source in itself, even in a darkened room it will illuminate nearby objects which will in turn reflect in the face of the tube. The dynamic range of the image is in this case not limited by the effects of surface finish, but by internal light and electron reflections within the tube. These tend to lighten the dark elements of the image.

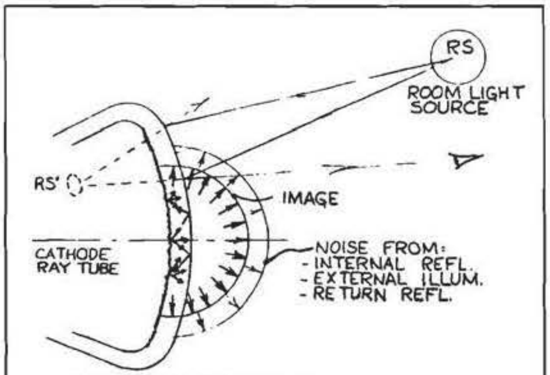


FIG 21 CONDITION G
SELF-LUMINOUS IMAGE
ON GLOSSY CURVED GLASS
CARRIER - TYP OF CRT

A CRT with a truly mat finish on the face of the tube will not produce a satisfactory image. The image would be severely diffused because of the spacing between the pigment surface and the outer surface caused by the thickness of the glass. Compromises are commonly made in which a small degree of surface roughness is used to reduce the sharpness of the reflected image without significantly affecting the primary image. These compromises result in all of the undesirable effects being present to some extent.

A special surface finish is possible with the CRT, since the outer surface is smooth and suitable for use of such a process. A coating can be applied to glass which will suppress the non-metallic surface reflection from the usual 4% to less than 1%. A 1/4 wavelength thick circularly polarizing layer causes the reflected light to be selectively attenuated without having a noticeable effect on the light emitted by the phosphors. One drawback that should be noted is that there is some wavelength dependency in the coating, thus imparting some coloration to the small amount of reflected light which remains. Although it is very effective, it is somewhat costly, and is not widely used.

General ambient illumination from the surround limits the darkness achievable in the image, whether coated or not, since the phosphor layer reflects some of that light. The result is flare of the type described in viewing mat prints. A CRT image can therefore be best viewed in a darkened room having no reflecting objects nearby. This limits the usefulness of the display in interpreting the image with other people or in comparing with other media.

Additional Factors Involving Surface Finish

Dryback

A wet ink film will have the smooth, glossy surface characteristic of a liquid. As it dries, the liquid layer collapses into the paper structure and takes on its surface quality. For a mat paper, the transition from a wet ink film to a dry one results in a corresponding change in appearance within the inked area.

Varnish

A varnish coating creates a smooth, glossy layer over the ink and the substrate which allows a mat stock to be used while retaining the ability to control surface reflections. The varnish must be clear to avoid imparting coloration of its own.

Photographic Prints

Very often photographic prints are given a slightly diffuse surface to break up the hard edges of the reflected objects, while retaining enough glossiness to provide good contrast and color saturation. This type of surface is described as having haze, and its quality can be controlled by measuring the spread of reflected light in the range of 2 to 5 degrees from the specular angle.

Metallic Surfaces

Light reflected from a metallic surface does not have two components. All the reflected light comes from the first reflection. It may be a smooth surface with mirror-like reflections, or it may be mat and scatter the reflected light. In either case, the color is imparted by selective spectral absorption in the first surface encounter.

If the metal is coated with a clear varnish, or if metallic flakes are embedded in a binder to form an ink layer, the surface reflections must be combined with the metallic reflections.

Orange Peel

A glossy surface with a coarse wavy pattern has a characteristic appearance often termed "orange peel." This type of surface is not useful in making critical comparisons, since the surface reflections are neither uniform nor controllable, and the appearance is dependent on the form of the surface.

Scattered Light Images

Vesicular films form images with tiny bubbles embedded in a clear plastic carrier. These are viewed by transmitted light from a directional source. The image is seen as a positive when viewed from outside the directional cone of illumination where clear areas appear dark and the image areas scatter light from the directional beam to the eye. The image is seen as a negative when viewed from within the directional cone of light and the scattered areas appear darker than the source. Surface finish differences can be used in the same way to create images in transmitted light, and as illustrated in Figure 3, by reflected light as well.

Summary of Significant Factors

The widest use of imaging media is in the viewing of a single example for interpreting the information it provides. In most cases the interference from surface reflections can be ignored. In some cases it is necessary to change viewing angles or lighting direction to avoid the sharply defined reflections which can mask the image. Very often the more subtle flare which accompanies mat surfaces is not noticed. This leads to wide use of mat surfaces to control the reflections associated with glossy surfaces.

It is when images are to be critically compared that these effects are noticeable and important. To achieve control, it is necessary to remove to the greatest extent possible the variables which are not predictable and which are not part of the image-forming components.

Mat surfaces will always reduce the contrast of the image. The very light needed to view the image whether from within, in front or from behind will be scattered to the eye from all parts of the image and will lighten the shadow areas and dilute the color saturation.

Smooth or glossy surfaces are essential for preserving the full contrast and color saturation capabilities of the imaging media. For effective use, the surface reflections must be eliminated in the viewing situation. Darkened room viewing is inconvenient and limited in effectiveness.

RECOMMENDATIONS

An enclosure with one or more restricted viewing locations and a black and baffled interior can provide the necessary control. Such an approach requires careful design not only to avoid effects of reflections, but to accommodate the other needs for image comparison. Compromises with convenience are expected.

To include CRT and transparency viewing, the design must permit controlled brightness border framing for visual accommodation, a white level reference for the image and it must prevent cross-illumination between images. Adjustable magnification is needed to allow matching of the image sizes. Glossy prints would have to be accommodated within the enclosure using a holder for flatness and baffled or shaded oblique lighting. A light trap is needed to capture and absorb the specular reflection.

Adjustable light sources for brightness and color balance are needed, along with color gun controls for the CRT.

With these kinds of accommodations, noise from surface reflections can be kept sufficiently low that other imaging factors can be fully developed.

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