A Thesis
On

Anomalous spectral behaviour and Tunable spectral switching with cosh super Gaussian pulse

Submitted in the partial fulfilment of requirement for the award of
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Degree of
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Submitted by

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CERTIFICATE

This is to certify that the report entitled " **Anomalous spectral behaviour and Tunable spectral switching with cosh super Gaussian pulse**" submitted by **Mr. Mukesh Kalra (301004007)** of M.Sc (Physics), Thapar University, Patiala was carried out by him under my Supervision. I certify that the matter reported in the thesis is of candidate's own record and not submitted to any other university in any part or full form for the award of such degree.

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Mukesh Kabra

CONTENT

CHAPTER-1

1. Introduction

Singular optics [1, 2] has attracted substantial attention during the last decade. For a radiation field, say, a monochromatic light, the phase is indeterminate at zero intensity points. These points are called phase singularity. Different types of optical phase singularities were described and classified long back by Nye and Berry [3] and Wright [4] Experimentally phase singularities were observed in Kr+ laser speckle fields [6]. At the vicinity of these singular points several interesting optical phenomenon like wave front dislocation, optical vortices [3,7] , spectral switching [8-10] may occur. Among them spectral shift, anomalous spectral behaviour and spectral switching is our present point of interest.

Spectral switching:

For the case of beam diffraction, the power spectrum drastically shifts i.e. spectral switching takes place at certain critical distance along the line of propagation. However, for the pulse case the scenario is quite different. For pulse diffraction, the on-axis case, at certain angle, the far field power spectrum is divided in to two parts of equal heights. This is the critical position of switching. At a critical angle, slightly lower than the critical angle, the power spectrum is called spectral switching.

Initially major attention regarding singular optics was confined to monochromatic light. However, recent investigations by several workers have extended the domain of singular optics to the polychromatic field. The research interest on phase singularity with poly chromatic field may be divided in to two major categories i.e. fully coherent and partially coherent. E.Wolf theoretically showed in 2002 that spectral switching is possible for spatially fully coherent light [8,9]. Gbur et al. showed it experimentally. They found that remarkable spectral changes take place in the neighborhood of phase singularities near the focus of a converging spatially fully coherent polychromatic wave diffracted through an aperture. Apart from this fully coherent light, phase singularity for partially coherent light has been also investigated [11-18]. Spectral shifts of partially coherent light are induced by coherence and/or diffraction. Pu et al. have shown that rapid spectral changes i.e. spectral switching may occur for partially coherent light, In this case the switching is observed at certain critical lengths along the axis of the aperture through which the light in diffracted [11,12].

The polarization singularity as well as Lisajous singularities has also been investigated for two color vector field [19]. Earlier Palma et al. have widely studied the spectral shifts for Gaussian Shell model (GSM) beams, which are partially coherent in nature, due to propagation through both free space and an aperture lens[20,21]. Similar investigation with a multimode laser (using Hermite Gaussian beams) instead of fundamental mode laser also show spectral switching.

The Fraunhofer diffraction of spatially coherent polychromatic beam through the single slit also exhibits sudden spectral shift near the dark lines of diffraction pattern. This has been proved both theoretically and experimentally [22]. Though most investigations on the anomalous spectral behaviour have been carried out for light beam, ultra short pulses [23-25] also have drawn attention. For example spectral behavior as well as spectral switching of diffracted chirped Gaussian pulses in near field [26] and far field have been studied recently [27-29]. Recently in an elegant investigation, cosh-Gaussian beam has been introduced in atmospheric optical communication links [30]. An important issue pertaining to spectral switching is whether such switching could be made tunable. In a milestone paper [31] , and followed by another [32] authors presented an investigation to highlight the possibility of tunable spectral switching in the far field of an aperture with a chirped cosh-Gaussian pulse and a super Gaussian pulse respectively. For the chirped cosh-Gaussian pulse tuning is done by varying the cosh parameter. Whereas, for super-Gaussian pulse tuning is done by varying the super Gaussian parameter. This seems to be promising because in addition to the chirp, the cosh parameter should provide another significant tool in controlling the spectral switching and also spectral shift. Since generating such pulses does not seem to be difficult with the optoelectronic technology. Particularly in free space optical communication system, different wavelengths of WDM (wavelength division multiplexed) signals can be switched at different angles. Moreover, since these angles can be varied by varying cosh parameter of pulse, thereby giving an opportunity to communicate signals of a particular wave length to receivers located at different angles from the source plane.

When the converging wave incident on aperture is a spatially fully coherent polychromatic wave rather than a monochromatic wave, the spectrum in the focal region also exhibits anomalous behaviour. If the spectrum of field in the aperture consists of a narrow spectral line centered at frequency ω_0, undergoes rapid changes as the point of observation moves along the loop. When a particular class of partially coherent light is incident on a circular aperture, the on axis spectrum of light in the far zone is different from the spectrum of light at the aperture.

1.1 Definition of the problem:

Till date, spectral switching has been shown for different pulses, namely Gaussian, super Gaussian, cosh Gaussian in different aperture systems. However, to the best of our knowledge, no such switching has been investigated with cosh super Gaussian pulse. Thus we propose to investigate anomalous spectral behaviour and hence spectral switching using cosh super Gaussian pulse, with this anticipation that cosh Gaussian parameter and super Gaussian parameter will control the spectral switching phenomenon more efficiently. We also propose to undertake a comparative study of tunability by cosh Gaussian parameter and super Gaussian parameter. This spectral switching can be used for satellite communications, optical interconnects, space communication, data processing, information encoding and information hiding etc.

1.2 Objective:

i) To investigate anomalous spectral behaviour and hence spectral switching using super cosh Gaussian pulse.

ii) To do comparative study of tunability with cosh parameter and super Gaussian parameter.

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CHAPTER - II

2. Methodology:

We consider a cosh super Gaussian laser pulse that incident on a rectangular aperture (at z = 0 plane) having widths 2a and 2b along x and y directions respectively. The initial field of the incident pulse is given by:

$$E(x_0, y_0, 0, t) = \exp\left(-\frac{x_0^2 + y_0^2}{w_0^2}\right) A(t) \tag{1}$$

where, w_0 is the pulse waist and $A(t)$ is the temporal profile of the pulse. A cosh super Gaussian pulse can be produced practically by out of phase superposition of two decentered super Gaussian pulses whose centers are respectively located at $\frac{t}{T} = \Omega$ and $\frac{t}{T} = -\Omega$. The mathematical formulation is as follows

$$A(t) = \frac{A_0}{2}\exp\left(\frac{\Omega^2}{2}\right)\left(\exp\left(-\frac{1}{2}\left(\frac{t}{T}+\Omega\right)^{2m}\right) + \exp\left(-\frac{1}{2}\left(\frac{t}{T}-\Omega\right)^{2m}\right)\right). \tag{2}$$

Here, T is the pulse duration and m is the super Gaussian parameter.

For m=1 the pulse will take (after some simplification, say A_0=1) the following form

$$A(t) = \exp\left(-\frac{t^2}{2T^2}\right)\cosh(\Omega t)\exp(-i\omega_0 t) \tag{3a}$$

where, ω_0 is the central frequency of the pulse.

For m=2 the pulse looks much complicated as follows:

$$A(t) = \exp\left(-\frac{1}{2}\left(\frac{t^4}{T^4} + 6\frac{t^2}{T^2}\Omega^2 + \Omega_2^4\right)\right)\cosh\left(4\frac{t^3}{T^3}\Omega + 4\frac{t}{T}\Omega^3\right)\exp(-i\omega_0 t) \tag{3b}$$

It's not surprising that the higher order pulses will be more complicated in form and nature.

Eq.(3a) is the unchirped pulse. It's chirped counterpart can be written as

$$A(t) = \exp\left(-\frac{(1+iC)t^2}{2T^2}\right)\cosh(\Omega t)\exp(-i\omega_0 t) \tag{3c}$$

Where, C is the chirp. C=+ve corresponds to up chirp, where C=-ve corresponds to down chirp.

Now, the field given by Eq.(1), can be converted in the space-frequency domain by Fourier transformation as

$$E(x_0, y_0, 0, \omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} E(x_0, y_0, 0, t) \exp(i\omega t)\, dt = \exp\left(-\frac{x_0^2 + y_0^2}{w_0^2}\right) F(\omega) \tag{4}$$

where $F(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} A(t) \exp(i\omega t)\, dt$ (5)

represents the Fourier spectrum of the pulse at the incident plane and ω is the frequency. The initial power spectrum at the incident plane $z = 0$ can be easily obtained from (5) as

$$I_0(\omega) = |F(\omega)|^2 \tag{6}$$

From Eq.(2), (4) and (5) we get the initial field at the plane $z = 0$ for m=1 as

$$E(x_0, y_0, 0, \omega) = \frac{1}{2}\sqrt{\frac{T^2(1-iC)}{1+C^2}} \exp\left[\frac{T^2(1-iC)}{2(1+C^2)}\left\{\Omega^2 - (\omega-\omega_0)^2\right\}\right]$$

$$\times\left[\exp\left\{\frac{(C+i)T^2\Omega(\omega-\omega_0)}{1+C^2}\right\} + \exp\left\{-\frac{(C+i)T^2\Omega(\omega-\omega_0)}{1+C^2}\right\}\right]\exp\left(-\frac{x_0^2+y_0^2}{w_0^2}\right) \tag{7}$$

For the above field he initial power spectrum at the incident plane $z = 0$ is easily obtained from Eq.(2) and (6) as

$$I_0(\omega) = |F(\omega)|^2$$

$$= \frac{T^2}{2\sqrt{1+C^2}} \exp\left[\frac{T^2\left\{\Omega^2 - (\omega-\omega_0)^2\right\}}{(1+C^2)}\right]\left[\cosh\left\{\frac{2T^2\Omega C(\omega-\omega_0)}{1+C^2}\right\} + \cos\left\{\frac{2T^2\Omega(\omega-\omega_0)}{1+C^2}\right\}\right] \tag{8}$$

Here, mentioning one point is worthy. The mathematical form what we have assumed for cosh super Gaussian pulse suggests that there is no general expression of initial field/ power spectrum due to the presence of m .It is equally true for far-field power spectrum too. Therefore, we proceed with the help of numerical simulations assisted by two software MATLAB® and MAPLE®.

The field described by Eq.(7) satisfies Huygens-Fresnel integration during its propagation. Considering far-field approximation the propagating field can be expressed at a distance z as

$$E(x, y, z, \omega) = \frac{i}{\lambda z} \exp(-ikz) \int_{-a}^{a}\int_{-b}^{b} E(x_0, y_0, 0, \omega) \exp\left[\frac{ik}{z}(xx_0 + yy_0)\right] dx_0 dy_0 \tag{8}$$

where, $k(=2\pi/\lambda)$ is the wave number. The diffraction-induced far-field modified power spectrum can be written as,

$$I(\alpha, z, \omega) = |E(\alpha, z, \omega)|^2 = I_0(\omega) M(\alpha, z, \omega) \tag{9}$$

M can be identified as spectral modifier that arises solely due to diffraction.

For *m=1*, $M(\alpha, z, \omega) = \frac{1}{16}\left(\frac{z_0 \omega}{z \omega_0}\right)^2 \exp\left[-2(\alpha_x^2 + \alpha_y^2)\frac{\omega^2}{\omega_0^2}\right]$

$$\times\left[erf\left(\delta_x - i\alpha_x \frac{\omega}{\omega_0}\right) + erf\left(\delta_x + i\alpha_x \frac{\omega}{\omega_0}\right)\right]^2 \left[erf\left(\delta_y - i\alpha_y \frac{\omega}{\omega_0}\right) + erf\left(\delta_y + i\alpha_y \frac{\omega}{\omega_0}\right)\right]^2 \tag{10}$$

Here, $z_0(=\pi w_0^2/\lambda_0)$ is the Rayleigh length, λ_0 is the central wavelength, $\alpha_x(= x/(z\theta_0))$ and $\alpha_y(= y/(z\theta_0))$ are respectively the normalized angles of diffraction in x and y directions, $\theta_0(=\lambda_0/\pi w_0)$ is the far-field divergence angle, $\delta_x(=a/w_0)$ and $\delta_y(=b/w_0)$ are the truncation parameters along x and y directions respectively, and "$erf(x)$" stands for error function of the argument. However, we study this problem in a simpler manner. Instead of considering diffraction in two transverse directions, we confine our discussion in one transverse direction. However, no significant information loses due to this simplification, rather the computation becomes easier.

We the use Eq.(9) to investigate the far-field spectral behavior and to find the spectral switching phenomena.

The following diagram shows a typical diffraction element we used in our investigation to get spectral switching.

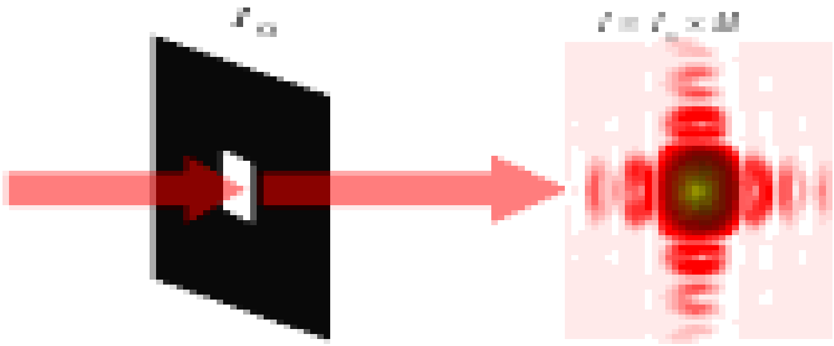


Fig.1 Intensity pattern due to diffraction through rectangular aperture

CHAPTER-III

3 Results and Discussion:

We first present the pulse profile as it is a very interesting one.

3 .1 Pulse Profile:

Following are the pulse profile we consider for our investigation. Fig.2 shows the impact of super Gaussian parameter *m* on the cosh super Gaussian pulse profile for a fixed cosh parameter. It's clear that the pulse top flattens with increasing *m*. Also the central portion deepens with increasing *m*.

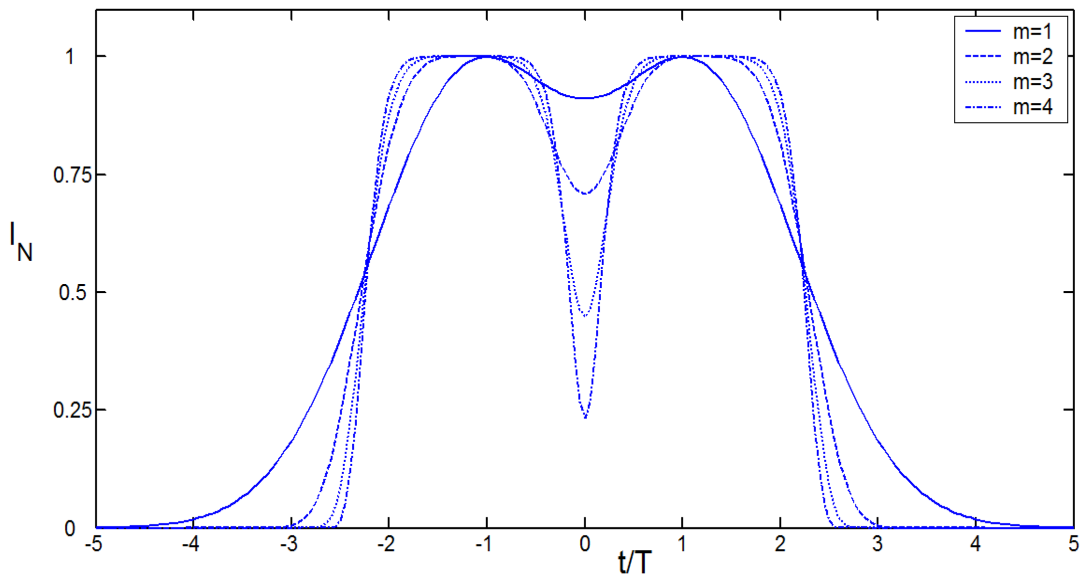


Fig.2 Cosh Super Gaussian pulse profile for a fixed cosh parameter $(\Omega = 1.2)$ *and different super Gaussian parameter m. Here, T=1.*

Fig.3 and Fig. 4 show the influence of cosh parameter on the cosh super Gaussian pulse profile for a fixed super Gaussian parameter *m* for both unchirped and chirped pulse respectively.

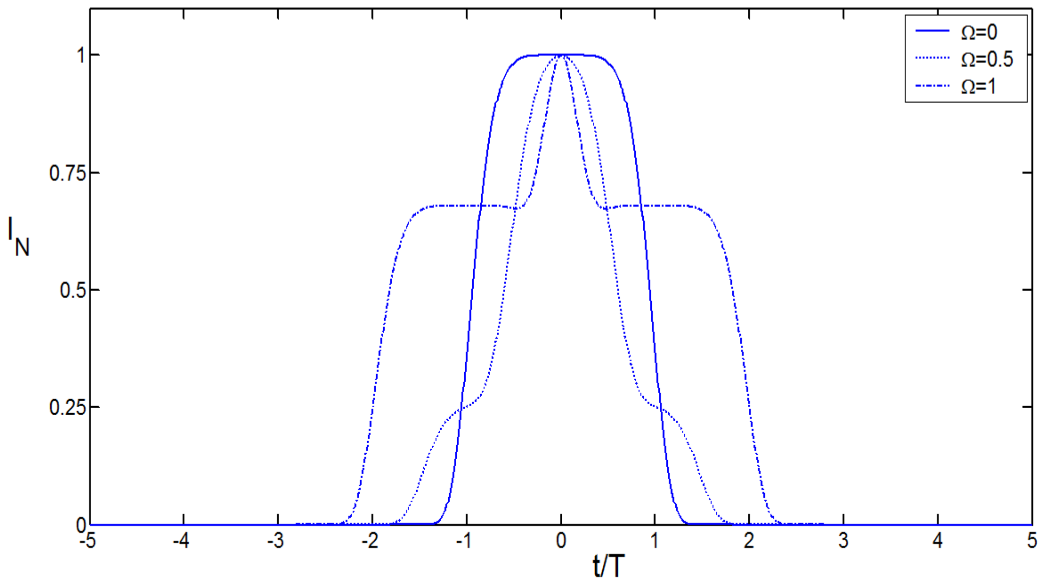


Fig.3 *Unchirped (i.e., C=0) Cosh Super Gaussian pulse profile for a fixed super Gaussian parameter (m=3) and different cosh parameter* Ω*. Here, as in Fig.2 T=1.*

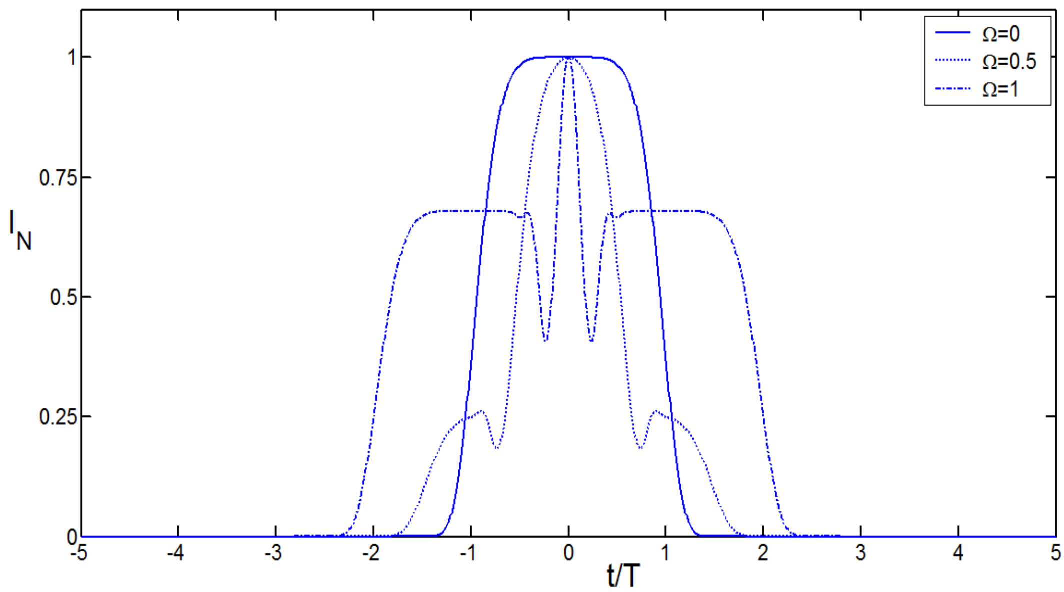


Fig.4 *Chirped (i.e., C=1.5) Cosh Super Gaussian pulse profile for a fixed super Gaussian parameter (m=3) and different cosh parameter* Ω*. Here, as in Fig.2 & 3 T=1.*

We additionally show the cosh super Gaussian pulse profile with higher value of cosh parameter Ω for a fixed super Gaussian parameter. The characteristic central dip is very clear from this curves. As the parameter Ω increases the dip too increases.

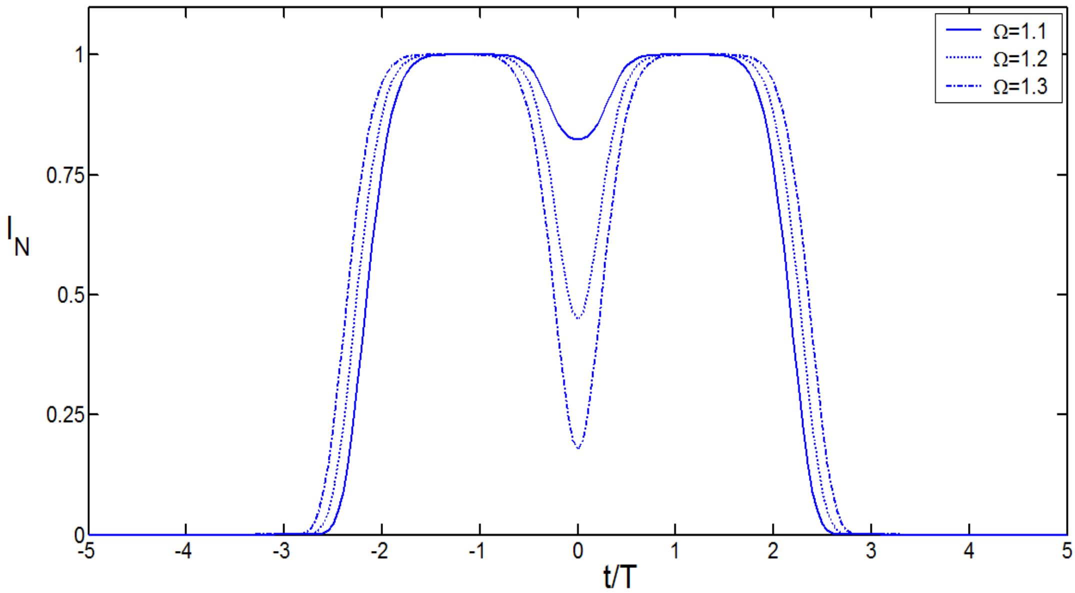


Fig.5 Cosh Super Gaussian pulse profile for a fixed super Gaussian parameter (m=3) and different cosh parameter Ω*. Here also T=1.*

3.2 Modifier:

Let us check the modifier shape. Modifier arises due to the aperture. The modifier is very important, in fact, it plays the key role in the far-field spectrum analysis. As mentioned earlier, we show the 3D spectral modifier and the 2D version of it. We basically use the 2D to make our approach simpler without losing any generality. Following Fig.6 & 7 depict the 3D and 2D spectral modifier at central frequency (ω_0) for symmetrical aperture and asymmetrical aperture respectively. The zero points in the modifier are the points of phase singularity and hence the points of spectral switching, which is our concern.

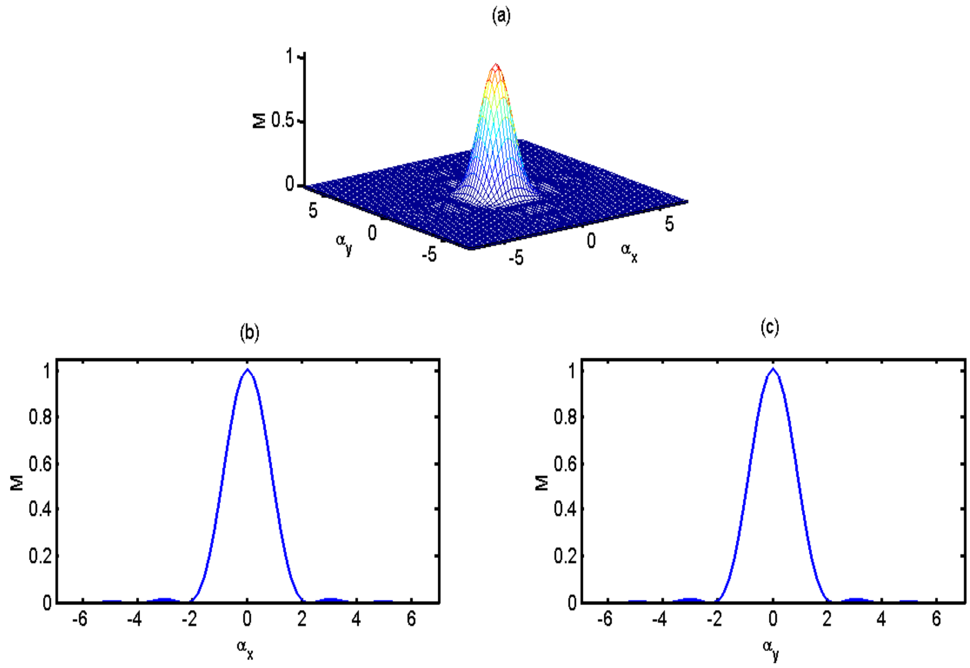


Fig.6 3D and 2D spectral modifier at central frequency (ω_0) for symmetrical aperture (i.e. $\delta_x = \delta_y = 0.8$).

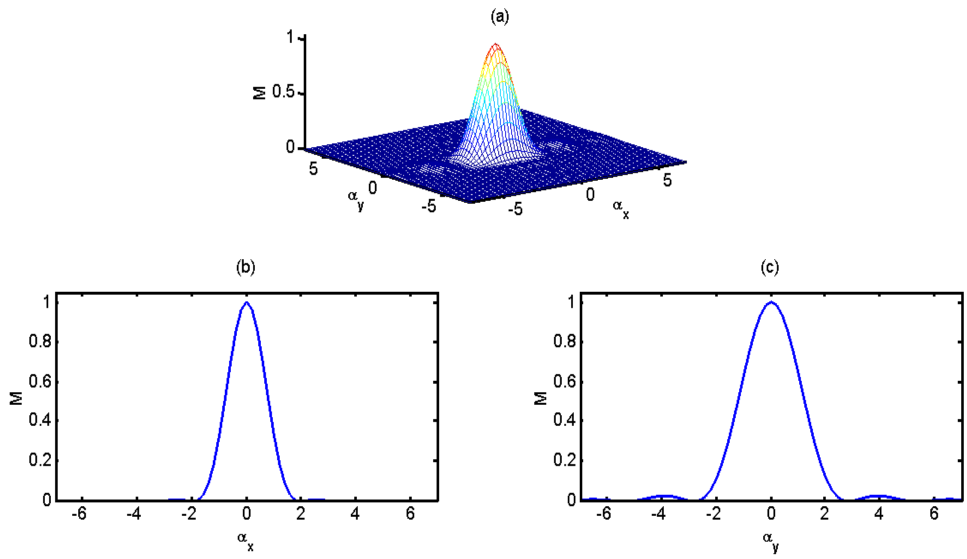


Fig.7 3D and 2D spectral modifier at central frequency (ω_0) for asymmetrical aperture (i.e. $\delta_x \neq \delta_y$)

3.3 Power Spectrum:

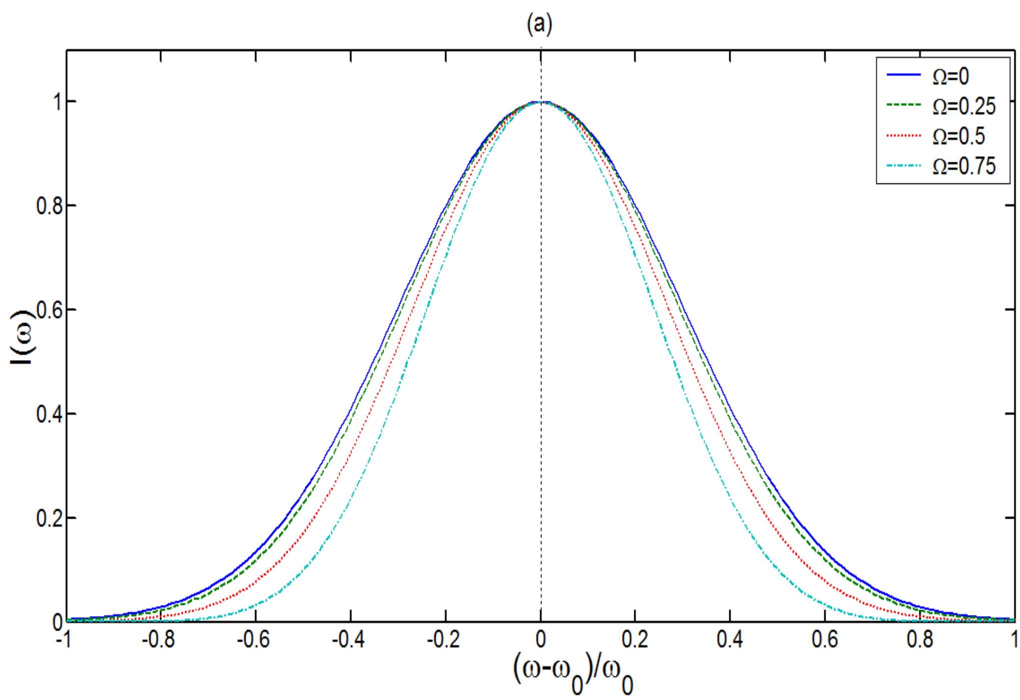
With the knowledge of the pulse profile and the modifier shape we now proceed to discuss the power spectrum in different cases. We divide our investigation in two zones: On-axis case and Off-axis case

3.3.1 On-axis power Spectrum

First we portray the influence of cosh parameter Ω in near and far-field power spectrum.

Influence of cosh parameter:

Fig.8 (a) & 8(b) respectively show the on-axis(i.e., for zero diffraction angle) initial and far field power spectrum for unchirped ($C = 0$) cosh super Gaussian pulses for different cosh parameter. From the figure it is evident the on axis far field power spectrum shifts towards higher frequency. Thus on-axis far-field spectrum is blue shifted by different amount for different Ω.



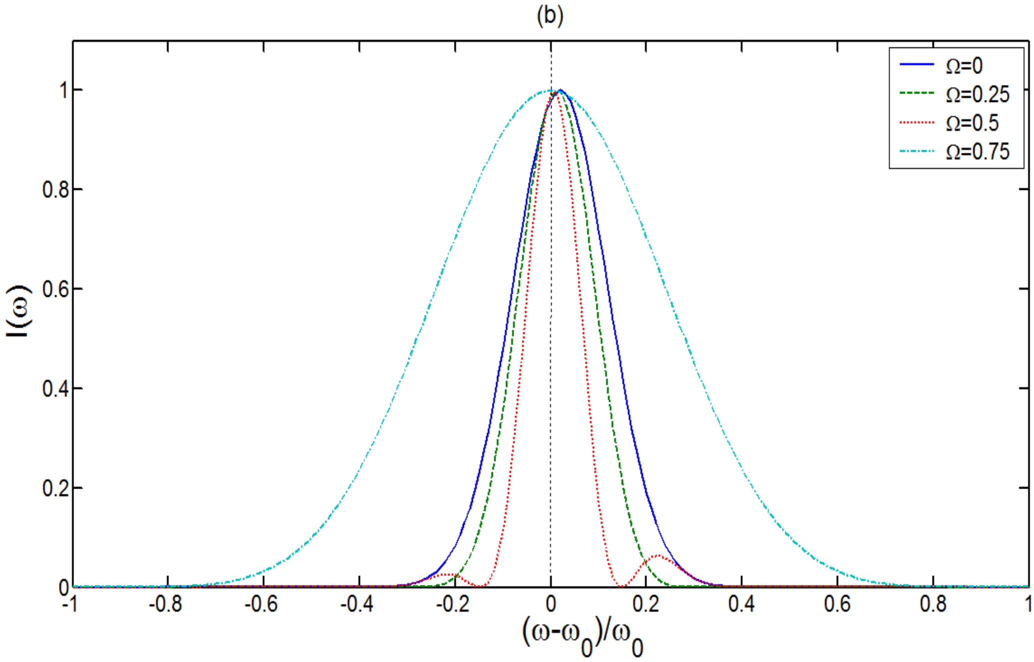


Fig.8 Normalized on-axis power spectrum for unchirped ($C = 0$) cosh super Gaussian pulses with normalized pulse duration $T = 1$ and normalized central frequency $\omega_0 = 2.36$, m=1, $\delta = 0.8$ (a) Initial spectrum (b) Modified far field spectrum.

For chirped ($C \neq 0$) cosh super Gaussian pulses the on-axis initial and far field power spectrum are given by Fig.9 (a) & 9(b) respectively. As in the case of unchirped pulse, in this case too we get the blue shift of the far field spectrum. And the blue shift is too Ω dependent.

We plot the variation of blue shift with Ωin Fig.10. The cosh parameter has little impact in blue shift for unchirped pulse in comparison to the chirped one, where the amount of blue shift reduces with increase in Ω. This finding is interesting as it says about some kind of control.

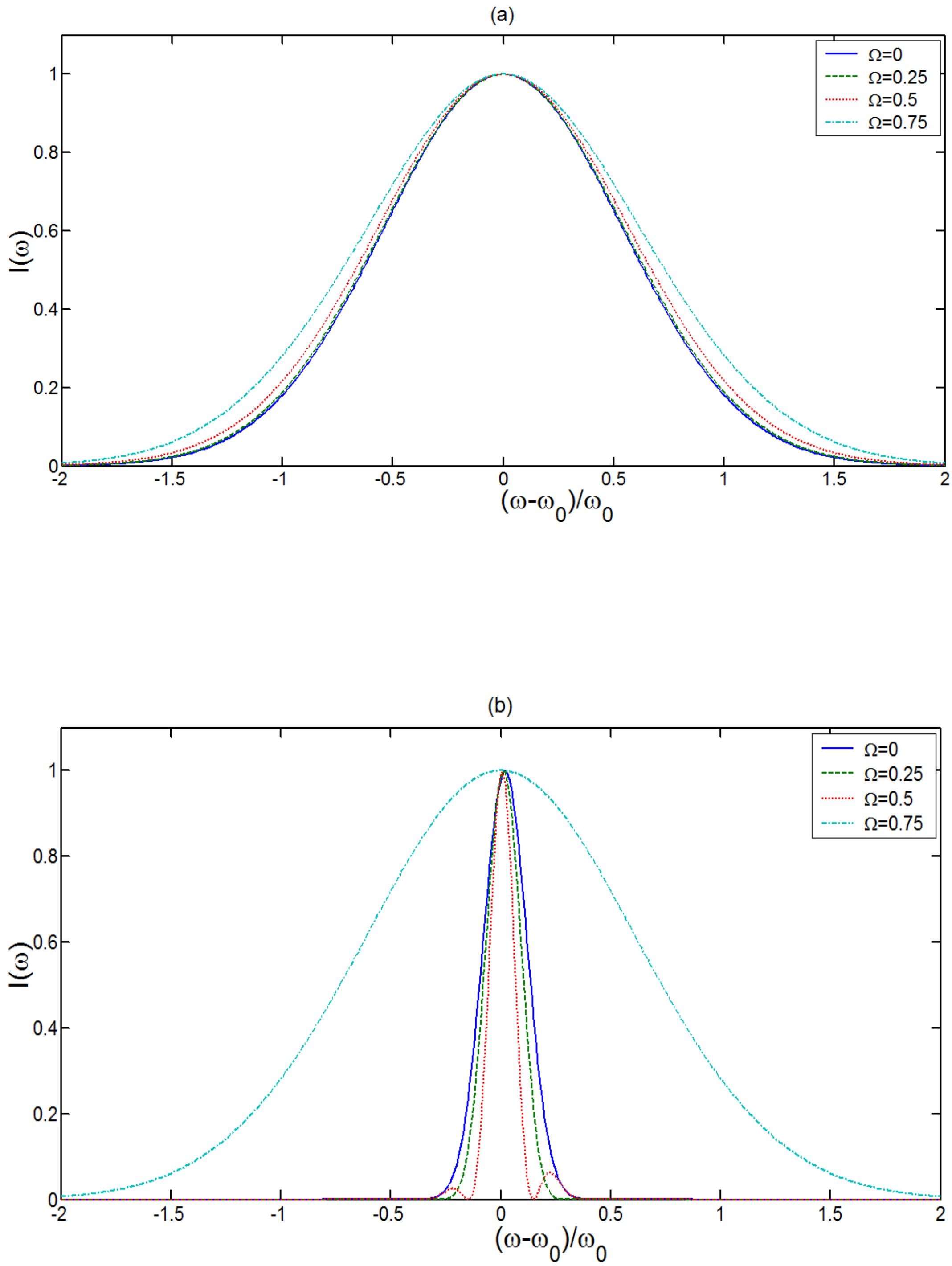


Fig.9 Normalized on-axis power spectrum for chirped ($C = 1.5$) cosh super Gaussian pulses with normalized pulse duration $T = 1$ and normalized central frequency $\omega_0 = 2.36$, m=1, $\delta = 0.8$ (a) Initial spectrum (b) Modified far field spectrum.

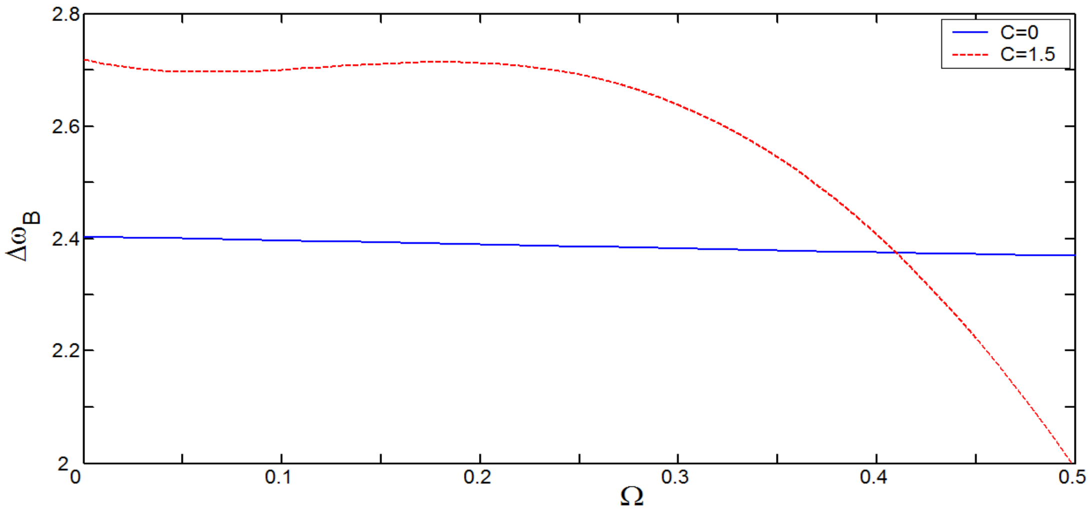


Fig.10 Variation of far field on axis blue shift ($\Delta\omega_B$) with respect to Ω for a fixed m. C is a parameter. Normalized pulse duration $T = 3$ and normalized central frequency $\omega_0 = 2.36$.

Influence of super-Gaussian parameter:

We now discuss the influence of super-Gaussian parameter m on the far-field spectral behavior. Following Fig.11 shows, as in previous case, the on-axis far-field spectrum is blue shifted and the on-axis blue shift increases with increase in super-Gaussian parameter m. This has been depicted in Fig.12.

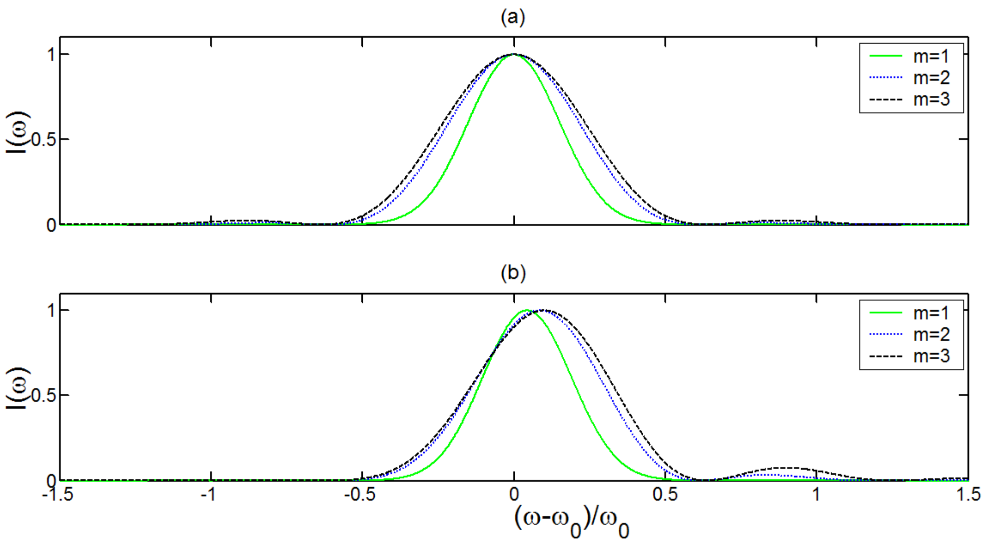


Fig.11 Normalized on-axis power spectrum Cosh super Gaussian pulses for different m and fixed Ω. (a) Initial spectrum (i.e., at $z = 0$), (b) far-field spectrum.

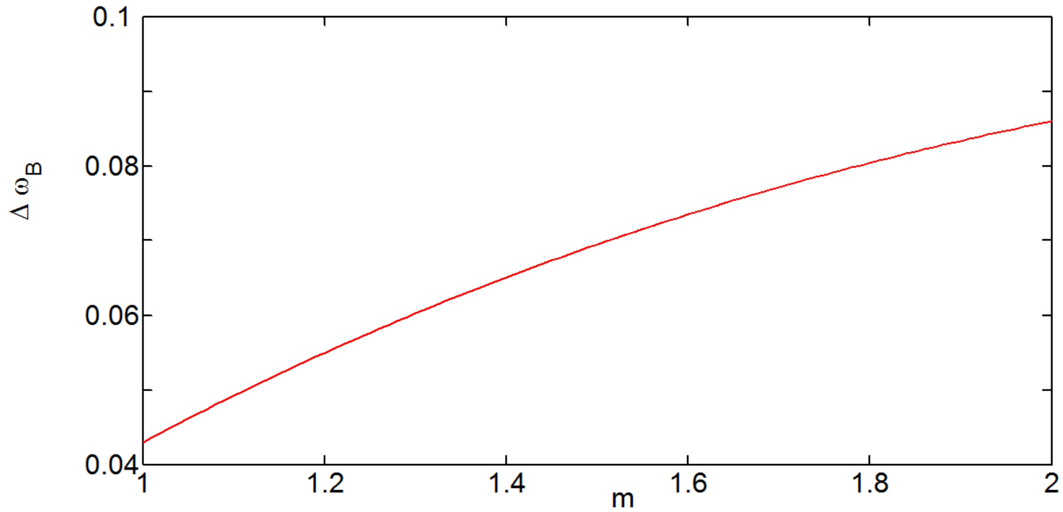


Fig.12 Variation of on-axis blue shift with super-Gaussian parameter m, keeping Ω fixed.

3.3.2 Off-axis power Spectrum:

Let us switch over to the most interesting part of our investigation, i.e., the off-axis far-field power Spectrum. As mentioned earlier at a critical diffraction angle (α_c) the power spectrum is split into two equal parts. At a slightly lower and higher angle it is red shifted and blue shifted respectively. This transition from 'red' to 'blue' is very sharp and this anomalous spectral behavior is referred as spectral switching. A typical spectral switching is shown in Fig.13. We find spectral switching for different set of cosh super Gaussian pulse and thus fulfill our first objective.

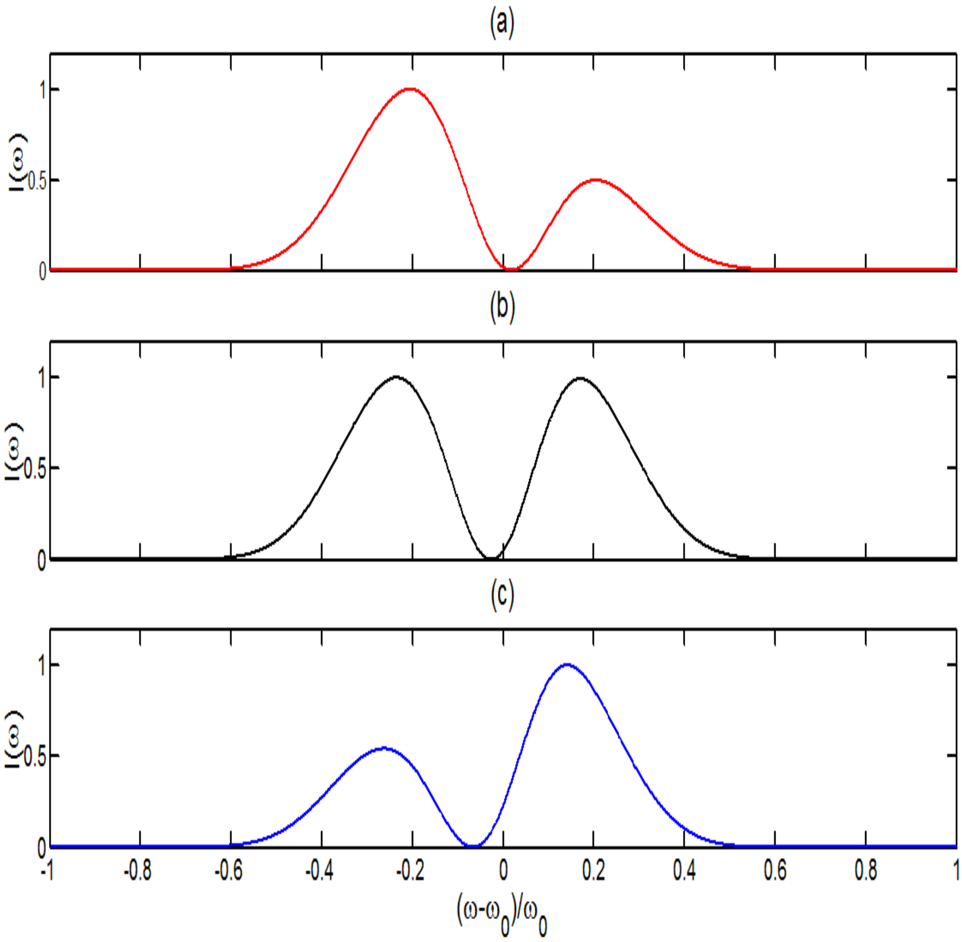


Fig.13 A typical spectral switching. (a) red shift $(\alpha < \alpha_C)$*, (b) Spectrum at critical angle* $(\alpha = \alpha_C)$*, (c) blue shift* $(\alpha > \alpha_C)$*.*

3.3.3 Tunability and Comparison:

We now check the tunability of the spectral switching with both the parameters ,i.e., cosh parameter Ω and super Gaussian parameter m. We also undertake a comparative study of their influence.

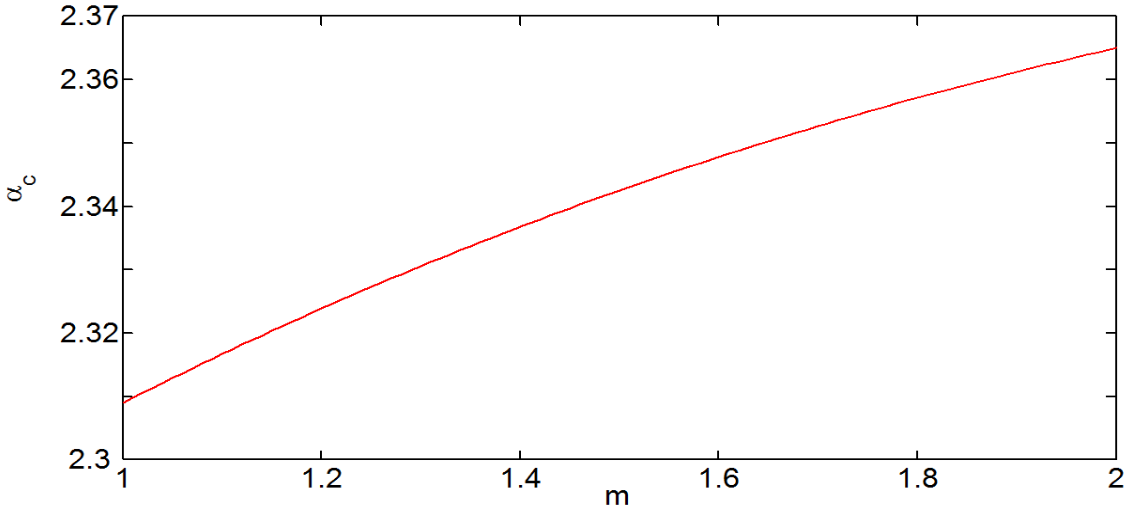


Fig.14 Variation of critical angle of switching (α_c) *with super-Gaussian parameter* m, *keeping* Ω *fixed.* $T = 2$, $\delta = 0.8$.

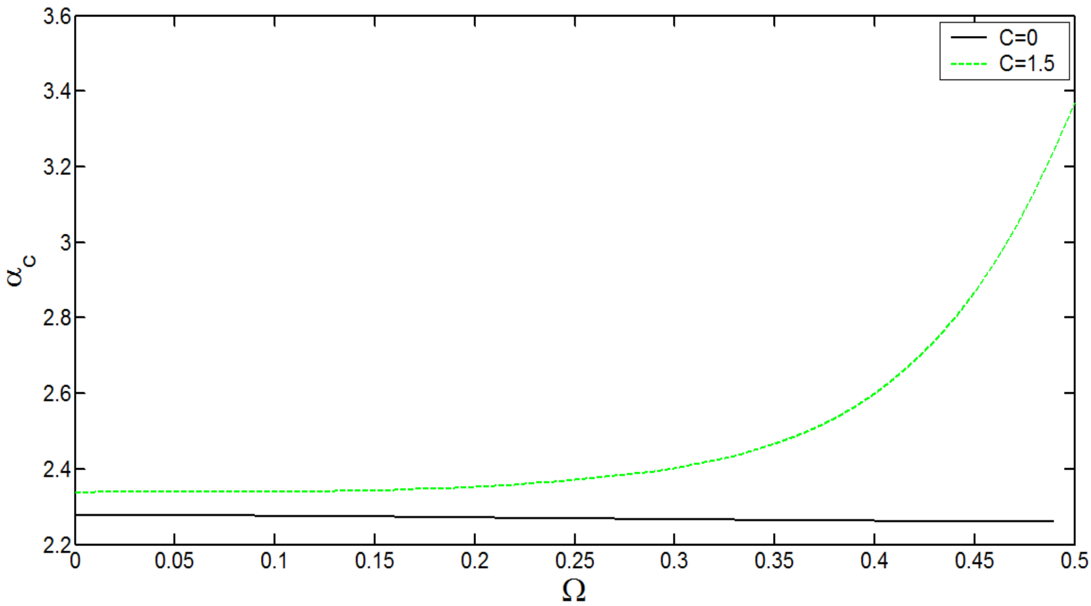


Fig.15 Variation of critical angle α_C *with* Ω. $\delta = 0.8$ *and m=1,* $T = 3$.

Tunability, here, means controlling the switching phenomena by changing a parameter. Fig.14 depicts the variation of critical angle of switching (α_c) with super-Gaussian parameter m, keeping Ω fixed, whereas Fig.15 shows the variation with cosh parameter Ω keeping m constant. Both the figures shows that switching occurs at greater critical angle (α_c) for larger values of the parameters. However, for unchirped pulse the effect is nominal as expected.

We define the frequency corresponding to the spectral switching point as 'switching frequency' (ω_s). This switching frequency ω_s does vary with both the parameters as depicted in Fig. 16 & 17. Both the parameters lower the switching frequency ω_s, however, in different manners. As before the influence is prominent in chirped pulse.

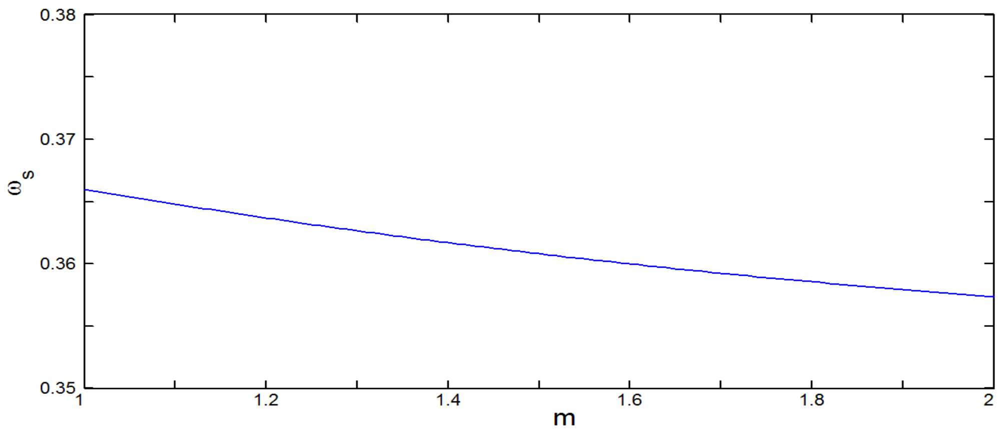


Fig.16 Variation of switching frequency (ω_s) with super-Gaussian parameter m, keeping Ω fixed. $T = 2$, $\delta = 0.8$.

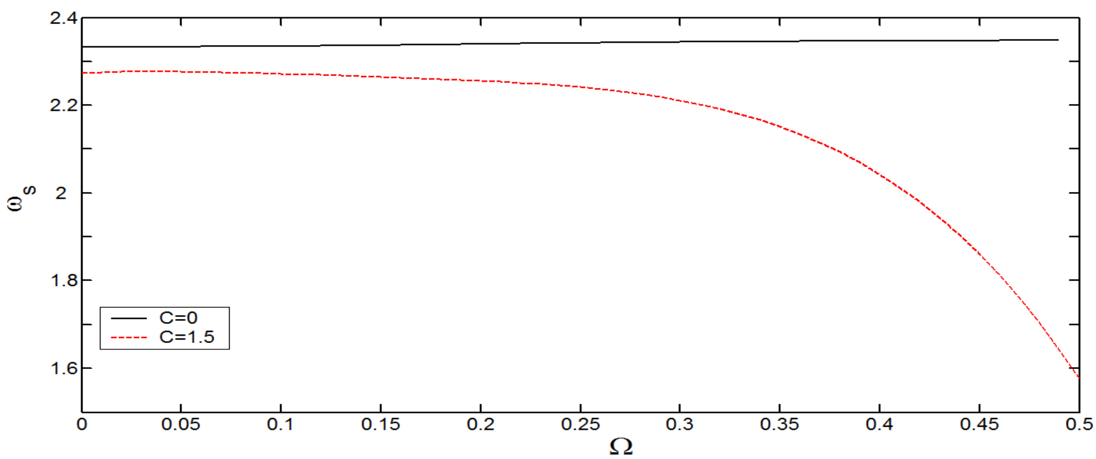


Fig.17 Variation of switching frequency ω_s with Ω. $\delta = 0.8$, m=1 and $T = 3$

3.4 Conclusion:

Thus our investigation shows that spectral switching efficiently occurs with cosh super Gaussian pulse. It also shows that the spectral switching is tunable by varying both the cosh and super Gaussian parameters. They have significant influence in tuning with chirped variety of the pulse. This result would further inspire experimentalists to check the best suitable parameter to tune the switching. The outcome of the investigation has potential application in many areas, e.g., terrestrial communication, satellite communications, optical interconnects, space communication, data processing, information encoding and information hiding etc.

Appendix

Literature review:

Specttral switching has been investigated for different system, like fully coherent and partially coherent light with both beams(eg.cosh-Gaussian, beam, Hermite Gaussian beam, Gaussian Schell model beam etc.) and pulse (eg.Gaussian, super gaussian, cosh Gaussian etc.) and with different apertures (circular, rectangular, elliptical, young's double slit, grating). Also tunable spectral switching has been predicted in different system (e.g., with cosh-Gaussian pulse and super-Gaussian pulse). Here we present a review of the spectral switching with those systems.

Fully coherent light:

Gbur et al.have showed in 2002 that spectral switching is possible for spatially fully coherent polychromatic light [1,2]. They theoretically showed that remarkable spectral change take place in the neighborhood of phase singularities near the focus of a converging spatially fully coherent polychromatic wave diffracted through an aperture. Their prediction for spectral switching has been experimentally verified by Pospescu et al. in the same year [3]. These spectral change are proved to be the characteristic features of polychromatic field near phase singularity [4]. For these fully coherent fields the spectral shifts are due to diffraction.In the paper of G. Gbur, T. D. Visser and E. Wolf (in 2002) they have showed that when the converging wave incident on aperture is a spatially fully coherent polychromatic wave rather than a monochromatic wave, the spectrum in the focal region also shows an anomalous behaviour. In particular they have shown that if the spectrum of field in the aperture consists of a narrow spectrum line centered at frequency ω_0, the spectrum of the focused field along a small closed loop enclosing a phase singularity of the spectral component of the frequency wo undergoes rapid changes as the point of observation moves along the loop.

Partially coherent light:

Spectral shifts for partially coherent light are induced by coherence and/ or diffraction. Pu et al. have shown that rapid spectral change i.e. spectral switching may occur for partially coherent light. In this case the switching is observed at certain critical lengths along the axis of aperture through which the light is diffracted [5,6]. The above prediction was experimentally verified by Kandpal at. al.[7,8]

Earlier Palma et al. have widely studied the spectral shifts for Gaussian Schell model beams, which are partially coherent in nature due to propagation through both free space and an aperture lens [9,10]. Recently Lu et al. have shown that the spectral switching for GSM beams propagating through an aperture lens is dependent on the truncation parameter, coherence parameter and Fresnel number [11]. Similar investigation with a multimode laser (using Hermite Gaussian beams) instead of a fundamental mode laser also shows spectral switching [l2].The diffraction of GSM beam through an astigmatic lens has also showed spectral switching in the vicinity of tie intensity minimum in the geometrical focal plane [13].

The Fraunhoffer diffraction of spatially coherent polychromatic beam through single slit also exhibits drastic spectral change near the dark lines of the diffraction pattern. This has been proved both theoretically and experimentally [14]. Young's double slit experiment for both partial coherent [15] and fully coherent light [16] are other notable investigations along this direction. Both investigations confirm spectral switching at the near zone of dark fringes. The spectral switch in the Young's two slit experiment with partially coherent light is studied based on the propagation law of partially coherent light. It is shown that by varying the source correlation, slit parameter and observation distance, the on axis spectrum changes gradually, and the spectral switch can take place, where the spectral shift exhibits a rapid transition from red to blue shift and vice-versa[l 7-24]

Jixiong Pu and Schojiro Ne'hioto have showed in their paper that when a particular class of partially coherent light is incident on a circular aperture, the on axis spectrum of light in the far zone is different from the spectrum of light at aperture. They obtained an explicit expression describing on-axis spectrum of light in the far zone and performed the numerical calculations. They showed that by measuring the spectral shifts against some parameter, such that a/L (a is the radius of aperture and L is the effective correlation length of the light at the aperture at central frequency of the source spectrum.), they found that spectral shifts show a gradual change. However when a/L is equal to particular values, the spectral shifts exhibit a rapid transition, i.e. spectral switches occur.

Recently there have been several papers concerning applications of spectral change induced by coherence or/ and the diffraction [25- 27]. Wolf showed that the correlation-induced spectral change can be used to produce a new kind of filter, which may have potential applications in optical signal processing [25, 26]. More recently it was proven that when a class of partially coherent light, which obeys the scaling law, is incident on a circular aperture, the on axis spectrum in the near zone is different from the source spectrum [27].

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