Evaluation MTF for Output Signal from Fractal Optical Modulator made of BaF_2 Material

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Abstract:

In this papers have designed the fractal optical modulator of circular aperture with various radius R and thickness 5mm and with consists of eighteen sectors, has been designed using visual basic language. As well as, nine opaque sectors and other nine transparent of light sectors in other regions of electro-magnetic wave spectrum.

The modulation transfer function is important key to know the optical system efficiency depend on the testing and evaluating of the image efficiency of point object in image plane at different wavelength.

The results revealed that at transmittance equal to 87%, the Barium Fluoride (BaF2) material optical modulator has highest modulate and the maximum value of modulation transfer function was 0.87 at wavelength λ=220 nm. While the lowest modulation was at transmittance equal to 64%. The minimum value modulation transfer function was 0.64 at wavelength λ=140 nm. In addition the modulation transfer function of the proposed optical modulator decreasing with increasing of radius.

Key words: Modulator, Fractal, MTF, Barium Fluoride

حساب دالة الانتقال المعدلة للاشارة الخارجة من قرص تضمين بصري كسوري مصنوع من مادة فلوريد الباريوم

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الخلاصة

تم تصميم قرص تضمين بصري باستخدام الهندسة الكسورية من مادة ثنائي فلوريد الباريوم وله سمك ثابت مقداره 5mm. النموذج يتألف من قرص دائري يحتوي على ثمانية عشر مقطعا مستخدما لغة البرمجة (الفيجول بيسك) في بناء النموذج المرغوب في دراسته, وأُفترض بأن للقرص تسع مقاطع معتمة والتسع الأخرى منفذه للضوء عند أطوال موجية معينه تسمح المادة المصنوع منها القرص بمرور هذه الأطوال من خلالها وذلك حسب نوع المادة المستخدمة.

إن أهمية دالة الانتقال المعدلة MTF تكمن في اختبار وحساب كفاءة الأنظمة البصرية, لتُظهر مدى ملائمة النظام البصري من خلال كفاءة الصورة المتكونة لجسم نقطي في مستوى الصورة عند قيم مختلفة من النفاذية والفتحة المُستخدمة لهذا النظام هي فتحة دائرية .

تم حساب الدالة للقرص الكسوري مصنوع من مادة فلوريد الباريوم عند قيم مختلفة من الاطوال الموجية و النفاذية. وتم ايجاد افضل حالة تضمين لقرص ثنائي فلوريد الباريوم عند الطول الموجي 220 nm و النفاذية T = 87%, و وُجد أقل حالة للتضمين عند الطول الموجي 140 nm والنفاذية T=64%. كذلك تم حساب قيم مختلفة مع انصاف الاقطار ووجد بأنها تتناسب عكسيا مع دالة الانتقال المعدلة.

1. Introduction

The production of the optical system has passed through several stages, the optical design is the first one, after this stage is completed, the optical components manufacturing will be the next stage and then, the evaluation and the testing of these components will be the last stage before the lens is being used. The optical design includes specification of the radii of the surfaces curvature, the thickness, the air spaces, the diameters of the various components, the type of glass to be used and the position of the stop. These parameters are known as "degrees of freedom" since the designer can change them to maintain the desired system. The image that is formed by these optical systems will be approximately corrected against the aberrations. But there isn't ideal image which corresponds to the object dimensions because of the wave nature of light, which is mostly affected by several factors like the type of illumination that is used (incoherent, coherent and partially coherent), the object shape (Point, Line or Edge) and the aperture shape. Gerbig & Lohman(1989).
There are several factors that affect the evaluation of the image quality which is formed by the optical system. Of these important factors that have effect on evaluation of the image quality is measured spread function (Point, Line and Edge), Gerbig & Lohman(1989) Kingslake (1965), Kapany & Burket (1962),which describes the intensity distribution in image plane for an object (Point, Line and Edge). The spread function depends on diffraction that is produced by the lens aperture and the amount of the aberration and its type in lens or in the optical system. The point spread function is an important parameter that is used for identification of the efficiency of the optical system, where several of the other functions are derived from the point spread function or in differential relation or integral relation with it.AL-LAMY(2008), AL-BEDARY(2007), Abdula(2008).

2. Lens Testing

2.1. The goals testing

There are generally three basic reasons for carrying out series of tests on lenses:
2.1.1.The lens is suitable for a given purpose.
2.1.2.The lens constructed lens is fulfills the design characteristics.
2.1.3.The limitation on accuracy of optical imagery and the relation among various methods of assessing image quality. AL-Hamdani(1997).
2.2 Testing Method
There are two ways to test lenses and optical systems.

2.2.1 Qualitative Test

By the qualitative test we have the ability to know the type of aberrations in the tested lens, without measuring it.

2.2.2 Quantitative Test

The quantitative test is divided into two types:

2.2.2.1.Visible Test

Visible test contains all the required measurements which designed on the basic principle of interference between the wavefronts coming from the lens through using ideal wave of monowavelength from point source (the ideal wave is considered as a reference to the wave coming from the testing lens). AL-LAMY(2008).

2.2.2.2. The Photometer Test

This way of examination includes the measurement of special function that explains the lens efficiency, ideality, and the amount of aberrations. Some of these functions e.g. point spread functions (PSF), line spread function(LSF), disk spread function(DSF)and other spread functions give good description of the intensity distribution in the image plane of an object by the optical system to be examined. The spread function depends on the lens aperture diffraction and the aberrations type and the amount of aberrations in the lens or in the optical components. There is another important function which is used to examine the optical system like the optical transfer function (OTF). OTF as the ability of the optical system to transfer the different frequencies from the object plane to the image plane, as shown in fig.(1). AL-LAMY(2008),AL-BEDARY (2007), Abdula(2008).

3.Theoretical background

3.1.Optical Transfer Function & Modulation Transfer Function

Another method to specify the resolving power of an optical imaging system is by means of the optical transfer function (OTF). This function is defined as the contrast in the image of a sinusoidal grating with a given spatial frequency,

$$\omega = 2\pi / L \qquad 1.$$

Let us assume that we form the image of an object containing a wide spectrum of spatial frequencies then analyze the frequency content in the image of this object. Then, the OTF is the ratio of the amplitude of a given spatial frequency in the image to the amplitude of the component with the same spatial frequency in the object. If the object contains all spatial frequencies with a constant amplitude, the OTF becomes the Fourier transform of the image. Such an object is a point object and its image is point spread function (PSF). Hence, the OTF is simply the Fourier transform of the point spread function.

The optical transfer function $F(\omega_x, \omega_y)$ may be obtained from the Fourier transform of the point spread function S(x,y) as follows:

$$F(\omega_x, \omega_y)=\iint S(X_F,Y_F)e^{\,i(wx\,XF,\;wy\,YF)}dx_F dy_F \qquad 2.$$

We see that in general this OTF is complex and, thus it has a real and an imaginary term. The modulus of the OTF is called the modulation transfer function (MTF) and represents the contrast in the image of a sinusoidal periodic structure. The imaginary term receives the name of phase transfer function (PTF) and gives information about the spatial phase shifting or any contrast reversal (when the phase shift is 180^{o}) in the image. Malacara (2004).

The MTF is then the magnitude response of the imaging system to sinusoids of different spatial frequencies. This response can also be defined as the attenuation factor in modulation depth:

$$M = \frac{Amax - Amin}{Amax + Amin} \qquad 3$$

where Amax and Amin refer to the maximum and minimum values of the waveform that describe the object or image in W/cm^2 versus position. The modulation depth is actually a measure of visibility or contrast. The effect of the finite-size impulse response (i.e., not a delta function) of the optical system is to decrease the modulation depth of the image relative to that in the object distribution. This attenuation in modulation depth is a function of position in the image plane. The MTF is the ratio of image-to-object modulation depth as a function of spatial frequency: Daniels(2014).

$$\text{MTF} = \frac{\text{Mimg}}{\text{Mobj}} \qquad 4$$

or

$$\text{MTF} = \frac{\text{Imax} - \text{Imin}}{\text{Imax} + \text{Imin}} \qquad 5$$

In summary, the MTF is a powerful tool used to characterize imaging system's ability to reproduce signals as a function of spatial frequency. It is a fundamental parameter that determines where the limitations of performance in optical and electro-optical systems occur, and which crucial components must be enhanced to yield a better overall image quality . It guides system design, and predicts system Performance. Daniels(2014).

3.2.Amplitude and Frequency Modulation

One of the optical modulator shapes is the Fan Shape, and sometimes called Wagon Wheel, which is shown in Fig.2 and it is used in many optical applications, In radiation measurement system, as optical chopper. In most Tracking and Guidance systems. This type of optical modulator works in two modes: First , when the optical modulator is rotated around its axis, the incident radiation will be modulated in amplitude modulation (AM) . Second, when the optical modulator is stationary, the object scene rotates about the disk axis by nutating movement. Or the optical modulator center will be rotated about the optical axis of the tracking system. then the incident radiation will be modulated in frequency modulation (FM). AL-Hamdani (1997), Wolfe & Zissis(1978).

4. Optical Modulator Construction

Optical modulator is a device ,which changes the angle between the vision line to the target and coordinate to electrical signal. AL-ERYANI (2004). An optical modulator is used to provide directional information for target , and to suppress unwanted signal from background Abdula(2008). It is used for chopping the emitted light from the source. And this will be done by choosing the best shape and size . The optical modulator takes many various circular shapes due to its need. Abdula(2008). Fig. (3) shows Position of the modulator in the optical system. The optical modulator is called in many different names: Optical modulator, Chopper, Raster, Reticle, and in case special is crosshair.

It is sometimes called chopper. i.e. the optical modulator is a device used for chopping the light beam and the output signal has frequency showed in fig. (4) and given by relation:

$$F = n\omega \qquad 6$$

Where n is the number of sector, ω is the angular velocity (rotation speed). and F is the spatial frequency.

The modulation operation in optical modulator depends on the movement between image object and optical modulator . In this concept the optical modulator can be classified in two types :-

1-Rotating Reticle Disk :- In this type the disk rotates about its axis ,while the object image rotates within the disk area. Sometimes the disk axis has been rotated about the optical axis of the Electro-Optical-System, in circular path. This type of disk is called (Nutating Reticle).

2-Stationary Reticle Disk :- In this type the disk is stationary, while the image object has been rotated on the disk surface by using rotational optical system.

The optical modulator has two important operations in detection, tracking and guidance system ,and this operations is to:-

1-Provide directional information about tracking and to suppress unwanted signal from background .This operation is called (Spatial-Filtering).

2-Change the optical signals parameter ,which is produced from the object, by designing suitable disk pattern.

The modulation can be done by using two types of mode Active and Passive modes . The two operations can be applied in the active mode in the same time, while just the second operation can be applied in the passive mode.

The better efficiency of the optical modulator can be produced when the spot size is not larger than three times the object image size. The real efficiency is produced when the spot size is equal to the object image. When the object image approaches the optical system, its size will be increased. Abdula(2008), Al-Hamdani(1997).

5.Fractal Function & Geometry

Euclidean geometry provides a first approximation to the structure of physical object. It describes objects of simple shapes, point, line segment, ellipses, circles, boxes, and cubes that have a few characteristic sizes, with dimensions one, two, and three. This geometry is mainly oriented around linear, integral system. Kadhim & Patel (1978).

Nonlinear shapes and nonintegral systems are not easily described by traditional Euclidean geometry. These shapes and systems need another geometry that is quite different from Euclidean geometry to describe and study these cases. Benoit Mandebort, Kazmerski(1980) suggested the existence of geometries near to the geometry of nature, known as fractal geometry.

Mandelbort, coined the term "Fractal" to describe object that are very "fractured" as a clouds, mountains, coastlines, leaves, sun....etc. Mandelbrot's famous and pioneering work with fractal geometry and his introduction of two new basic concepts including ; first, self-similarity, which is to say that the fractal shapes are to be self-similar and independent of scale or scaling. The general nature of the fractal irregular bumpy structure remains constant through successive magnifications such as is the case for coastlines and mountains. Each small portion when magnified can reproduce exactly a large portion. Fractal images exists as the limit of both random and deterministic processes based upon the representation called Iterated Function System (IFS).Second, a fractal has non-integer dimension known as the fractal dimension, which allows scale independent measurement of such objects, and gives a numerical measure of the degree of boundary irregularity or surface roughness. The fractal dimensions one of the most important concepts in the study distribution. It is analogous to the concepts of length, area and volume in Euclidean Geometry. Frame & et.al. (2006). And from examples on nonlinear fractals: Mandelbrot set, and Julia set which they shown in Fig.5.

Now it is seen an alternative way to specify the dimension of a self-similar object. The dimension is simply the exponent of the number of self-similar pieces with magnification factor N into which the figure may be broken.

$$N = \left(\frac{L}{K}\right)^{D'} \qquad 7$$

$$D' = \frac{LogN}{Log\left(\frac{L}{K}\right)} \qquad 8$$

Where $D^{\backslash}$ is fractal dimension, N is number segment, L is length and K is length each piece.

5.1.Iterated function system (IFS)

Fractals can be any number of dimensions, but are commonly computed and drawn in 2D.The fractal is made up of the union of several copies of itself, each copy being transformed by a function. This is the source of its self-similar fractal nature. Frame & et.al. (2006). Formally,

$$s = \bigcup_i f_{i(s)} \quad \text{Where } s \subset R^2 \text{ and } f_i : R^2 \rightarrow R^2 \qquad 9$$

(i=1, 2, 3, 4……..m).

Sometimes each function f_i is required to be linear, or more accurately an affine transformation and hence can be represented by a matrix.

$$w\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix} = \begin{bmatrix} ax+by+e \\ cx+dy+f \end{bmatrix} \qquad 10$$

Where (x, y): a metric space, (e, f): transformation parameters, (a, b, c, d) are real numbers (in two-dimensional).

However, IFSs may also be built from non-line a function, including projective transformations.

One can describe a general construction for fractal that occurs in classical number theory, of which sierpinski triangle, von koch curve, and cantor set are examples.

5.2.Cantor Set

In order to understand the cantor set, the construction becomes with a line segment of length (1) which is subdivided into three sections, removing the middle third; then removing the middle third of the remaining segment and so on. So, the number of segment is increased to two and length is reduced to (2/3). The cantor set is simply the dust of point they remain. The number of these points is infinite, but their total length is zero. As shown in Fig. 6. Frame & et.al. (2006).

6.Results and discussions

The optical modulator is a disc constructed from Barium Fluoride BaF_2 which has a radius R, thickness 5mm, and assumes the number of sectors are (eighteen sector), The computer program was written by using visual basic language. In the present study assume that nine sectors opaque and nine sectors are transparent alternating to the light as shown in Fig. 7. The transmitting sectors might be consider as opaque to the other wavelength. Fractal function was used to divide optical modulator into very small segment of line, it's simply the dust of point as shown in Fig. 8 . The circular aperture was a clear transparence aperture (100%).

Assuming that the incident light is a perpendicular to the chopper. The chopper is moveable in a circular form. Hence the light beam will make discrete circles according to the number of sectors. The distance of the light movement on all sectors of it part is an arc from a circumference of the total circle. Thus, the light form will through one revolution of the radius (the point of beam incidence of light on the sector). It is considered that arc of sector which moves on the transparent sector is the required distance only. The resultant circumference of the circle was divided on the total number of sector.

The Modulation Transfer Function (MTF) is evaluated using the relation(5). Also the unit of spatial frequency will be in (Rev/s) which depends on the velocity, and the number of sectors. The relation of frequency is shown in equation (6). The table (1) shows the increase in spatial frequency by decreasing the MTF. Also the MTF of the supposed fractal optical modulator will be decreasing with increasing the radius.

In general, the range of transmittance for Barium Fluoride BaF_2 was found between (64% to 87%) was related to the wavelength between (140 to 220)nm. The MTF has a maximum value when the transmittance at maximum value.

The first inflection point always gets at the spatial frequency value equal=2(Rev/s) which is compatible to the MTF value for theoretical real optical system theoretically, Dewolf.& et.al. From Fig. (9), has been noticed the change in spatial frequency with difference in the modulation transfer function, while the high inflection point for MTF changes with transmittance changes. The curves have a similar behavior to its shape, but is varied according to the position inflection point for MTF. It has been noted that the value of MTF for Barium Fluoride has two inflection points at the spatial frequency =2 and 4 (Rev/s). The curves showed, the spatial frequency changes between 1 to 2 (Rev/s) the value MTF is quickly gradient. When the spatial frequency changes from 2 to 4 (Rev/s) the gradient in value MTF becomes less than the first case. Then, the gradient in the values MTF becomes approximately stationary. This gradient in the values MTF makes the spatial frequency changes. The spatial frequency is very small at the maximum value of MTF. Also From Table (1) and fig. (10), it is noticed that the modulation transfer function decreases with increasing the circle radius (R), because at R equal to (1.25) mm, the MTF is (0.64), but when the radius R equal to 12.50 mm the MTF is 0.064, and same case in other the values of MTF.

7.conclusion

The comparison among the values for MTF at different values for transmittances, showed that at values large for transmittance the value of MTF become large (at increasing the transmittance will be increasing the MTF). The MTF of the supposed optical modulator will be decreasing with increasing Radius. The best modulation of Barium Fluoride (BaF_2) material optical modulator was when transmittance T = 87%. Where the value of Modulation Transfer Function (MTF) is maximum at wave length (BaF_2)= 220nm. The worst case of modulation was at transmittance T = 64%. Where the value MTF is minimum at wavelength(BaF_2)= 140nm.There is a considerable increase in Modulation Transfer Function (MTF) by decreasing the spatial frequency for all materials. The fractal modulator can be used in optical systems, such as fiber optics, filter , tracking and guidance system. The fractal function can be used to design the optical modulator, especially for fine optical measurement

Reference

1- Abdula A.S. "Calculation of MTF for Optical Disk Modulator by Using Fractal Function" University of Technology Baghdad ,April 2008A.D.

2- AL-ERYANI W.F.A., " Design optical Modulator By Using Fractal function Geometry" AL-Mustansiryah University. Jul. 2004A.D.

3- AL-Hamdani. A. H., "Numerical Evaluation of lenses Quality Using Computer Software", Ph.D.Thesis Al-Mustansiriyah University", (1997).

4- AL-LAMY K.H. Kazem "Design Study of Various Synthetic Aperture Configuration" University of Technology, 2008 A.D.

5- AL-BEDARY TH. H. Abed " Energy Distribution of Apodized Laser Beam in Annular System" University of Technology, October 2007 A.D

6- Daniels A., " Field Guide to Infrared Systems" Bellingham,Washington USA, 2014

7- Dewolf, D. A. Distasio A. J., Faulkner R. D., Fitts R.W., Huston P.D., Lewis T.T., Kissinger G.D., Lindley W.D., Meyer C.A., Nekut A.G. "Electro-Optics Handbook".

8- Frame M., Mandelbort B. and Neger N., "Fractal Geometry", Yale University, 28 April 2006.

9- V. Gerbig , A. W. Lohman . Applied Optics , Vol.28, No. 24, P. 5198 , (1989).

10- K. S. Kapany, J. J. Burket. Optics Soc. Am. ,Vol. 52,No.12,P. 1351,(1962).

11- Kadhim M.A.H., and Patel K.," Engineering Material", University of Technology Baghdad, part 1, 1978.

12- Kazmerski L. L., "Polycrystalline and Amorphous Thin-Film and Devices" Academic press, New York, 1980.

13- Kingslake. R Applied Optics and Optical Engineering , V. III , P. 183, (1965) .

14- Malacara D. ,Malacara Z. ,"Handbook of Optical Design" Second Edition, Centrode Investigaciones enOprica, A.C. Ledn, Mexico, 2004

15- Wolfe W.L.&.Zissis G.J "The Infrared Handbook" (IRIA center), Environmental Research Institute of Michigan, 1978.

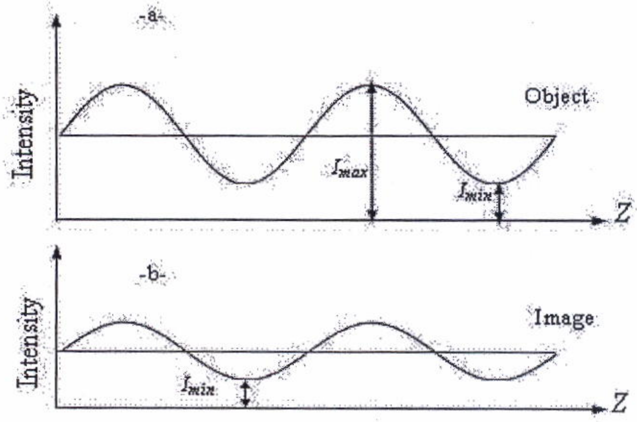

Fig. (1): The optical transfer function [5]

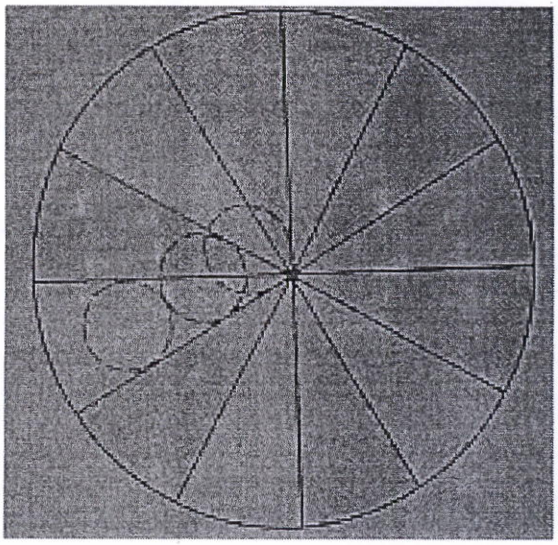

Fig. (2): Wagon wheel pattern [15]

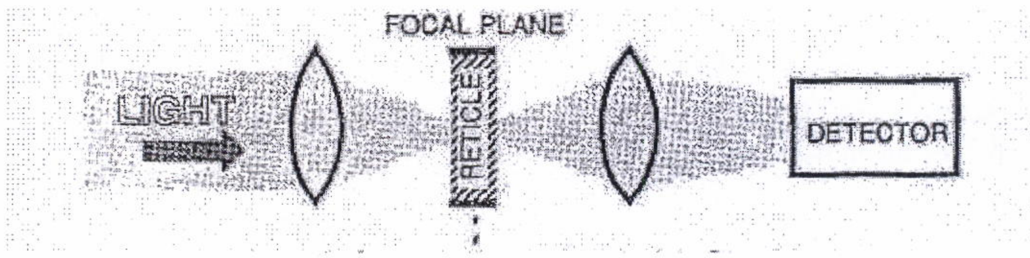

Fig. (3) The Position of the modulator in the optical system [2]