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Study of Efficiency Fractal Optical Modulator for insulator material by testing modulation transfer function

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Abstract:

Chopper is an important component in optical system. It represents a device, which changes the angle between the coordinate and vision lines of the target for the electrical signal. The chopper modulates the optical signal by a frequency dependent on the number and sectors shapes. The optical modulator takes shapes of various circular due to the need for it. Through this study we have designed the fractal optical modulator its two circles inner and outer, each circle involving in eighteen sectors, by building a computer program using visual basic language. In this paper, we assume that nine sectors one opaque and the other nine sectors are transmitted for the light. Even though the importance of the modulation transfers function (MTF) in testing and evaluating optical systems, it becomes the dependent measurement to know efficiency of the optical systems. It has been studied for optical systems at circular apertures, where that function could evaluate the image efficiency for point object in image planes at different magnitude of a radius and time. The fractal reticle have been designed of insulator material by using the fractal function. Then , evaluating the values of MTF at different values of a radius and time. Also we studied relation between number of sections and spatial frequency.

Keywords: Optical modulator, chopper, MTF, fractal reticle, spatial frequency.

دراسة كفاءة قرص تضمين بصري مصنوع من مادة عازلة و اختباره بواسطة دالة الانتقال المعدلة

عباس شويع علوان محمد لطيف جبار

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الخلاصة:

قرص التضمين البصري مركبة مهمة في الانظمة البصرية، فهو عبارة عن جهاز يقوم بتغيير الزاوية بين خط النظر الى الهدف و المحور البصري الى اشارة كهربائية. كما يقوم بتوليد إشارة ضوئية ذات تردد معين) من خلال تقطيع الحزمة الضوئية (اي حسب تصميم شكل القرص و كذلك حسب سرعة دوران القرص و بنفس الوقت يمكن أن يعمل عمل المرشحات الضوئية لأطوال موجية معينة حسب نوع المادة المصنوع منها قرص.التضمين البصري).
تم تصميم قرص تضمين بصري يتكون من دائرة داخلية و دائرة خارجية وكل من الدائرتين تتالف من ثمان عشر مقطعا, و ذلك بواسطة استخدام البرنامج بلغة الفجول بيسك الاصدار 6.0. ولكل دائرة تم افتراض تسع مقاطع منفذة للضوء والتسع الاخرى معتمة بالنسبة للضوء الساقط على القرص البصري. وفي نفس الوقت فان التسع المنفذة تعتبر معتمة للأطوال الموجية غير المرغوب فيها من الطيف الكيرومغناطيسي وذلك بالاعتماد على معامل انكسار المادة المصنوع منها القرص. ان دالة الانتقال المعدلة MTF هي احدى الدوال المستخدمة في فحص مدى كفاءة الانظمة البصرية. حيث بواسطة الدالة يمكن ان

نحسب كفاءة الصورة لجسم نقطي وكذلكُ ستخدمت دالة الكسوريات في تصميم قرص من مادة عازلة. ثم تم حساب قيم دالة الانتقال المعدلة(MTF) باخذ مستوى الصورة بالنسبة للجسم عند تغير نصف القطر و ثبات الزمن و بالعكس اي تغير الزمن و ثبات نصف القطر.

1. Introduction:

The production for the optical system has passed through some stages, the optical design is the first one, after first stage is completed, the optical components manufacturing will be the next stage and then, the testing and the calculation of these components will be the last stage before the lens is being used. The optical design includes specification for the radii of the surfaces curvature, the thickness, and the air spaces, the diameters of the various components, the glass type to be used and the position of the stop. These factors are well-known as "degrees of freedom" since designer can change them to maintain the desired system. The image that is formed by these optical systems will be approximately corrected from aberrations. But there isn't ideal image which corresponds to dimensions of the object because of the wave nature for the light, which is mostly affected by several parameters like the type of illumination that is used (incoherent, coherent, and partially coherent), the object shape (Edge, Point, or Line) and also the shape of aperture [A.S.Abdula]. Chopper any device used to modify any characteristic of an optical signal (light wave) for the purpose of conveying information [B. Gholamzadeh, and H. Nabovati]. Optical choppers are mechanical devices that physically block a light beam of some type. Rotating optical modulators (reticle) are perhaps the most common form and are they produced by SciTech Instrument Ltd. A metal disc with slots etched into it's mounted on a dc motor and rotated. Disc is placed in the light beam path which will then cause the beam to be periodically interrupted by the blocking part of the disc [R. Wolfson].

The term fractal was created in 1975 by Benoit Mandelbrot, from the Latin fractious, which means "broken" or "fractured" The word fractal has two related means. In colloquial usage, it denotes a shape that is self-similar or recursively constructed that is a shape that shows similar at all measures of magnification and is therefore often referred to as "infinitely complex".[W.F.Ali AL-ERYANI].

2. Optical Modulator:

Chopper is a device, which changes in angle between the vision line to the goal and coordinate to electrical signal [W.F.Ali AL-ERYANI]. Also optical modulator is used to provide directional information for target, and to suppress unwanted signal from background. This device can be used for chopping the emitted light from the source. This will be done by choosing the best size and shape. The optical modulator takes many several circular shapes due to its need [A.S.Abdula].

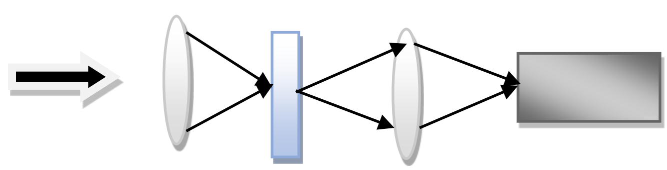


Fig. (1) The Position of the modulator in the optical system.

The optical modulator can be presented in different forms like: optical modulator, chopper, raster, reticle and crosshair (in special cases).

The word reticle has been defined as "a pattern located in the focal plane of an instrument to measure or locate a point in an image". Reticle has been used and is still used in a multitude of operations from commercial applications or surveying to military uses of boresighting surveillance and fire control systems. The general case that most people is familiar with is the simple sight on a rifle or gun. There are as many types of reticle as there are uses for them. However, one type of reticle, commonly referred to as a spinning frequency modulated (FM) reticle, can be used to provide range and bearing information [Ronald G.Driggers et.al].

The minimum reticle consist of simple "cross-hairs"[Abdulrazak A. S. Mohammed L], a crosshair is a shape superimposed on an image that is used for a device precise alignment. There are most commonly a "+" shape, though many variations exist, such as dots, spots, and circles. Even although commonly associated with telescope sights for aiming firearms, also crosshairs are common in optical devices used for surveying, astronomy and also popular in graphical user interfaces as a precision pointer. It is sometimes called chopper. This means optical modulator is instrument used for chopping the light beam and then the output signal has frequency which can be described by the relation [Abdulrazak A. S. Mohammed L].

$$F = v * n \qquad (1)$$

Where n:the sectors number, **v**: is the speed of rotation and F: is the spatial frequency.

The modulation can be done by using two types of mode passive and active modes. The two operations can be useful in the active mode at the same time, while just the other operation can be applied at 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. [A.S.Abdula, A. H.Al- Hamdani].

3. FM and AM Optical Modulator:

One of the optical modulator shapes is (Fan Shape), and sometimes called (Wagon Wheel), it is shown in Fig. (2) and it is used in many optical applications, in radiation measurement system, it is used as optical chopper. Therefore it is used in optical modulation in most tracking and guidance systems.

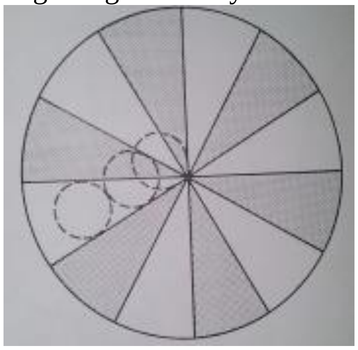


Fig. (2): wagonwheel pattern [W.L.Wolfe]

This type of reticle works in two modes:

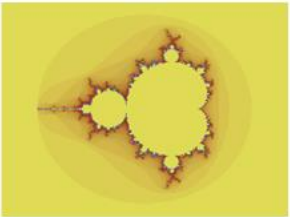
First, at the optical modulator is rotated around its axis, then the incident radiation will be modulated in amplitude modulation AM. Second, at the optical modulator is stationary, while the object scene rotates about the disk axis by nutating movement or the optical modulator center will be rotated about the optical axis of the tracking system. Then, the incident radiation will be modulated in frequency modulation FM. [A. H.Al-Hamdani ,W.L.Wolfe].

4. Fractal Function:

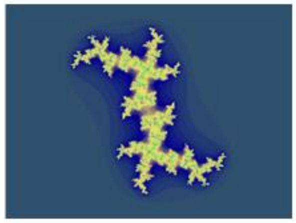
Euclidean geometry provides a first approximation to the structure of physical object. It describes objects of simple shapes, point, line segment, ellipses, circles, boxes, and cubes that have a few characteristic sizes, with dimensions one, two, and three. This geometry is mainly oriented a round linear, integral system. [M.A.H.Kadhim and K.Patel].

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 [L. L. Kazmerski] suggested the existence of geometries near to the geometry of nature, known as fractal geometry. Mandelbort, coined the term "Fractal". 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 scaling or scale.

The general nature of fractal irregular bumpy structure remains constant through successive magnifications such as 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 named 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 [M. Frame]. From examples on nonlinear fractals: Mandelbrot set, and Julia set which they shown in Fig. (3).



(a) set of Mandelbrot



(b) set of Julia

Fig. (3): sets of Mandelbort and Julia

Now it is seen an alternate method 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.

$$N = \left(\frac{L}{K}\right)^{D'} \qquad (2)$$

$$D' = \frac{LogN}{Log\left(\frac{L}{K}\right)} \qquad (3)$$

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

5. Iterated function system (IFS):

Fractals as they are normally termed can be any number of dimensions, but are commonly computed and drawn in tow dimensions.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.Formally, [Christopher Natoli].

$$s = \bigcup_i f_{i(s)} \quad Where\ s \subset R^2\ and\ f_i : R^2 \rightarrow R^2 \qquad (4)$$

and (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.

$$w\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix} \qquad (5)$$

Where w: the affine transformation. x, y: the metric space, (e, f): the transformation parameters. a, b, c, d: the 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.

6. 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 remain. The number of these points is infinite, but their total length is zero. As shown in fig(4) [Zhixing Guo].

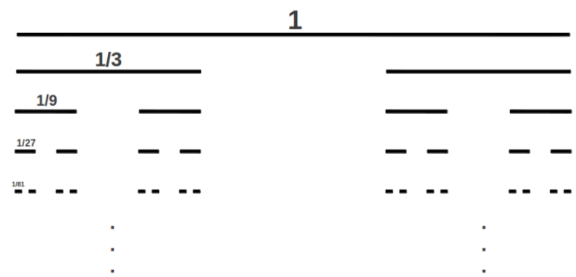


Fig.(4) Construction of the classical cantor set [Zhixing Guo].

7. The OTF & the MTF:

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.

$$\omega = 2\Pi / L \qquad (6)$$

Let us assume that we form the image of an object containing a wide spectrum of spatial frequencies and then analyze the frequency content in the image of this object. Then, 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: [D. Malacara Z. Malacara]

$$F(\omega_x, \omega_y) = \iint S(X_F, Y_F) e^{i(w_x X_F, w_y Y_F)} dx_F dy \qquad (7)$$

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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. [D. Malacara Z. Malacara]

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

$$M = \frac{Amax - Amin}{Amax + Amin} \quad (8)$$

where Amin and Amax refer to the minimum and maximum values of the waveform that describe the object or image in W/cm2 versus position. The modulation depth is actually a measure of visibility or contrast. Effect of the finite-size impulse response (this mean that 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 position function in the image plane. MTF is the ratio of image-to-object modulation depth as a function of spatial frequency:

$$MTF = \frac{Mimg}{Mobj} \quad (9)$$

Or

$$MTF = \frac{Imax - Imin}{Imax + Imin} \quad (10)$$

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 performance limitations 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. [A. Daniels].

8. Results and Discussion:

The reticle is an important component in optical system. The optical modulator is defined a disc from insulator material which has a radius R1and R2where R1 refer to radius of inner of circle and R2 indicate to outer radius of circle, and assumes the number of sector is eighteen sectors. The computer program was written by using visual basic language. In the present study assume that nine sectors opaque and nine sectors are transmitted alternating to the light as shown in figure (5). Fractal function was used to divide optical modulator into very small segment of line, it's simply the dust of point. 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 is part 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 opaque sector is the required distance only. The resultant circumference of the circle was divided on the total number of sector.

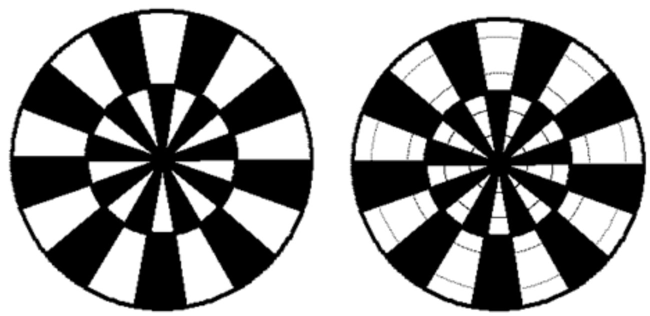

Fig.(5) optical modulator and fractal optical modulator (design by researcher)

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 (1). Also the MTF is evaluated using the relation(10). In general, the range of change in spatial frequency for optical modulator with number of sections at different times (0.05, and 0.5 sec). It has been changing can be shown in fig. (6), were found between (6280 to 0), and (628 to 0) Rev/sec.

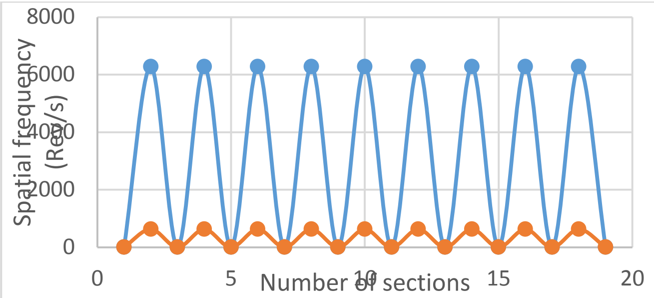

Fig. (6) Spatial Frequency and section Number at time (0.05, 0.5 sec)

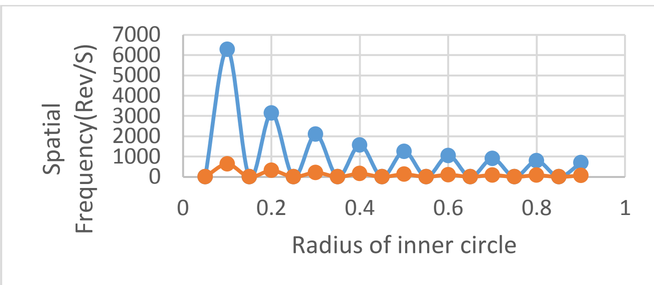

Fig. (7) Radius of inner circle versus Spatial Frequency at time (0.05, 0.5 sec)

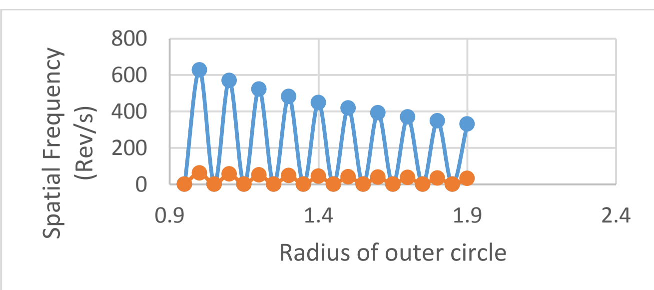

Fig. (8) Radius of outer circle versus Spatial Frequency at time (0.05, 0.5 sec)

Modulation transfer function evaluated at three values of radius (0.5,1,1.5)cm of fractal optical modulator and the range of time was between (0.01-0.09)sec and (0.1-0.9)sec. The high inflection point for MTF changes with time and radius of fractal optical modulator changes. The curves are similar behavior to its shape, but is varied according to the position inflection point for MTF. The curves showed, the spatial frequency also changes with time and radius change. The value MTF is quickly gradient. In figures (9,10) it have been noted that the spatial frequency changes from 2000 to 3000 (Rev/s) or from 200 to 300 (Rev/s) respectively, the gradient in value of MTF becomes less than the first case. Then, the gradient in the values of MTF becomes approximately stationary. This gradient in the values of MTF makes the spatial frequency changes. The first inflection point always gets at the spatial frequency value equal, 2 or 200 or 2000 (Rev/s) which is compatible to the MTF value for theoretical real optical system theoretically[D. A. Dewolf et.al]. The spatial frequency is very small at the maximum value of MTF, and the spatial frequency begins increase with decreasing of MTF values.

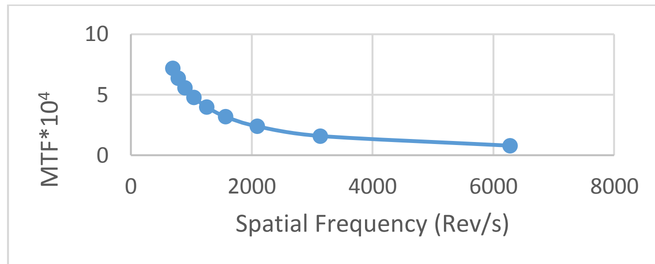

Fig.(9)Spatial frequency with MTF at different times and radius (0.5cm)

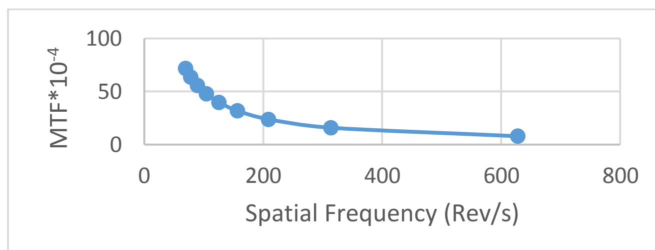

Fig.(10)Spatial frequency with MTF at different times and radius (0.5cm)

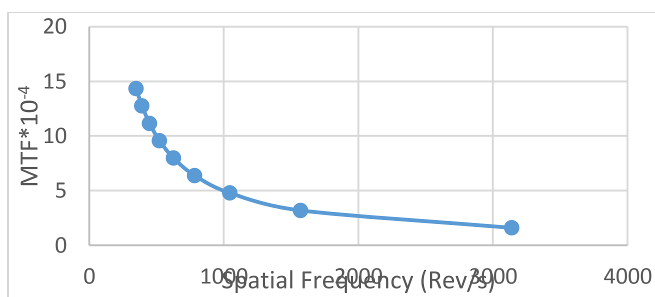

Fig.(11)spatial frequency with MTF at different times and radius (1cm)

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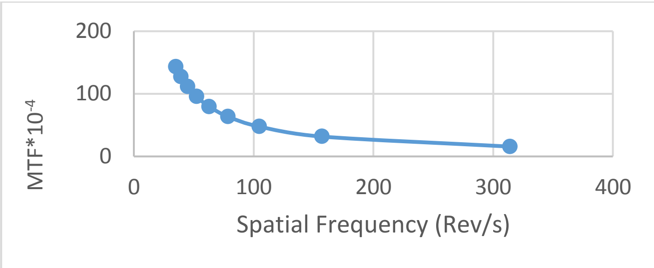

Fig.(12)spatial frequency with MTF at different times and radius (1cm)

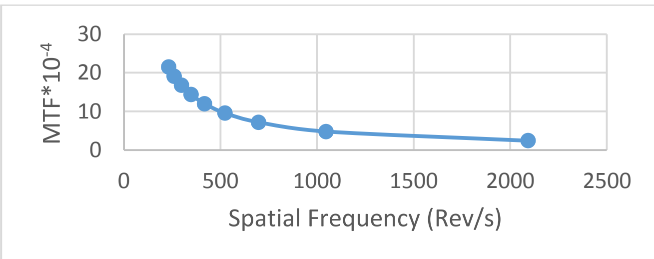

Fig.(13)spatial frequency with MTF at different times and radius (1.5cm)

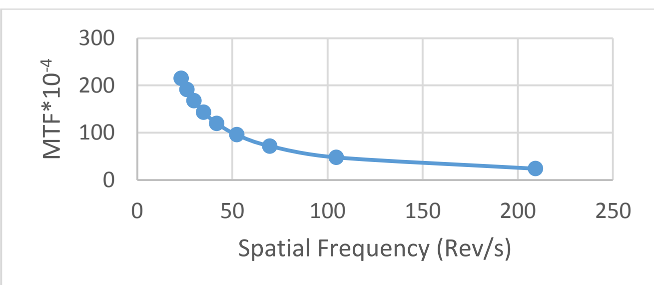

Fig.(14)spatial frequency with MTF at different times and radius (1.5cm)

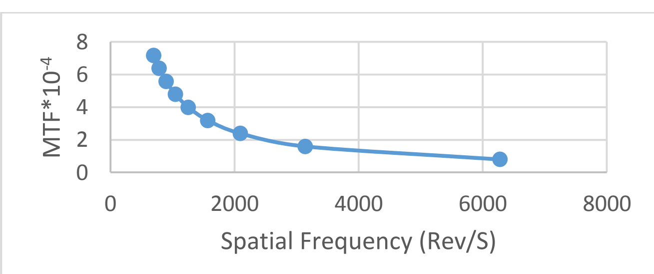

Fig.(15)spatial frequency versus MTF at different radius and time (0.05cm)

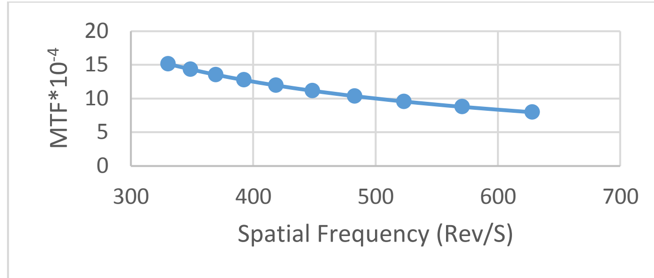

Fig.(16)spatial frequency versus MTF at different radius and time (0.05cm)

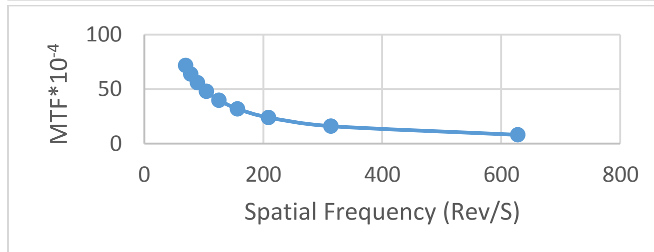

Fig.(17)spatial frequency versus MTF at different radius and time (0. 5cm)

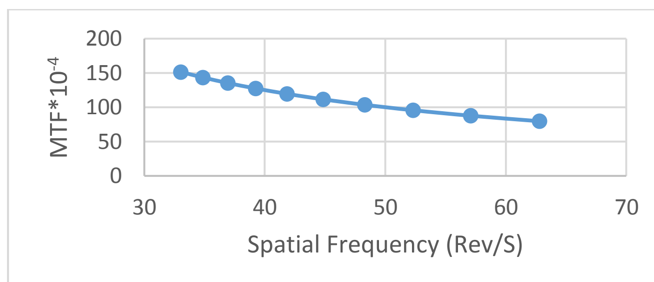

Fig.(18)spatial frequency versus MTF at different radius and time (0. 5cm)

9. Conclusion:

The comparison between the values for MTF at different values at different times, showed that at large values of time the value of MTF becomes large (with increasing the time, MTF will increase), and this means that detector has high efficiency. It has been visualized that the values of time increase versus the spatial frequency decrease, i.e. that fractal optical modulator work good. There is an inversely relation between the radius of fractal optical modulator and the spatial frequency in all cases. There is a considerable increase in MTF with decreasing of the spatial frequency. It is very important in the optical fractal modulator, when it is designed from a specific material such as insulator as special filter will generate frequency.

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