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MODULATION TRANSFER FUNCTION

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THIS CHAPTER WILL INCLUDE A REVIEW OF:

- Modulation transfer function (MTF)

MODULATION TRANSFER FUNCTION (MTF)

Since all images can be made of sine wave gratings, and all optical systems, as well as our neural visual system, process images by means of Fourier transformation, a good way to evaluate both optical and visual performance is to test using sine wave gratings.

All image-forming optical systems, including the human eye, create less than perfect images. We can say that the optical system transfers the luminance distribution of the object to the image, but in the process, something is always lost. Even in an eye that is perfectly corrected for spherical and astigmatic refractive errors, optical effects such as **diffraction, higher order aberrations**, and perhaps some **scatter**, degrade the image to some degree. Compared to the object, even the best image will have slightly less contrast. The degree to which contrast is lost varies depending on the spatial frequency of the sine wave grating in the image. That is, high spatial frequency images tend to lose more contrast than low spatial frequency images. One way to characterize the imaging performance of an optical system is to describe how much contrast is lost across a range of sine wave gratings with various spatial frequencies.

This can be done in the following way, which is illustrated in Schwartz, 2004 Fig. 7-6. If a sinusoidal test pattern is presented to an optical system, the image will still **be a sinusoidal pattern with the same spatial frequency**, but with slightly reduced **contrast**. Sometimes contrast is referred to by the term modulation. The contrast reduction varies with spatial frequency, and usually there is a greater loss for higher frequencies. We are interested in measuring how well the contrast (or modulation) is transferred from the object to the image for every frequency.

We can restate the same concept in another way. One way to evaluate the optical performance of, for example, a camera, is to see how good its images are compared to the real objects. A very good camera would produce extremely clear images that look almost exactly like the object, but a cheap camera would produce a poorer quality photograph that is less sharp (more blurred).

Engineers are more systematic, and they use standard high-contrast test patterns. By comparing the test pattern (the object) and its image, they can determine how well the optical system transfers contrast from object to image. The test patterns cover a wide range of spatial frequencies, and it allows them to see how good the optical system is. Figure 13-1 shows one example of an optical test pattern used by the U.S. Air Force. Note that this particular pattern does not use sine wave gratings, but rather, square-wave gratings.

MODULATION TRANSFER FUNCTION (MTF) (CONT.)

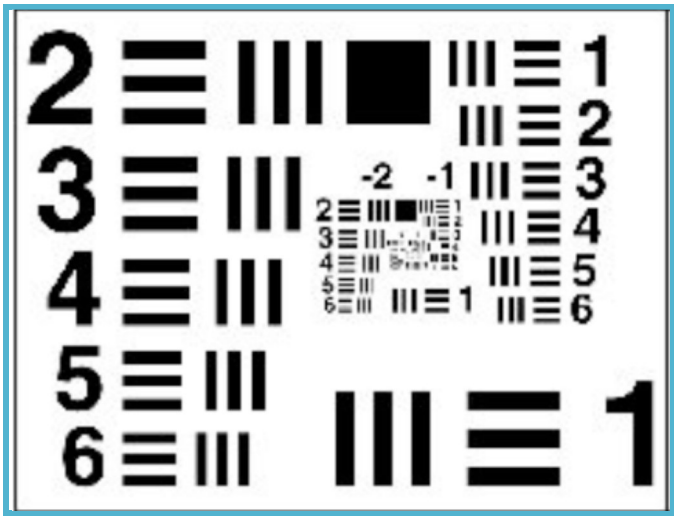

Figure 13-1: *USAF 1951 test pattern*

Q. How would sine wave gratings differ in appearance from the chart shown in Figure 13.1?

A. _____

Q. What are two advantages to using sine wave gratings as the test pattern?

A. _____

The **modulation transfer function (MTF)** is a standard way to describe the imaging performance of an optical system, and it is based on the principle of testing the system using sine wave gratings. To measure the MTF, various high-contrast sine wave gratings are presented to the optical system and the contrast in the image is compared to the contrast in the test pattern. For each spatial frequency, the **modulation (or contrast) transferred (MT)** from object to image, is computed according to the equation below:

$$MT = \frac{(\text{image_contrast})}{(\text{object_contrast})}$$

A value of 1.0 indicates that the image contrast equals that found in the object, that is, no contrast is lost, and for that frequency the image is perfect. If, for example, we test MT using a large set of vertical sine wave gratings of various spatial frequencies, as is typically done, we can plot a graph of the MTF, with spatial frequency along the x-axis and modulation transferred along the y-axis (Fig. 13-2).

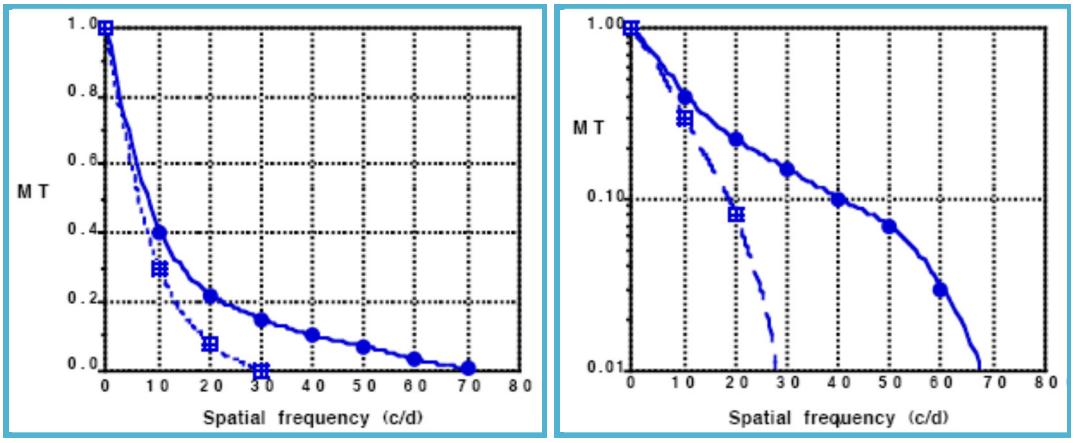

Figure 13-2: *Examples of ocular MTFs drawn with a linear (left) and log (right) scale for MT*

MODULATION TRANSFER FUNCTION (MTF) (CONT.)

Figure 13-3 also illustrates the concept of describing optical performance in terms of the MTF. In that figure, the target in front of the eye contains many different spatial frequencies (stripes with different widths), so we can see how the loss of contrast in the image is different for different parts of the image. Notice the following features, both in Figures 13-2 and 13-3:

- There is almost no loss of contrast for the lowest spatial frequency. That is, the MT has a value of 1.0 at the far left of the MTF curve
- As spatial frequency increases, there is a steady drop in the MT value
- The **cut-off frequency** is the frequency at which the MTF drops to zero

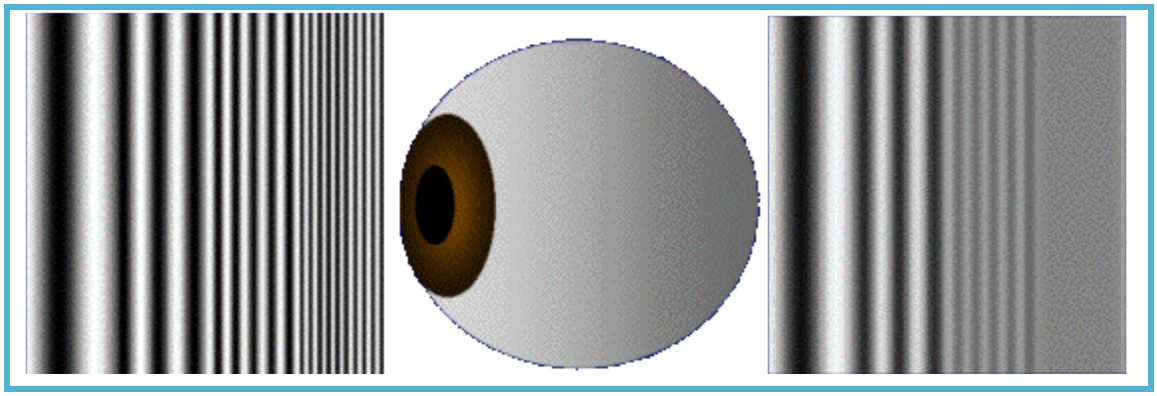

Figure 13-3: *The modulation transfer function describes optical performance in terms of how well contrast is transferred from the object (left) to the image (right). Notice the loss in contrast for the retinal image compared to the object. Which spatial frequencies show the greatest loss in contrast? (Courtesy of Dr. Susana Marcos, Instituto de Optica, Madrid, Spain)*

Schwartz, 2004 Fig. 7-7 shows other examples of ocular MTFs and the affect of different optical defects on image quality.

- **Defocus**, which degrades optical performance and blurs images, reduces the MTF at the higher, but not lower spatial frequencies. With greater defocus, the high frequency cut-off will come sooner; the curve will be shifted to the left and down. Refractive errors cause defocus. Defocus removes the higher spatial frequencies from the image, so it acts as a filter that removes high spatial frequencies. It can be thought of as **a low-pass filter**
- **Scatter** in the optical media reduces the MTF at low as well as high spatial frequencies. Cataracts cause scatter.

SUMMARY

The modulation transfer function (MTF) tells how well an optical system forms images. Since sine wave gratings are the fundamental building blocks of all images, the MTF can completely characterize imaging performance by stating how well the system forms images of sine wave gratings.

In general, optical blur, such as an uncorrected refractive error, reduces the MTF at high frequencies only and causes a lower **cut-off frequency**. On the other hand, media opacities that scatter light in the eye tend to reduce the MTF across a broader range of spatial frequencies, including mid or even low spatial frequencies.

SELECTED READING/REFERENCES

- Schwartz SH. **Visual Perception - A Clinical Orientation, 3rd Edition**. Appleton & Lange, Stamford, Connecticut, 2004