



*The Institute for
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Electronic Circuits*

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Standard for Visual Optical Inspection Aids

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- Keep people out
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The material in this standard was developed by the Optical Inspection Aids Task Groups (7-31d) of the Acceptability Subcommittee (7-31) of the Institute for Interconnecting and Packaging Electronic Circuits.



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Users of this standard are encouraged to participate in the development of future revisions.

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Acknowledgment

Any Standard involving a complex technology draws material from a vast number of sources. While the principle members of the IPC Optical

Inspection Aids Task Group of the IPC Acceptability Subcommittee are shown below, it is not possible to include all of those who assisted in

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Standard for Visual Optical Inspection Aids

1.0 GENERAL

1.1 Scope This standard establishes the requirements, definitions, and certification provisions for optical inspection aids and defines inspection grades that can be used as accept/reject criteria for the instrumentation used in an inspection process that uses optical inspection aids.

1.2 Purpose The intent of this document is to provide information to be used in the selection and application of optical magnifying inspection aids. It also provides specific preferred wording and specific definitions of inspection grades to be used for inspection operations requiring varying degrees of optical magnification assistance.

1.3 Usage Grades This specification provides Grades [I through XII] to reflect progressive increases in magnification and resolution. These different grades indicate a progression of increased usage complexity and application cost. The use of one grade for a specific acceptance test does not mean that other acceptance features must use the same grade for acceptance. Selection should be based on the minimum needed to control required reliability. A grade should not be over specified, causing too-critical inspection of the product without a real need for the added complexity and cost involved with increases in grade.

1.4 Certification Test The certification for both the initial qualification of the magnifying aid and the periodic quality conformance tests and methods are intended to demonstrate the ability of the optical inspection aid to meet the requirements of this standard. The examples used in the Appendices are not the only way this can be demonstrated, but are supplied as one of many acceptable ways. The methods defined in this standard are supplied so users of this standard not familiar with optical technology applications have a reference for consideration.

2.0 APPLICABLE DOCUMENTS

The following documents, of the issue currently in effect, form a part of this document to the extent specified herein.

2.1 IPC¹

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits.

2.2 Military²

MIL-STD-150A Military Standard Photographic Lenses

MIL-STD-1241A Military Standard Optical Terms and Definitions

MIL-STD-1686A Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Devices)

2.3 Underwriters Laboratories³

U.L. Standard 1581 Reference Standard for Electrical Wire, Cable, and Flexible Cords.

U.L. Standard 153 Portable Lamps.

3.0 REQUIREMENTS

3.1 Related Terms and Definitions Related definitions and all terms used herein shall be as specified in IPC-T-50, MIL-STD-1241A, MIL-STD-150A, and MIL-STD-1686A or if not included in them, the definitions in this section applies.

3.1.1 Apparent Field-Of-View Angle The angular subtense of the field-of-view in the image space of the optical system (the angle seen by the observer's eye) as differentiated from that in the object space (the real field).

3.1.2 Color Temperature A measure of the energy distribution over the visible spectral range (i.e., the color quality) of a light source with a continuous spectrum expressed in Kelvins (K). The color temperature is the temperature on the absolute scale (degrees C+273) to which a perfect blackbody radiator would have to be heated to appear visually as the same color as the light source in question.

3.1.3 Density, Optical Logarithm to the base 10 of the reciprocal of transmittance.

3.1.4 Diopter Abbreviated DIOPT. A unit of refractive power of a lens. In a lens or lens system it is numerically equal to the reciprocal of the focal length measured in meters. For example, if a lens has a focal length of 25 centimeters, i.e., 1/4 meter, its refractive power is 4 diopters.

1. Publications may be obtained from the Institute for Interconnecting and Packaging Electronic Circuits, 2215 Sanders Road, Northbrook, IL 60062-6135.

2. Publications may be obtained from the Standardization Documents Order Desk, Building 4D, 700 Robbins Ave., Philadelphia, PA 19111-5094.

3. Publications may be obtained from Underwriters Laboratories, 333 Pfingsten Rd., Northbrook, IL 60062

3.1.5 Effective Color Temperature A measure of the energy distribution over the visible spectral range of a light source using an approximation of an equivalent continuous spectrum resultant source expressed in Kelvins. The effective color temperature is the temperature on the absolute scale (degree C+273) to which a perfect blackbody radiator would have to be heated to emit light with the closest visual color match to that of the approximation of the equivalent continuous spectrum resultant light source in question.

3.1.6 Effective Focal Length of a Magnifying Aid A measure of the distance from either of the principal points of the magnifying aid's optical system to its corresponding focal point for an infinitely distant object.

3.1.7 Eye Relief of a Magnifying Aid The projected axial distance from the surface of the eye to the nearest magnifying aid hardware or lens when a required field-of-view from the magnifying aid is achieved by the viewer using the magnifying aid.

3.1.8 Illuminated A surface or object is said to be illuminated whenever luminous flux is incident upon it.

3.1.9 Magnifying Aid A magnifying aid is an instrument for producing enlarged virtual or real images of small objects.

3.1.10 Magnifying Power The magnifying power (MP) for a visual magnifying aid is determined with the magnification aid focused so that the viewer's eye is focused at infinity and by using the equation:

$$MP = \frac{\tan(\beta)}{\tan(\alpha)}$$

Beta shall be one-half the angle subtended by the image (H') of an object (H) as seen through and centered in the field of view of the magnifying aid.

Alpha shall be one-half the angle subtended by the object (H) as seen at 254 mm [10 in] by the unaided eye. Tangent alpha therefore equals 1/2 H divided by 254 mm. The relationship between beta, alpha(H), and (H') is illustrated in Figure 1:

3.1.11 Percent Of Field-Of-View Of A Magnifying Aid

The percent of the minimum required field-of-view of that magnifying aid.

3.1.12 Proportional Dimensions As Viewed In Magnifying Aid—To render proportional dimensions is the ability of the optical system used in the magnifying aid to correct the distortions enough to allow the magnifying aid to resolve the required details of this standard.

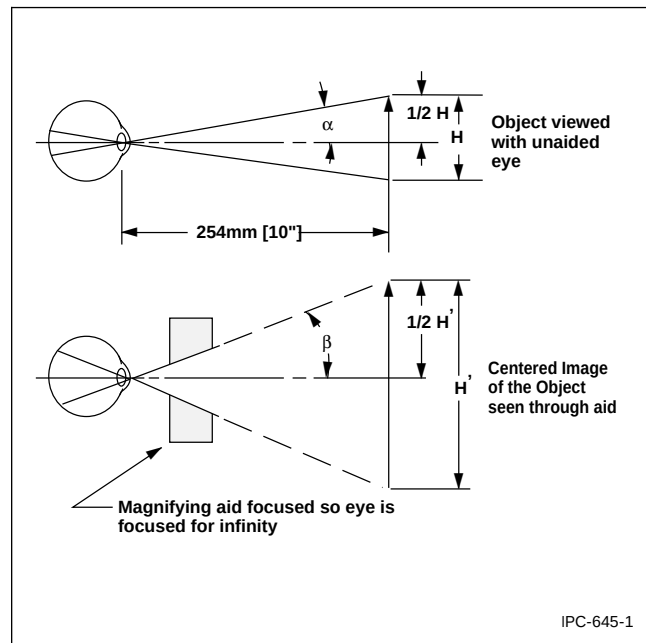


Figure 1 Magnifying power

3.1.13 Qualified Apparent Field-of-View Angle The apparent field-of-view angle that is qualified for use in acceptance inspection by passing all the requirements of this standard. It is defined in degrees of apparent field of view as measured from the center of the field viewed by the viewer using the magnifying aid.

3.1.14 Render True Color In A Magnifying Aid To render true color is the ability of the optical system to correct the color aberrations enough to allow the magnifying aid to resolve the required details of this Standard.

3.1.15 Shadowless Illumination For Magnifying Aids

Illumination on the specimen's area of interest so that no shadows from objects that are not of prime interest fall on the area being viewed for acceptance. However, the specimen of interest may have shadows generated from itself so defects may be observed.

3.1.16 Specimen The target, or object being examined for acceptance.

3.1.17 System Effective Color Temperature A measure of the energy distribution using an approximation of an equivalent continuous spectrum resultant source, expressed in Kelvins, of the transmitted visible spectral energy distribution range using the optical system's light source to illuminate the optical system's target area. The system effective color temperature is the temperature on the absolute scale (degree C+273) to which a perfect blackbody radiator would have to be heated to emit light with the closest visual color match to that of the approximation of the equivalent continuous spectrum resultant system transmission in question using the system's light source to illuminate the optical system's target area.

3.1.18 Visual Resolving Power Visual resolving power is the ability of a viewer using the magnifying aid to observe detail of a minimum spacing between object elements while observing a high contrast standard resolving power target. It is expressed in lines per millimeter as defined in MIL-STD-150A, paragraphs 5.1.1.7, 5.1.1.7.1 and 3.3.7 of this standard.

3.1.19 Working Distance Distance from the specimen to the closest part of the optical system or the hardware surrounding the optical system, whichever is smaller.

3.2 Conflict In the event of a conflict between the requirements of this specification and those of any referenced document, the requirement of this specification shall take precedence.

3.3 General Requirements For All Inspection Grade Specifications In This Standard

3.3.1 Test Conditions Unless particularly required by intended uses, all tests and measurements shall be conducted under normal room conditions.

3.3.2 Magnifying Power The magnifying power (MP) for a visual magnifying aid shall be determined with the magnification aid focused so that the viewer's eye is focused at infinity and by using the equation:

$$MP = \frac{\tan(\beta)}{\tan(\alpha)}$$

Beta shall be one-half the angle subtended by the image (H') of an object (H) as seen through and centered in the field of view of the magnifying aid.

Alpha shall be one-half the angle subtended by the object (H) as seen at 254 mm [10 in] by the unaided eye. Tangent alpha therefore equals 1/2 H measured in inches divided by 254 mm. The relationship between beta, alpha(H), and (H') is illustrated in Figure 1.

3.3.3 Magnifying Power Tolerance The tolerance for magnifying aid's magnifying power, unless otherwise specified, is 15% of the selected magnification power (i.e. 15% or a range of 30% centered at the selected magnification power) for the grades chosen from paragraph 3.4.1 through 3.4.12 of this standard.

3.3.4 Operator Visual Acuity All candidates shall meet the following minimum vision requirements:

- Far Vision: Better than 20/50 per Snellen
- Color Perception: Normal as determined by standard color plates.

All personnel certified to this standard shall be given an eye test by an accredited eye examiner to determine their ability to meet these vision requirements. Frequency of eye

tests shall be annually for persons 35 years of age or older and every two years for persons less than 35 years of age, except frequency for an individual may be increased if so prescribed by a licensed ophthalmologist. Use of prescription lenses to meet the vision requirements is permissible. When such lenses are required, the certification card shall so state and such lenses shall be used whenever visual acuity is required. If a magnifying aid has adjustable focus and a viewer can focus the magnifying aid so that the viewer can discriminate the lines per millimeter resolution requirements of the magnifying aid inspection grade required from section 3.4.1 through 3.4.12 of this Standard without the use of prescription lenses, the prescription lenses are not required.

Failure to meet these requirements shall disqualify a candidate from using a magnifying aid.

3.3.5 Lighting Illumination Light sources shall illuminate the specimen of interest providing effective illumination so that no shadow falls on the specimen, except those shadows caused by the specimen itself.

The light source shall be sufficient to allow the detection and perception of the minimum required visible resolving power per the magnifying aid inspection grade chosen from sections 3.4.1 through 3.4.12 of this Standard. The illumination used for inspection shall be selected such that defects, including exposed copper, can be detected if the magnifying aid is used to inspect solder connections.

All Electrical wiring, cables, and fixtures shall meet U.L. Standards 1581 and 153.

3.3.6 Visual Resolving Power The user of a magnifying aid shall be capable of distinguishing the required visual resolving power lines per millimeter for the grade chosen from sections 3.4.1 through 3.4.12 and using a resolving power target as defined in section 3.3.7 of this Standard. This visual resolving power shall be obtained at the center of the magnifying aid's apparent field-of-view, and at ± 5 degrees to each side of center. If the magnifying aid's "apparent field-of-view angle" is larger than ± 5 degrees, the visual resolving power at the edge of the "qualified apparent field-of-view angle" within which inspection is permitted or at ± 10 degrees, whichever is smaller, shall be at least 70 percent of that required in the center of the apparent field-of-view.

3.3.7 Resolving Power Target The resolving power target used on all tests shall be as follows: The target shall consist of a series of target elements, each decreasing in size as the sixth root of two ($2^{1/6}$), with a range sufficient to cover the requirements of the grade under test. The standard target element shall consist of two patterns (two sets of lines) at right angles to each other. Each pattern shall consist of three lines separated by spaces of equal width.

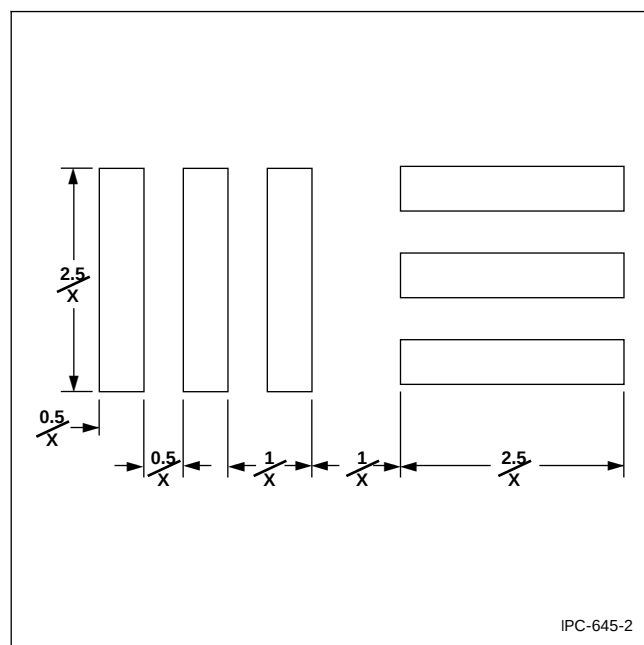


Figure 2 Standard resolving power test target element

Each line shall be five times as long as it is wide. (See Figure 2). This target shall be a transparency with a black target pattern on a clear background. When used the targets shall be viewed against a white background and illuminated from the rear. The tolerances on this standard resolving power target dimensions are 10%. The target contrast (the difference in optical density between the lines and spaces) shall be high with the density difference between the light and dark areas greater than 2.00.

The patterns of lines are parallel lines $2.5/X$ mm long, and $0.5/X$ mm wide, with a space $0.5/X$ mm wide between the parallel lines, where $1/X$ equals the number of “lines per millimeter.” This is synonymous with the terms “line pairs per millimeter” and “cycles per millimeter,” which refer to one black line and one whole spacing as a line pair or cycle.

3.3.8 Qualified Apparent Field-Of-View Angle The magnifying aid’s qualified apparent field-of-view angle is that angle qualified for use in acceptance inspection by passing all the requirements of this standard. This angle shall be at least 5 degrees measured from the center of the field as seen by the viewer.

3.3.9 Eye-To-Specimen Distance The viewer’s eye, while using a magnifying aid, shall be at least 57.15 mm [2.25 in] away from the specimen under inspection.

3.3.10 Working Distance The magnifying aid shall have a working distance of not less than 55% of its effective focal length when viewing the specimen being inspected.

3.3.11 Simultaneous Viewing With Both Eyes For

acceptance of inspected products, magnification aids of a type that permit simultaneous viewing with both eyes are preferred, however, single-eye viewing devices shall be acceptable.

3.3.12 Electrostatic Discharge Control If any magnifying aid is used within an “electrostatic discharge protected area” the requirements of MIL-STD-1686A shall apply. Paragraphs 5.4 and 5.5 of that standard are of particular interest:

MIL-STD-1686A Paragraphs 5.4 and 5.5

5.4 Protected Areas Handling of ESDS parts, assemblies, and equipment without ESD protective covering or packaging shall be performed in protected areas in accordance with detailed ESD protective handling procedures (see paragraph 5.5). If there are practical considerations which preclude handling in the protected areas, detailed alternative handling precautions and procedures shall be prepared and utilized in the unprotected areas. Electrostatic voltages in areas where class 1, class 2 and (as specified in accordance with the requirements of 1.3.2.1) class 3 parts, assemblies, and equipment are handled without protective covering or packaging shall be maintained below the lowest voltage sensitivity level of these items as determined in accordance with 5.2.1.1.

5.5 Handling procedures ESD protective handling procedures shall be developed, documented, and implemented. The details of the procedures depend on the degree of controls afforded by the protected area. The fewer controls afforded by the protected area, the more detailed the procedures shall be to provide the required protection from damage due to ESD. Handling procedures shall be prepared and submitted for approval in accordance with the data ordering document included in the contract or order (see paragraph 6.2).

This requirement generally implies that materials used for these magnifying aids should be made of anti-static, ESD protective material having a surface resistivity greater than 10^9 ohms per square, but not greater than 10^{14} ohms per square.

3.4 Magnifying Aid Inspection Grades When using any of the following inspection grades as acceptance requirements the rest of this document applies. A grade should be chosen as the minimum required to accomplish the inspection task functional needs. Referee examination may be performed only on products that have previously been rejected as a result of inspection using the specified magnifying aid inspection grade. Under those conditions, referee inspection may be performed using magnifying aids that are defined in the next higher inspection grade.

higher minimum magnifying power than that specified to accomplish the inspection.

3.4.1 Grade I Acceptance of the specimen under inspection shall be based on using the unaided eye with no magnifying aid required. The viewer shall discriminate a minimum visual resolving power of 6.35 lines per millimeter.

3.4.2 Grade II Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 4.49 lines per millimeter and with the magnifying aid having a minimum magnifying power of 0.75.

3.4.3 Grade III Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 6.35 lines per millimeter and with the magnifying aid having a minimum magnifying power of 1.0.

3.4.4 Grade IV Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 12.7 lines per millimeter and with the magnifying aid having a minimum magnifying power of 2.0.

3.4.5 Grade V Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 25.4 lines per millimeter and with the magnifying aid having a minimum magnifying power of 4.0.

3.4.6 Grade VI Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 64 lines per millimeter and with the magnifying aid having a minimum magnifying power of 10.0.

3.4.7 Grade VII Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 102 lines per millimeter and with the magnifying aid having a minimum magnifying power of 20.0.

3.4.8 Grade VIII Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 161 lines per millimeter and with the magnifying aid having a minimum magnifying power of 40.0.

3.4.9 Grade IX Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 181 lines per millimeter and with the magnifying aid having a minimum magnifying power of 60.0.

3.4.10 Grade X Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 228 lines per millimeter and with the magnifying aid having a minimum magnifying power of 80.0.

3.4.11 Grade XI Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 322 lines per millimeter and with the magnifying aid having a minimum magnifying power of 120.0.

3.4.12 Grade XII Acceptance of the specimen under inspection shall be based on using a magnifying aid with the viewer discriminating a minimum visual resolving power of 362 lines per millimeter and with the magnifying aid having a minimum magnifying power of 200.0.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility For Certification Except as otherwise specified in the procurement document, the magnifying aid user may use its own or any other facilities suitable for the performance of the certification requirements specified herein. The procurement activity reserves the right to perform any of the certifications set forth in this specification where such certifications are deemed necessary to assure that materials and services conform to prescribed requirements.

4.2 Categories Of Certification The inspections specified herein are categorized as follows:

- a. Initial Certification (see 4.3).
- b. Periodic Recertification (see 4.4).

4.3 Initial Certification Initial certification shall be performed in accordance with the requirements of Table 1 by an inspector certified in accordance with paragraph 3.3.4 under the lighting conditions of paragraph 3.3.5. Paragraph 3.3.12 shall apply when required.

4.3.1 Certification Routine The user shall select those parameters required for testing from Table 1.

4.3.2 Failures Unless otherwise specified, one or more failures shall be cause for rejection of that magnifying aid.

4.4 Periodic Recertification Periodic recertification of magnifying aids shall be performed in accordance with the requirements of Table 1 by an inspector certified in accordance with paragraph 3.3.4 under the lighting conditions of paragraph 3.3.5. Paragraph 3.3.12 shall apply when required.



Table 1 Quality Assurance Tests

Requirement	Requirement Paragraph	Frequency	Sampling
Visual Resolving Power	3.3.6	Once	100%
Magnifying Power	3.3.3	Once	100%
Eye to Specimen Distance	3.3.9	Once	100%
Working Distance	3.3.10	Once	100%
Qualified Apparent Field of View Angle	3.3.8	Once	100%
Visual Resolving Power	3.3.6	4.4.1	4.4.1
Magnifying Power	3.3.3	4.4.1	4.4.1

4.4.1 Frequency Of Recertification And Sampling

Requirements The periodic recertification shall be run on 100% of the magnifying aids one year after initial certification was completed or upon first usage of the magnifying aids, whichever is longer. If no failures are present in this testing, then a 50% sampling is required within one year of the last test. If no failures are present in this testing, then a 25% sampling is required within one year of the last test. The 25% sampling is required within one year of each additional test thereafter if no failures are present. However, if any failures are present at any time the defect is fixed and the test cycle restarts at 100% sampling for the requirements in Table 1.

4.4.2 Acceptance Unless otherwise specified, one or more failures shall be cause for rejection of that magnifying aid and cause for 100% recertification of all other magnifying aids of the same kind.

4.5 Certification Procedures. The methods used for certification to the requirements are the responsibility of the magnifying aid user. In order to aid users who are not familiar with optical testing procedures and good quality practices, the Appendices include typical methods that may be used as a guide or reference method.



Appendix A Magnification

Magnification is a dimensionless quantity, a ratio of apparent image size compared to the apparent size of the object at some specified viewing distance. The term “magnifying power” is frequently used synonymously with magnification. Either the angular subtenses or the linear dimensions of the image and object may be ratioed depending upon the device used and the application. The magnification of relay optics (microscope objectives, copier lenses, photographic enlarging and reducing lens, etc.) that operate at finite conjugates is commonly expressed as the ratio of the linear sizes of the image and object. The magnification of optics using at least one infinite conjugate (eyepieces, magnifiers, astronomical telescopes, etc.) is commonly expressed as a ratio of image and object angular subtenses. Some optical systems, such as microscopes, use both relay optics and eyepieces. The magnification of these systems must be determined by breaking the system down into finite and infinite conjugate components and using the appropriate definition of magnification for each specific component. The system magnification may then be determined by multiplying all the component magnifications together.

In general, the magnifying power or magnification of a simple magnifier such as an eye loupe is given below where the terms in the equation are illustrated in, Figure A-1. No attempt will be made to derive these equations. To be correct the following quantities: s , the object distance; s' , the image distance; and d , the eye relief should be measured from the corresponding principal point and not from the front or rear lens vertex.

Equation 1

$$\text{Magnification} = \frac{\tan(\beta)}{\tan(\alpha)} = \frac{h/(d-s^1)}{h/L} = \frac{L(1/f-1/s^1)}{1-(d/s^1)} = \frac{L}{d+s[(d/f)-1]}$$

L is the standard viewing distance for unaided eye viewing of the object. Most frequently L is stated to be (10.0 inches) 254 mm. The first expression for magnification may be used when the image distance (from the lens) is known. The second expression is used when the object distance is known. Both yield the same result. Similarly, the angular subtense of the image is given in equation 2.

Equation 2

$$\tan(\beta) = h^1/(d-s^1) = \frac{h(1/f-1/s^1)}{1-(d/s^1)} = \frac{h}{d+s[(d/f)-1]}$$

Frequently, in the literature, other simpler expressions are used for magnification. For example, when the object viewed is located at the back focal point of the magnifier $s = -f$ and $s' = \infty$. Equation 1 reduces to the familiar:

Equation 3

$$\text{Magnification} = 254 \text{ mm}/f$$

Similarly, when the eye relief, d , is zero and the object is moved closer to the magnifier until the image appears at the close eye focus point, $s' = -254 \text{ mm}$, equation 1 reduces to:

Equation 4

$$\text{Magnification} = (254 \text{ mm}/f) + 1$$

Other useful information can be obtained from equation 1. First of all, due to the fact that power is distributed among the optical surfaces within the magnifier and the elements have a finite thickness, the eye relief of a magnifier is almost never zero. This means that equation 4 must be modified to be accurate. Taking into account a non-zero eye relief equation 1 can be modified to yield:

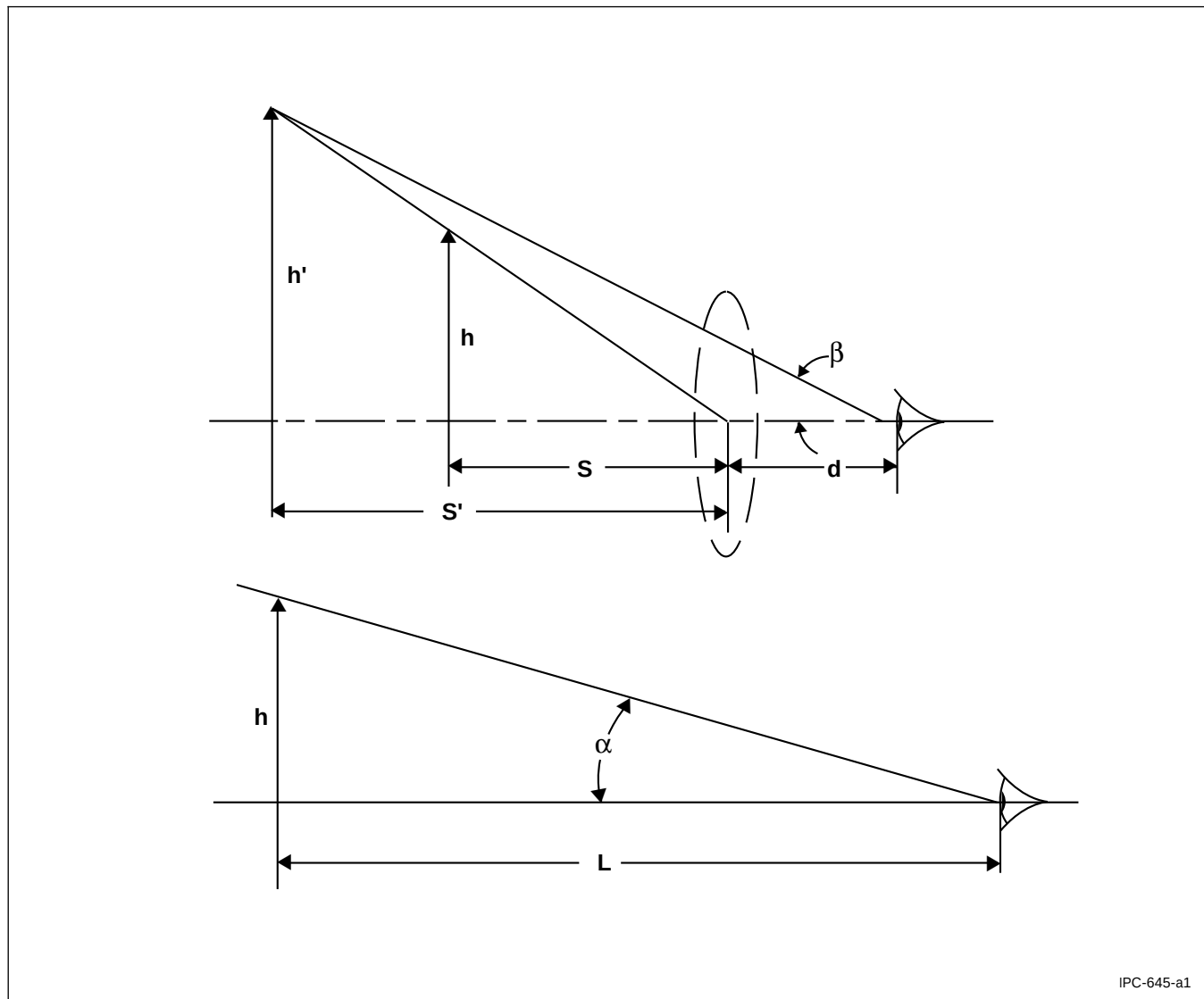
Equation 5

$$\text{Magnification} = (254 \text{ mm}-d/f) + 1$$

when the magnifier is focused to produce an image located 254 mm [10 in] in front of the eye. Note that in this case it is the distance, $d - s'$, that equals 254 mm, and that the image is less than 254 mm from the magnifier. Practically speaking, this equation indicates that it is almost never possible to add a full 1x to the inherent magnifying power of a magnifier by focusing it at the near eye point. For example, a typical 4x eye loupe has a focal length of 63.5 mm [2.5 in] and is designed so that the true eye relief is never less than 31.75 mm [1.25 in]. At the near focus condition equation 5 yields a magnification of 4.5x rather than the value of 5.0x which would be obtained from improperly using equation 4. For shorter focal length, larger magnifying power devices, focusing the device at the near eye point may actually reduce rather than increase the magnification. This is addressed later in this paper.

Upon examination of equations 1 or 5 something else becomes apparent. When the eye is located at the front focal point of the magnifier (i.e., $d = f$) equations 1 and 5 reduce to equation 3 independent of object or image distance. Magnification is a constant and equal to 254 mm/ f regardless of the object or image location.

One can show that when the eye relief distance is greater than zero but less than f that the minimum magnification is obtained when the object is located at the back focal point of the magnifier and is given by equation 3. The maximum magnification occurs when the image is located 254 mm [10 in] ($d - s' = 254 \text{ mm}$) in front of the eye and is given by equation 5. Note that if the eye



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Figure A-1 Magnifying power of a simple device, such as an eye loupe

closer than 254 mm that higher values of magnification are possible. However for this paper we take the position that anything closer than 254 mm will produce an unacceptable amount of eye strain. Therefore, the discussion is limited to image distances greater than or equal to 254 mm (i.e., $d - s'$ lies between $-\infty$ and 254 mm). However, when the eye is located farther away from the magnifier than its front focal distance ($d > f$) the situation is reversed. The magnification is a maximum equal to 254 mm/ f when the object is located at the back focal point and a minimum given by equation 5 when the image is located 254 mm ($d - s' = -254$ mm) from the eye.

Obviously, these same relationships hold with respect to the angular subtense of the image as well since equation 2 is of the same form as equation 1. Indeed, similar expressions can be derived for $\tan(\beta)$ for the same conditions which have been described above.

The dependence of magnification and angular image size on eye relief and image distance can be easily demonstrated with a magnifier with a focal length of between 127 mm [5 in] and 254 mm [10 in] (1x to 2x magnification). With the eye crowding the magnifier so that $d < f$ condition and only the $d \geq f$ effects may be seen. Low magnification devices are usually used with long eye relief for user comfort so the near focus effects are significantly reduced in accordance the equation 5. The image does indeed increase as the object is moved from the back focal point toward the magnifier. Similarly, an eye location can be found where the angular size of the image (and hence the magnification) does not seem to be affected. And, when the user backs off such that the eye relief is clearly greater than the focal length of the magnifier, it will be observed that the angular image size decreases as the object is moved from the back focal point toward the magnifier. Generally



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for short focal length (high magnification) devices one cannot get close enough to the device to observe the $d < f$ condition and only the $d \geq f$ effects may be seen. Low magnification devices are usually used with long eye relief for user comfort so the near focus effects are significantly reduced in accordance the equation 5.

An additional comment is in order. When the eye relief exceeds 254 mm [10 in], equation 5 breaks down. This is because we have assumed that the image is never located closer to the eye than 254 mm. Under such conditions, if the eye relief exceeded 254 mm then the image would have to located on the same side of the magnifier as the eye. This is clearly not the manner in which such a magnifier is intended to be used. The more general equation 1 must be used when eye to image distances other than -254 mm or -INF are used as would be the case when the eye relief is >254 mm.

In conclusion: it has been demonstrated that the magnification obtained from a magnifier depends upon the manner in which it is used. However, under the most common operating conditions and with most magnifiers it is quite unusual to be able to take advantage of the near focus eye effects to add appreciably to the magnification the user sees. The eye will almost always be used in the far focus condition or with sufficient eye relief as to reduce the near focus effects to a very small level. Additionally, for specifications and for calibration purposes magnification should be independent of the observer. For this reason, when a specific magnification is required for an inspection task it should always be understood as referring to the magnification obtained when the magnifying aid is focused for an infinite image. That is to say, the object viewed is located at the back focal point of the magnifier and equation 3 applies. Similarly, calibration of all magnifiers should be performed under these same operating conditions so as to remove the user from the magnifying system. These are the reasons behind the definition of magnifying power provided in paragraph 3.1.10 of this document.

Appendix B

Visual Resolving Power

Optical resolution or resolving power is a measure of the ability of an optical system or component to image closely spaced objects such that they are recognizable as separate objects. Resolution may be defined for optical systems used visually, photographically, or for those using electronic detectors. Resolution is also frequently defined for various imaging detectors such as photographic film or photoelectronic imaging tubes. Depending upon the application, resolution may be specified in terms of line pairs/millimeter, lines/millimeter, cycles/millimeter, TV lines, or in terms of the smallest detectable linear or angular separation. It is important to realize that the resolving power of an optical device is not necessarily related to its magnifying power. This point needs to be addressed when issues of visual inspection are discussed.

The goal of visual inspection is to assure the delivery of quality parts by identifying those parts on the production line which have defect levels exceeding acceptance requirements so those parts can be removed and the cause of the defect corrected. The engineer is responsible for establishing just what constitutes a quality part and what is an unacceptable defect. The magnifying device should then be chosen such that those defects which are to be recognized in the production line are rendered clearly visible to the inspector. It is here that the difference between magnification and resolution becomes important. The magnification of a device relates only to the size of the image produced without saying anything about the sharpness or clarity of that image. Resolution relates to the clarity of the image produced. Image size depends primarily upon effective focal length, object and image position, and the eye position of the user, whereas resolution depends upon a completely different set of factors. These include:

- 1) The wavelength of light used to create the image.
- 2) The "F number," numerical aperture, or convergence angle of the imaging light.
- 3) The number of optical elements, specific curvatures, thicknesses, and glass types used in the magnification aid.
- 4) The degree of accuracy to which the manufacturer was able to make the magnifier to the specific requirements of the magnifier designer.

It may be said that magnification and focal length are physical properties of an optical system while resolution is a performance characteristic. It is quite possible to have high magnification without high resolution and vice versa. However, one cannot make defects visible to an inspector

without adequate resolution. A minimum magnification may be required to increase an objects' apparent size above the limiting resolution of the detector (the inspector's eye, video camera, film, etc.), but the image itself also must be of sufficient quality to allow the detector to discriminate the desired level of detail. The system resolution is the key characteristic that must be specified for adequate visual inspection. Specifying magnification does not guarantee that any defects can be observed, whereas specifying system resolution insures that the required detail is visible and allows the inspector to use any magnification that yields the desired resolution.

Twelve grades of magnifying devices have been defined in this Standard based upon minimum magnifying power and resolution. The resolution for each grade is specifically related to the commonly quoted value of 1 arc minute for the visual acuity of an average person's eye. The physical width of a bar or space on a resolution target that subtends an angle of 1 arc minute at the near focus point of 254 mm [10 in] is 0.0737 mm [0.0029 in]. This equates to a resolution limit of 6.8 line pairs/millimeter (lp/mm). The smallest target on the widely used USAF 1951 resolution test pattern that the average person can be expected to see under these conditions is group 2, element 5, which corresponds to 6.35 lp/mm. If the magnifying device does not limit the resolution of the users' eye one could expect to see a resolution limit of M times 6.35 lp/mm where M is the magnification of the device (i.e., a 4x magnifier should enable an average person to see 25.4 lp/mm, 10x should yield 64 lp/mm, etc). This is indeed the case for good magnifying devices with magnifying powers less than about 10x and thus device grades I through VI reflect this reasoning. Most bench magnifiers and hand held devices fall within these grades of instrumentation. At magnifications higher than 10x, stereo microscopes are increasingly subject to limitations caused by fundamental principals of optics and hence, resolving power does not increase linearly with magnification. Monocular microscopes, by virtue of their greater numerical aperture (smaller working F#), will usually out resolve stereo microscopes of similar quality. Measurements of resolution performed on medium to high quality stereo microscopes reveal that resolving power increases slower than magnification. Grades VII through XII reflect actual measurements of commercially available stereo microscopes.

To summarize, magnification and resolution are not the same thing, and it is possible to have either one without the other. However, in order to be effective, visual inspection

methods require the observer to be able to recognize specific defects. Therefore the purpose of any magnifying aid used in visual inspection is to make details easier to see. Image size and magnification are important only to the extent that they enable the inspector to observe the required amount of detail. For this reason grades of magnifying devices have been proposed which are based upon increasing levels of resolution. Magnification is included as a rough guide in selecting a device which has the appropriate resolution.

