Evaluate the Effective of Modulation Function on Spot Size For Multifunction modulator

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Abstract

Optical modulator is an important component in optical systems. The present optical modulator has been designed consisting of three concentric circles (C_0, C_1, C_2). Each circle has different shape divided to transmittance and oblique sectors, the numbers of sectors chosen are equal to (20, 40, 60) respectively. The central circle was designed using fractal geometry with a modified program. The efficiency of this optical modulator disk was tested by applying the [MTF](It is a function that calculate the transferee function for any modulation , in other hand it is calculation of contrast degree of the an image for any object) , and the best modulation was at spot light size equal to (2 mm^2) and it's effective on the modulation.

Introduction

Optical modulator is an important device of electro-optics system. It changes the angle between the vision lines to the target and coordinates to electrical signal on the shape. Also it modulates the optical signal by a frequency depending on the shape & numbers of sectors. [1]

The modulator usually takes various circular shapes according to the need. In present optical modulator consisting of three concentric circles (C_o, C1, C2), each circle is divided to transmittance & oblique sectors. The numbers of sectors chosen are equal to (20, 40, 60) respectively and they are increased progressively with the increase of the number of circles .The width of each circle chosen is equal to (R_o=1.5 cm), this means that the total radius of optical disk (modulator) is (R_r =4.5cm).

The central circle is designed using fractal geometry function which is a function used to draw a shape of modulator by choosing an element (such as triangle or square or line) and then generates number of them randomly, and Normal Geometry Function which is normal way of drawing (or designing) modulator shape , such as dividing the area of circle to 20 sectors each sector has an angle 360/20 = 18o 10 sectors will be transmitter and other 10 sectors are oblique and the two other circle designed by general geometrical way.

The efficiency of this optical modulator disk is tested by applying the [MTF] for finding maximum and minimum chopping frequencies.

The Modulators & Modulation

Optical modulators are devices used to provide directional information for target & suppress unwanted signal from background [2]. It is sometimes called reticule, chopper and raster. I.e. the optical modulator is a device used for chopping the light beam and the output signal has frequency fig (1), the type of the frequency depend on the shape and rotating speed of the modulator. It takes many various circular shapes due to its need [3]. The position of [OM] is in front of the light source as shown in fig (2).

The optical modulator can be represented by real function, this function is called the optical modulator function, r(x, y, t), which represents the transmittance factor of the object image intensity at the point (x, y) and time (t). Therefore the radiation distribution of the object image on the object image coordinates itself, can be represented by the function s(x, y). The radiation flux V (t) that transmitted through the disk and incident on the optical detector can be integrated and given by [4].

$$V(t) = \iint r(x, y, t).s(x, y)dxdy \quad \ldots\ldots\ldots.. (1)$$

This equation represents the general relationship of the optical modulator. The object image function s(x, y), with spatial coordinate, can be modulated to temporal signal produced from the detector.

The figure (3) shows the optical modulator system. The aperture (A) has an independent area and shape on the time. The optical modulator is rotated about it's axis and scan the aperture, This scan work by rotational or translational movement, or may be both [5]

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

1- Rotating Reticle Disk: - In this type the disk rotates around its axis, while the object image rotates among the disk area. At the same time, the disk axis is rotated around the optical axis of the Electro-Optical-System, in circular path, this type of disk called (Notating Reticle) [8].
2- Stationary Reticle Disk: - In this type the disk is stationary, while the image of object is rotated on the disk surface by using rotational optical system (tilt lenses and mirrors).

Type of Modulation

1-Amplitud Modulation [A M]

$$A.M = \Phi_0 \sin \omega_c t + m\,\mathrm{AM} \frac{\Phi_0}{2} \cos(\omega_c + \omega_m)t - m_{AM} \frac{\Phi_0}{2} \cos(\omega_c - \omega_m)t \ldots.(2)$$

$where..\Phi_0\ The.\max\ amplitude.of.carrier.pulse.or.Radiance.power.density$

$.\omega_c$ ..the.angular.frequency.of.carrier.wave

$.\omega_m$ ..the.angular.frequency.of.modulation.wave

$.m_{AM}$ .the.amplitud.modulation.index $= \dfrac{\Phi_0}{\mu_{mo}}$

$.\mu_{mo}$ ..the.modulation...signal.

t.. time interval

The frequency modulator wave:

$$\Phi_m(t) = \frac{\Phi_0}{2}[1 + m_{AM}\,\mu_m(t)]\cos(\omega_c t)$$

There are three parts in the equation (2):

a- The first part represents the formula of un-modulated carrier pulse wave, and it's angular frequency is ω_c.

b- The second part represents the formula of the wave modulation in Upper-Side-Band (USB). And it's angular frequency is equal to the sum of carrier wave frequency & modulation signal ($\omega_c + \omega_m$).

c- The third part is the formula of the waves modulated in Lower-Side-Band (LSB). And it's angular frequency is equal to the difference between carrier waves frequency and modulation signal ($\omega_c - \omega_m$).

The Fourier series [9, 10]:

The series of rectangular pulses, which have pulse duty factor equal to (γ) and amplitude (Φ_0), can be represented as Fourier, series: - $\Phi_m(t) = \gamma\Phi_o - 2\Phi_o\sum_{n=1}^{\infty}\left[\frac{\sin(\pi n\gamma)}{\pi n}\right]\cos(n\omega_c t)$ …. (3)

$$\gamma.(pulse.duty.factor) = \frac{1}{\Gamma}, .\Gamma(\mathrm{mod}\,ulation.\sin gle.pulse)$$

Where $\Gamma = \frac{T_p}{\tau_p}. = \leq 2.[the.\mathrm{mod}\,ulation.will.be.continues]$

$where..T_p.is.time.\mathrm{int}\,erval.between.pulses.$

$\tau_p..is.band.width.of.the.\sin gl..pulse$

By increasing Γ (or decreasing the band width spectrum will be increasing & the power carried by the first harmonic will be decreasing and the end the modulation become pulse type modulation (PM)

2. Frequency Modulation (angular modulation) [FM] & Phase Modulation [PM]. The modulation signal frequency can be represented by using a verge. Change of a carrier wave frequency

$$\Phi_c = \Phi_0 Sin(\omega_c t + \varphi) \qquad \text{……… (4)}$$

Where: - φ =Represents phase wave.

And the modulation signal function shape given by:-

$$\mu_m(t) = \mu_{m0}\cos(\omega_m t)\text{........................(5)}$$

$$\omega_c = 2\pi fc$$

$$\omega_m = 2\pi fm$$

Then the modulation wave frequency can be given by [12]:

$$f_m = f_c[1 + k\,\mu_{m0}\cos(\omega_m t)]$$

Where k is proportion constant, the second part of this equation represents the maximum deviation in frequency

$$\Delta\delta = f_c\,k\,\mu_{m0}$$

The carrier wave function after its modulation can be given by:-

$$\Phi_m(t) = \Phi_0 Sin\,\vartheta\text{..............(6)}$$

$$\vartheta = \omega_c t + \frac{\Delta\delta}{f_m}$$

The second part of the equation (6) represents the [FM]-modulation index

(m_{FM}) and given by:-

$$m_{FM} = \frac{\Delta\delta}{f_m} \qquad \text{............ (7)}$$

Then the frequency modulation wave become:-

$$\Phi_m(t) = \Phi_0 Sin[\omega_c t + m_{FM} \int_0^t Sin(\omega_m t)] \text{.... (8)}$$

The [FM] waves have many frequencies. While the [AM] wave has two frequencies (USB&LSB) , That will be clear when we write the [FM] function in (Bessel function expansion). The Fourier transform of the function $\Phi_m(t)$ is given by [5]:-

$$\Phi_m(t)$$
$$= \Phi_0[J_0(m_{FM})Sin(\omega_c t) + J_1(m_{FM})\{\sin(\omega_c + \omega_m)t - \sin(\omega_c - \omega_m)t\} + J_2(m_{FM})\{\sin(\omega_c + 2\omega_m)t + \sin(\omega_c - 2\omega_m)t\} + \text{..........}$$
$$+ J_n(m_{FM})\{\sin(\omega_c + n\omega_m)t + (-1)^n \sin(\omega_c - n\omega_m)t\}] \text{.............................(9)}$$

In general, most modulation is used in many optical application radiance measurement systems. It works in two modes [13]:

a- The first is when the optical modulator rotated around its axis then the incident radiation will be modulated in amplitude modulation [AM].

b- The second is when the optical modulator is stationary while the object scene rotates about the disk by rotating (notating) movement or the optical modulation center will be rotated a bout the optical axis of the tracking system. Then the incident radiation will be modulated in frequency modulation [FM].

In the present paper, we have chosen three patterns of optical modulator; each one has a couple of transparent and oblique sectors. The inner pattern has (10) sectors designed by using fractal function, the middle has (20) sectors & the outer one has (30) sectors that have been designed by the normal way as shown in fig (5).The rotating frequency of the optical modulator (f_r) is given:

$$fr = \frac{\omega r}{2\pi} \qquad \text{.................. (10)}$$

Where:- ωr =Represents the angular velocity. The Chopping frequency of the transmitted rays is given by:-

$$fc = q.fr \qquad \text{............. (11)}$$

Where: $q =$ Represents the pairs of clear opaque segment number.

Then it is clear that the number of transmittance & oblique sectors increase with the number of circles (20, 40, 60) for (C_o, C1, C2) respectively.

If the central circles radius is (R_o) therefore the radius of other circles (dicks) is (n R_o).This means that the thickness of each circle around the central circles R_o .The central circle (C_o) is designed by using precise principle of fractal geometry . Special program has been used to sketch the shape of this circle (Fractal Modulator). It is assumed that the optical modulator is rotated about its axis and the rotational velocity is (w_c) in rev/sec then the rotational frequency of optical modulator is $fr = \frac{\omega r}{2\pi}$ if the spot light source is incident on the [OM]. Then the spotlight makes chopping frequency (f_c) depending on the number of sector (q). The value of chopping frequency is equal to (f_c= qf_r) and the chopping frequency of each circle is given by:

$f_c n = n qf_r$

Where (n) is number of circles

(q) is number of sectors

(f_r) is the rotational frequency of the modulator

It has been assumed that the rotational frequency (f_r) in KHz calculates the chopping frequencies (F_{co} , F_{c1}, F_{c2}) of circles (C_o,C_1,C_2) in KHZ,

Fractal Geometry Function

Simple non-linear deterministic equations system can self-generate irregular outputs and simulates when the behavior is linear or nearly non-linear. When it increases, smoothly on short time scales, random and unpredictable behavior can be seen over longer periods. If we take a straight line with the length (L) and divided into set of pieces which have the length (K) ,then the number of these pieces will be equal to N=L/K . To measure the curve of fractal, first we should divide it into many pieces, increased exponentially to have high quality as shown in fig (6). [14]

$$N = (L / K)^{D'} \quad \text{……..} (12)$$

$$D' = \log(N) / \log(L / K) \quad \text{…….} (13)$$

Where $D^{/}$ represents the fractal dimension.By using iterated function systems or [IFS] which is a method of constructing fractals.

There are normally numbers of dimensions, but are commonly computed and drawn in (2D). Make up of the union of several copies of itself, each copy being transformed by a function “function system", and made shapes.

IF the (x, y) is mapping space of a matrix, Then the $f(x)$ represents the space, that all points are part of (x).

IF $(W_i : i = 1,2,3,4..............m)$ then the transformation (W) in Euclidean plane can be given by [15]:-

$$W(x, y) = (ax + by + e, cx + dy + f) \quad ..(14)$$

The points a, b, c, and d define rotation and scaling operations to be applied to the point and called affine transformation. The e and f points define a translation to be applied to the point. The transformation (W) can be defined in this formula:-

$$W_i(x) = W\begin{pmatrix} x_i \\ y_i \end{pmatrix} = \begin{pmatrix} a_i & b_i \\ c_i & d_i \end{pmatrix}\begin{pmatrix} x_i \\ y_i \end{pmatrix} + \begin{pmatrix} e_i \\ f_i \end{pmatrix} \quad .... (15)$$

$$W_i = A_i X_i + T_i \quad .... (16)$$

$$Wi(x) = W\begin{pmatrix} x_i \\ y_i \end{pmatrix} \quad .... (17)$$

Or

$$W_i(x) = A_i x_i + T_i \quad .... (18)$$

Where (A) represents the matrix $\begin{pmatrix} a....b \\ c....d \end{pmatrix}\begin{bmatrix} x \\ y \end{bmatrix}$

(T) is the horizontal vector $\begin{bmatrix} e \\ f \end{bmatrix}$

By using this concept and(DUG. Nelson) program [16], we sketched many shapes of fractal optical modulators; one of these shapes figure (7, 8) was used to design the optical modulator of this research.

Evaluation of [MTF]:

The optical transfer function [OTF] is an important function which can be defined as the ability of an optical system to transfer different frequencies from object to image, and sometimes it is defined as (Frequency Response Function) [8]. The [OTF] is a complex function that measures the loss in image contrast of a sinusoidal target as well as any phase shifts .The [MTF] is amplitude (i.e. [MTF]= |OTF|) and the phase transfer function [PTF] is the phase portion of the [OTF] [5,8] . There for the image irradiance distribution [17]:

$g(x, y) = f(x, y)* h(x, y)$

Where f(x, y) is ideal image, h(x, y) is impulse response

By the normalization of the [OTF] formula, we have Fourier transform ($H(\xi, \eta)$) referred to as the "optical transfer function" , unless the impulse response function { h(x ,y)} satisfies certain symmetry condition .In general a complex function having both a magnitude and phase portion is referred to as the [MTF] and the phase transfer function (PTF) respectively [13,18]

$[OTF] = H(\xi, \eta) \exp[j\, \theta(\xi, \eta)]$ …. (19)

The [MTF] is the ability of an optical system to transfer various levels of details from object to image. There for [MTF] is the magnitude response of the optical system to sinusoids of different spatial frequency. To analyze an optical system in the frequency domain, it has been considered the imaging of the sine wave input rather than point object:

From [PTF] equation

Then $[PTF] = \theta(\xi, \eta)$

$$[CTF] = H(\xi, \eta) = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad \text{…. (20)}$$

Where I_{max} is maximum intensity.

I_{min} is minimum intensity.

When the [OTF] is real function there is no change in phase shift

$[PTF] = \theta(\xi, \eta)$

Then $[OTF] = H(\xi, \eta) = [MTF]$

For a linear shift – invariant optical system images a sinusoid will be the limited spatial resolution of the optical system results is in modulation depth (M) of the image relative to object distribution as shown in fig (9).

Then the modulation depth is defined as the amplitude of the irradiance variation divided by the bias level:

$$M = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}} = \frac{2xac - component}{2xdc - copmonent} = \frac{ac}{dc}$$

Results and Discussion

A new optical modulator has been designed as shown in fig (7, 8) consisting of three patterns circles (C_o, C_1, C_2). Each circle is divided into transparence and opaque sectors (q), the number of sectors will increase progressive (nq), where n represents the number of circles (n=1, 2, 3). In the present work (q=10) and (n=10, 20, 30) which is the number of sectors for three circles (C_o,C_1,C_2) respectively where the total no. of sectors of transmittance & oblique will be (20,40,60) for C_o,C_1,C_2 respectively .

The radius of central circle is R_o, and the radius of other circle is (nR_o). {This means that the thickness of each circle around the central circle is nR_o}.

The central disc (C_o) is designed by using the principle of "Fractal Geometry" (fractal modulator) .For the modulation, it is assumed that the optical modulator rotates about its axis, and the rotational velocity is (wr) in (rev/sec), then the rotational frequency of optical modulator is $fr = \frac{\omega r}{2\pi}$

if the spot light of the source , incident on such modulator the out put light will be chopped and have a frequency (f_c) {of course it depending on number of sectors (q) and the $f_c = qf_r$, and chopping frequency of each circle is given by the relation

$f_{cn} = nqf_r$ ………….. (21) Where n is the number of circles

q is the number of sectors.

f_r is the rotational frequency of the modulation.

By using Q-basic program, the rotational frequency (fr) kHz for different time (t) (0.004→0.2) has been calculated by using eq. (20). The out put chopping frequency

(F_{c0},F_{c1},F_{c2}) for circles (C_o,C_1,C_2) has been calculated in kHz as shown in table(1). By analyzing the output results by running the program with above data of table(1) ,we obtain a relation between the change in time (t) and the rotational frequency as shown in fig(10) ,then we sketch the relation between the change in time(t) and the chopping frequencies of circles (C_o,C_1,C_2) and the output results as shown in fig(11,12,13) which shows that the frequency decreases with the increase of time (t).The relation between the chopping frequency and the number of sectors for each circle at time is equal to (0.004,0.2) sec is sketched. The figs. (14, 15) show the chopping frequency (fco) at time (0.004, 0.2) respectively. We found that the frequency chopped of fractal shape is ten times in each part. The chopping frequencies (fc_1, fc_2) of circles (C_1, C_2) are shown in diagrams (16, 17).

Result of [MTF]

[MTF] is evaluated for each circle (C_0, C_1, and C_2) by calculating the transmittance intensity and by using the relation (9):- $[MTF] = \dfrac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$

Where: - I_{max} is transmittance maximum intensity & I_{min} is oblique minimum intensity.

The area of each circle (Sn) was calculated, it is assumed that the optical modulator has diameter equals to (9cm), and radius (R_r) equals to (4.5cm), therefore the central circle (C_0) has radius (R_0) equals to (1.5cm) and the other two circles (C_1, C_2) have thickness equal to (R_0). The area of each circle is given by:-

$So = (Ro)^2 . \pi$ =707 mm^2 for C_0

$S1 = (2Ro)^2 . \pi - 706$ =211.9 mm^2 for C_1

$S2 = (3Ro)^2 . \pi - 282.6$ =353.2 mm^2 for C_2

The circumference of each circle (C_0, C_1, C_2) is (9.42, 18.87, 28.26) cm respectively. In this research the transmittance intensity is measured by the movement of spot light size. The measurement operation begins from the center of modulator (Ro=0), and the spot light rotates about the center axis (360^0) with constant radius (1.5 mm). This means that the spot light makes ten circles (rings) in each circle (C_0, C_1, C_2). Measurement of transmittance intensity depends on the ratio between the spot size (2) mm^2 (which is the middle value of three 1, 1.5 and 2mm^2) and the area of the sub circle (S_{cn}) of each three circle. We calculate I_{max} (the ratio between the spot size and the transmittance area), and I_{min} (the ratio between the spot size and oblique area). Then the modulation transfer function [MTF] has been measured by using equation (9). The [MTF] is calculated for all the three circles (C_0, C_1, and C_2).

[MTF] of Central Circle (C_0) (Fractal Modulator)

The fractal modulator (C_0) is designed by using (DUG. Nelson) program. From this program, the iterated function system [IFS] has been found and it is given in Table (2).To measure the modulation transfer function [MTF], the (fractal element) is chosen. Here the fractal element is selected as triangle shape, because the [IFS] codes are transformation of triangle. Assuming the fractal element is equilateral triangle, its dimension is (0.9 mm), and its altitude is (0.779 mm), therefore its area is (3.5 mm^2). The number of triangles in (C_0) is (20); these triangles are divided to (10) transmittance and (10) oblique. The modulation transfer function [MTF] is measured with respect to spot size movement. The spot size rotates about the modulation center axis, and in constant radius (1.5 mm). The spot size movement begins from (0-15) mm. This means that there are ten sub circles (rings) in circle (C_0). By using the program, the area of sub circles (S_n), and area of transmittance and oblique sectors (S_{cn}) are calculated. The maximum intensity (I_{max}) and minimum intensity (I_{min}) has been calculated. Then by using equation (9), [MTF] was measured. We have chosen the value of spot size (2) mm^2, because it gives the best results, and it is given in Table (3).

[MTF] of Circle One (C_1) (Acquisition Modulator)

This circle contains (20-sectors) which means that there are (20) transmittances and (20) obliques. The spot size movement begins from (R_0=16.5 mm to 30 mm) by steps (1.5 mm) (ten circles). The modulation transfer function [MTF] is calculated, Table (4), shows the ([MTF], S_n and Scn), for spot size (2) mm^2.

[MTF] of Circle Two (C_2) (Detection Modulator)

This circle contains 30-sectors which mean that there are 30 transmittances and 30 oblique. The spot size movement begins from R_0=31.5 mm to 45 mm by steps1.5mm (ten circles). The modulation transfer function [MTF] has been calculated, Table (5) shows the ([MTF], S_n and Scn), for spot size (2) mm^2.

Conclusions

1. The [MTF] of the supposed optical modulator will increase with the increasing of the spot size and decrease with increasing (Ro).
2. The maximum chopping frequencies in circles (C_0, C_1, C_2) are (2.5,5,10)KHZ respectively at (t=0.004)sec, and minimum chopping frequencies are (0.05,0.1,0.2)KHZ at (t=0.2)sec, and the best modulation at spot light size equals to (2 mm^2).
3. The type of supposed optical modulator can be defined by using the suitable spot size.
4. Circle two can be used as detection modulator by using large size of spot size, and circle one can be used as acquisition modulator by using size smaller than spot size, and the central circle (Fractal) can be used as tracking modulator because it is more accurate.
5. The fractal modulator can be used with another normal optical modulator in optical systems.
6. The fractal function can be used to design the optical modulator, especially for fine optical measurement.

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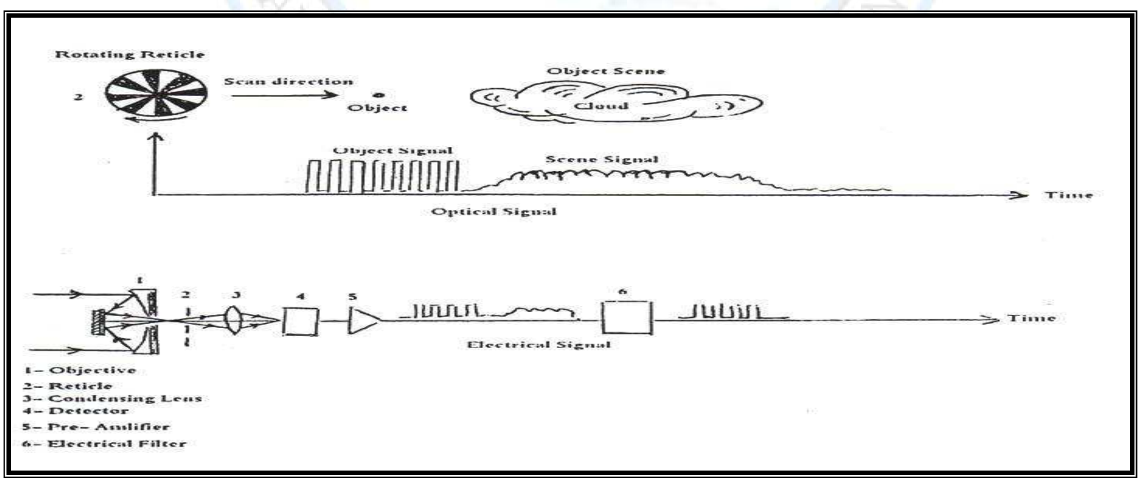

Figure (1) the principles of the optical modulator action [6]

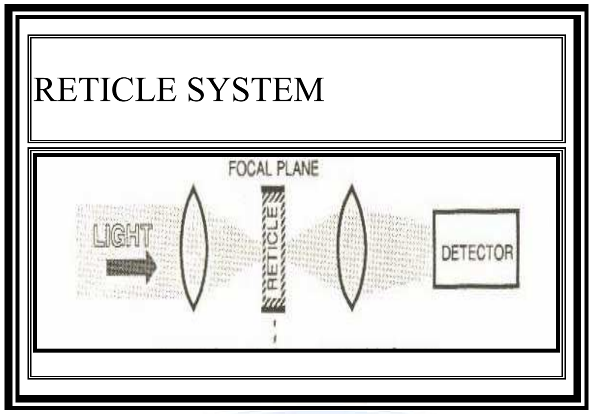

Figure (2) The Position of the modulator in the optical system [7]

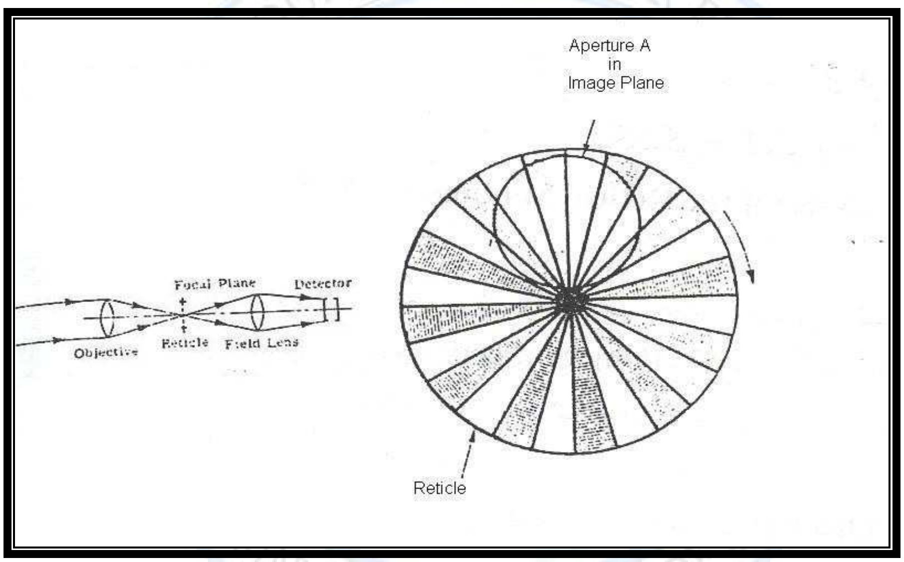

Figure (3) General Optical Modulator System [5].

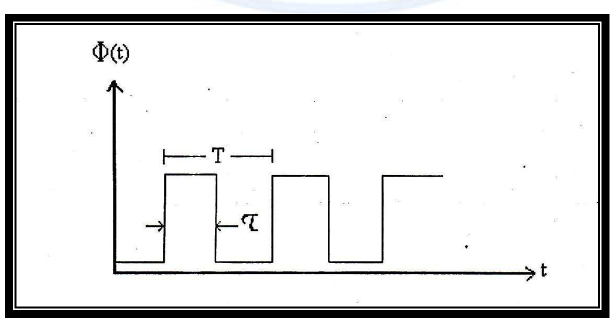

Fig (4) Optical signal shape produced by the modulation disk [11]

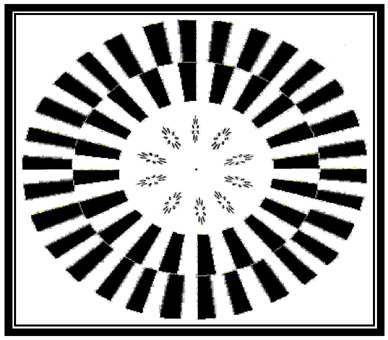

Figure (5) the supposed multifunction optical modulator

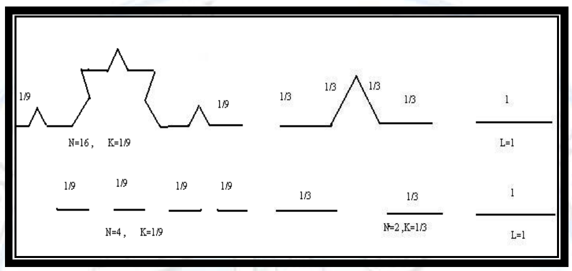

Figure (6) Fractal curve deviation method [14]

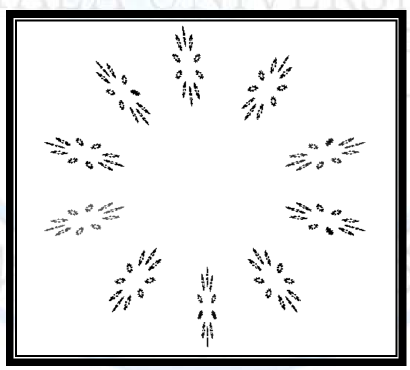

Figure (7) Fractal Modulator with 10-slots

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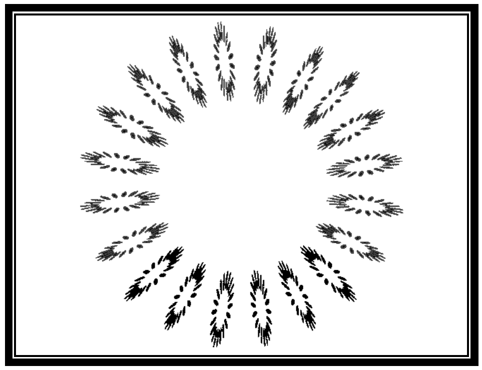

Figure (8) Fractal Modulator with 20-slots

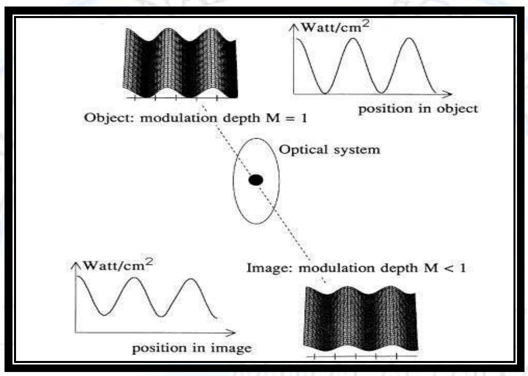

Figure (9) Transfer modulation signal from object to image [19]

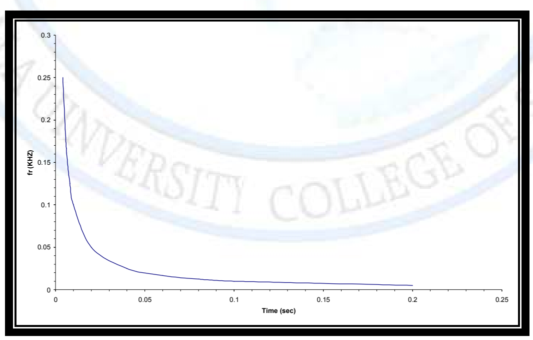

Fig. (10): Rotation frequency (fr) visa change in (t)

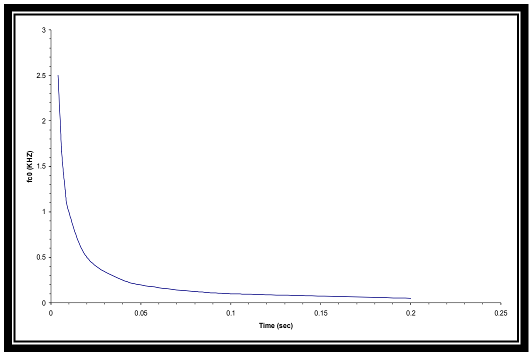

Fig. (11): Different times of Chopping frequency (f_{co}) for central circle (C_o).

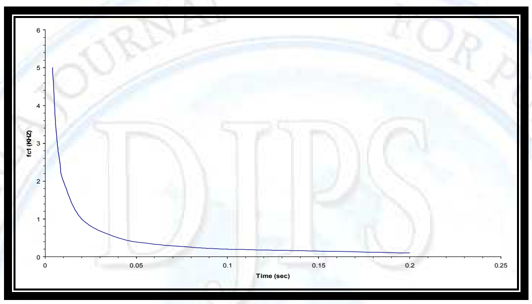

Fig. (12): Different times of Chopping frequency (fc_1) for circle one (C_1).

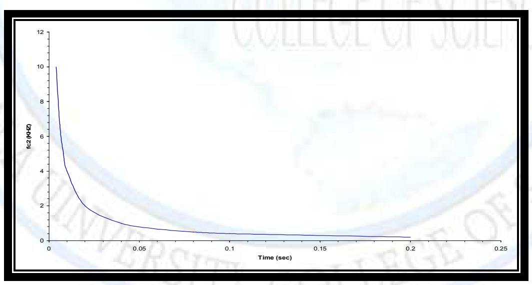

Fig. (13): Different times of Chopping frequency (fc_2) for circle two (C_2).

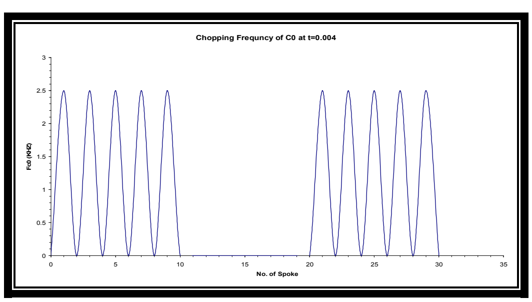

Fig. (14): At time t=0.004 sec and Chopping frequency of C_0 .

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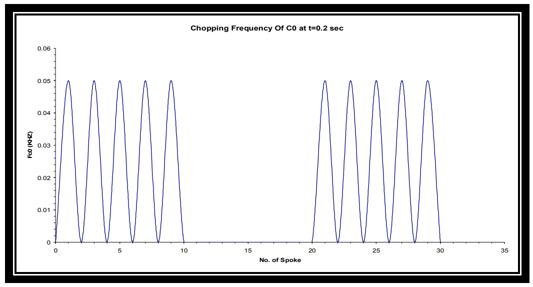

Fig. (15): At time t=0.2 sec and Chopping frequency of C_0.

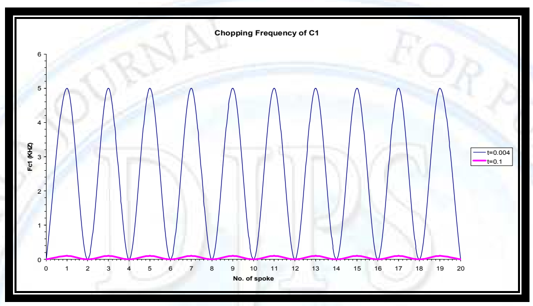

Fig. (16): At time t= (0.2, & 0.004) sec and Chopping frequency of C_1.

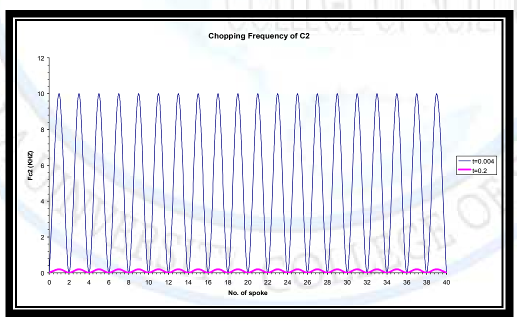

Fig. (17): At time t= (0.2, & 0.004) sec and Chopping frequency of C_2.

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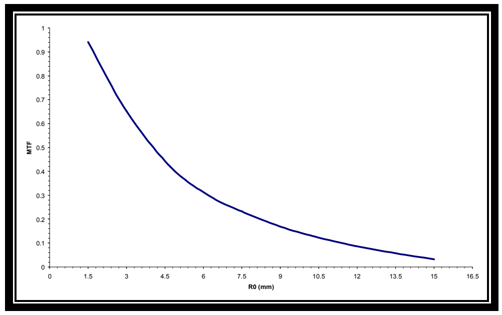

Fig. (18): Spot size (2mm ^{2}) and mean [MTF] of central circle (C_0) is 0.3025

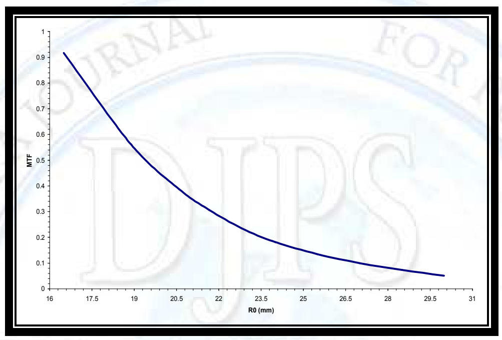

Fig. (19): Spot size (2mm ^{2}) and mean [MTF] of circle (C_1) is 0.322

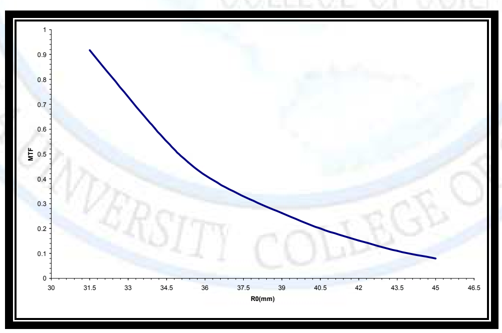

Fig. (20): Spot size (2mm ^{2}) and mean [MTF] of circle (C_2) is 0.3731

Table (1): Chopping and Rotation frequencies for optical modulator.

t (sec)	fr (KHZ)	Fc0 (KHZ) n=1 q=10	Fc1 (KHZ) n=2 q=10	Fc2 (KHZ) n=3 q=10
0.004	0.25	2.5	5	10
0.006	0.1666	1.66	3.333	6.666
0.008	0.125	1.25	2.5	5
0.01	0.1	1	2	4
0.02	0.05	0.5	1	2
0.04	0.025	0.25	0.5	1
0.06	0.0166	0.166	0.333	0.666
0.08	0.0125	0.125	0.25	0.5
0.1	0.01	0.1	0.2	0.4
0.2	0.005	0.05	0.1	0.2

Table (2) The Fractal modulator and it's [IFS] codes.

W	A	B	C	D	E	F
-0.901	- 0.828	0.891	-0.781	277.71	127.05	0.125
-0.891	- 0.781	0.901	-0.828	339.32	351.29	0.125
0.891	- 0.781	0.901	0.828	430.15	235.77	0.125
0.901	- 0.828	0.891	0.781	208.17	245.23	0.125
0.901	- 0.828	0.891	0.781	344.98	129.31	0.125
0.891	0.781	-0.901	0.828	231.73	169.63	0.125
0.891	0.781	-0.901	0.828	208.17	242.56	0.125
-0.901	0.828	-0.891	-0.781	430.15	231.84	0.125
-0.901	0.828	-0.891	-0.781	232.86	308.72	0.125
-0.891	0.781	-0.901	-0.828	405.46	324.56	0.125

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Table (3): The [MTF] of C_0 At spot size ($2mm^2$)

Ro (mm)	Sn (mm^2)	Scn (mm^2)	MTF
1.5	7.060	0.353	0.942
3	21.21	1.059	0.652
4.5	35.34	1.766	0.44
6	49.48	2.472	0.32
7.5	63.61	3.179	0.232
9	77.75	3.885	0.169
10.5	91.89	4.592	0.125
12	106.02	5.298	0.081
13.5	120.16	6.005	0.057
15	134.30	6.711	0.032

Table (4): The [MTF] of C_1 At spot size ($2mm^2$)

Ro (mm)	Sn (mm^2)	Scn (mm^2)	MTF
16.5	148.37	3.71	0.917
18	162.50	4.06	0.68
19.5	176.63	4.42	0.485
21	190.76	4.77	0.351
22.5	204.89	5.12	0.251
24	219.02	5.47	0.182
25.5	233.15	5.83	0.135
27	247.28	6.18	0.1
28	261.41	6.53	0.073
30	275.54	6.89	0.051

Table (5): The [MTF] of C_2 At spot size ($2mm^2$)

Ro (mm)	Sn (mm^2)	Scn (mm^2)	MTF
31.5	289.66	4.827	0.917
33	303.79	5.063	0.715
34.5	317.92	5.298	0.55
36	332.05	5.334	0.42
37.5	346.18	5.796	0.335
39	360.31	6.005	0.262
40.5	374.44	6.240	0.2
42	388.57	6.471	0.152
43.5	402.70	6.711	0.11
45	416.83	6.947	0.08