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# Microwave reflection on echelon cum lamellar grating and its application in astrophysics

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**Abstract** : A new approach has been presented to generate strongly intense diffraction spectra in millimeter and microwave region employing combined reflection echelon-lamellar grating. A theoretical investigation using Fourier transform technique is made to obtain the resultant intensity pattern for the diffracted waves. The results presented indicate their significant applications in detection of biomolecules and astrophysical studies.

**Keywords** : Microwave diffraction, lamellar grating, echelon grating, astrophysics.

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## 1. Introduction

The Grating spectroscopy has taken a spectacular advancement in recent times after its importance in integrated optics was felt. Lamellar and blazed type gratings are finding increasing applications in electronics. They could be used as wave-guides and antenna in the microwave region as well. Research in the millimeter and microwave bands [1,2] is being carried out in the forefront in radio-astronomy, communications and various other fields for their important operational advantages like better penetration properties over their high frequency counter parts. They have the ability of simultaneous recording of many spectral elements at a low band width. However, due to very low intensity and completely different penetration properties of these waves, gratings with special design would be necessary. The characteristics of diffracted waves from reflection echelon, echellete and

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lamellar gratings have been studied in the microwave region by Chakravorty *et al* [3-7] In the present communication we have confined our attention to having an intense diffraction spectra which could be secured if a grating can be constructed having characteristics both of an echelon and that of a lamellar We anticipate, such an echelon cum lamellar grating would be a good candidate for a millimeter or microwave grating instrument With this end in view, it is considered worthwhile to investigate theoretically the properties of such mixed gratings specially with regard to its intensity distribution Such gratings operating on millimeter and microwave bands may be useful in astrophysics and astro-chemistry [8] in detecting of bio-molecules The intensity expression has been derived both by using conventional scalar approach and also by using Fourier transform technique The results obtained are found to be identical, we present our calculations made with the Fourier transform technique

## 2. Theory of reflection type combined echelon cum lamellar grating using fourier transformation

Let us consider a special profile lamellar grating which consist of $N$ number of echelons each having $n$ number of steps as shown in Figure 1 We may call this grating as an Echelon Cum Lamellar Grating (ECLG) Thus each element of this new type of grating is an echelon of which 'a' is the breadth of each step and '$d$' its depth Let a plane wave be incident normally on the grating element (of $j$ th kind on $p$ th echelon) Each point such as $S'(x', y')$ acts as a source of secondary wavelets We determine the resultant intensity

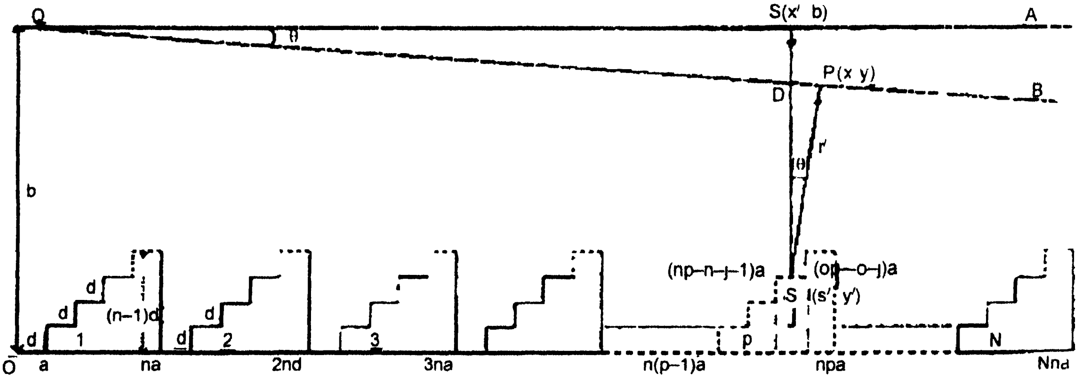


**Figure 1.** Geometry of combined echelon cum lamellar grating

which makes an angle ($\theta$) with the incident wave front Therefore, formation of the ECLG of all kind ($j$ = 1, 2, $n$) in the $p$ th echelon may be given as

$$y' = h(x') = c \qquad \text{for } 0 < x < a,$$

$$= c + d \qquad \text{for } a < x < 2a,$$

$$= c + (j - 1)\, d \qquad \text{for } (j - 1)\, a < x < ja,$$

$$= c + (n - 1)d \qquad \text{for } (n - 1)a < x < na \tag{1}$$

Consider the incident wave at $P(x, y)$ on the screen due to $dx'$ at $S'$ on the grating element, is given by,

$$dE = \frac{C_0}{r'} e^{i(\omega t - Kr_0)} \tag{2}$$

Here, $S'P = r'$ and $r_0 = SS' + S'P \cong (b + r) - [x' \sin\theta + h(x')(1+\cos\theta)]$ where, $r$ is the radial distance of $P(x, y)$ from fixed origin O such that $r^2 = x^2 + y^2$, $\sin\theta = x/r$, $\cos\theta = y/r$ and $C_0$ is constant, $K = 2\pi/\lambda$ is the propagation vector The wave at $P(x, y)$ due to all elements in the $p$ th echelon is given by,

$$E_p = \frac{C_0}{R_0} e^{i\omega t} \int_{T_p}^{T_p+na} e^{iK[(b+r) - \{x' \sin\theta + h(x')(1+\cos\theta)\}]} dx' \tag{3}$$

where, $T_p$ is the starting value of $x'$ for the $p$th echelon and $T_{p+na}$ is the end value of $x'$ for the said echelon Here, $r'$ has been replaced by an average distance $R_0$ Since $\theta$ is small in practice $(\theta_{max} < 10^0)$, such replacement does not affect the result The total intensity at the focus for entire echelon cum lamellar consisting $n$ kind of element in each of $N$ number of echelon is finally obtained as,

$$E = \sum_{p=-N/2}^{N/2} E_p = \frac{C_0}{R_0} e^{i\omega t + iK[r+b-c(1+\cos\theta)]} \left[\frac{e^{-iKa\sin\theta} - 1}{-iKa\sin\theta}\right]\left[\frac{1-e^{iKn\delta}}{1-e^{iK\delta}}\right]\left[\frac{1-e^{iKNna\sin\theta}}{1-e^{-iKna\sin\theta}}\right] \tag{4}$$

where $\delta = (1+\cos\theta)d + a\sin\theta$ Hence the resultant intensity ($I$) at the focus will be,

$$I = |A|^2 = I_0 \left[\frac{\sin^2 \frac{Ka\sin\theta}{2}}{\sin^2\theta}\right]\left[\frac{\sin^2 \frac{Kn[(1+\cos\theta)d + a\sin\theta]}{2}}{\sin^2 \frac{K[(1+\cos\theta)d + a\sin\theta]}{2}}\right]\left[\frac{\sin^2 \frac{KNna\sin\theta}{2}}{\sin^2 \frac{Kna\sin\theta}{2}}\right] \tag{5}$$

## 3. Results and discussions

Using the intensity expression, three dimensioal plot of intensity (1) *vs* wave length ($\lambda$) and diffracted angle ($\theta$) are plotted for grating elements with different combinations of $n$ and $N$ Figure 2 and Figure 3 show the three dimensional plot of intensity (I) *vs* wave length ($\lambda$) of the incident microwave and the diffracted angle ($\theta$) for two types configurations of grating elements $n$ = 5, $N$ = 10 and $n$ = 6, $N$ = 8 respectively with $a$ = $d$ = 1 cm Contours are also plotted against the high peak values *i e* for the strong intense spectra Therefore it is possible to detect those points Here we have considered the wave length ( $\lambda$ ) of the microwave ranging from of the 0.1 cm to 0.5 cm along X-axis and diffracted angle ( $\theta$ ) within the interval –7 to +7 degree along Y-axis. The possible principal maxima and secondary maxima are shown in this interval. The contours of strong

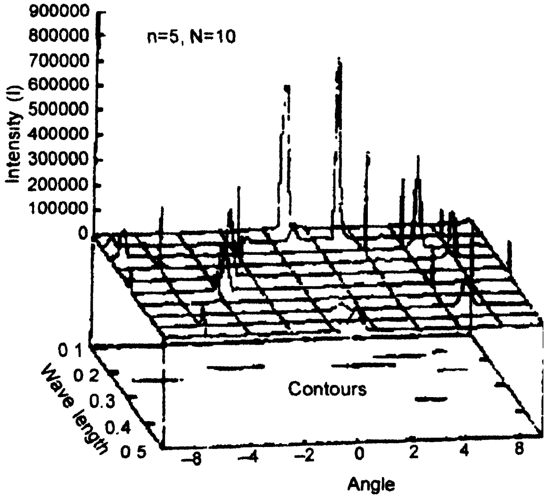


Fig. 2

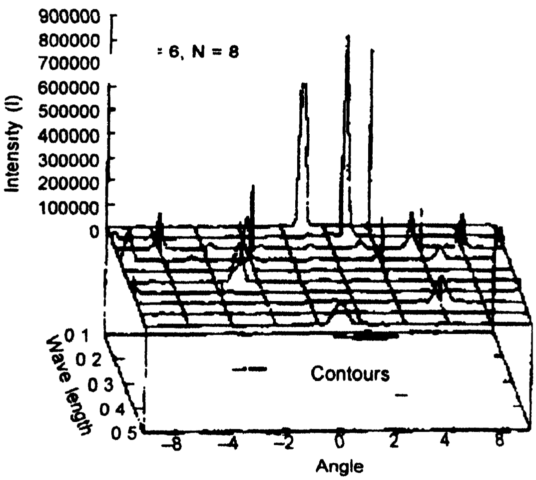


Fig 3

**Figures 2 and 3.** Shows the three dimensional plot of intensity (I) *vs* wave length ( $\lambda$ ) and diffracted angle ( $\theta$ ) for the grating elements $n$ = 5, $N$ = 10 and $n$ = 6, $N$ = 8 respectively with $a$ = $d$ = 1 cm

maxima's are also plotted along XY-plane which are supposed to be detectable in the detector. The positions of the maxima's and minima's will solely depend upon the configuration of grating elements *i.e.*, upon the $n$ and $N$ values. We have also considered the different values of $n$ and $N$ and found the strong secondary maxima's will be detectable when the possible configurations ($n$, $N$) are (5, 6), (5, 8), (5, 9), (6, 8), (6, 9) (7, 4), (7,6), (7,7), (8, 7). Figure 4 shows plot of intensity *vs* wavelength ( $\lambda$ ) for the three different values of the diffracted angle ( $\theta$ ), namely solid one for $\theta$ = 3°, dashed one for $\theta$ = 4°, and dotted for $\theta$ = 5°. It is therefore possible to detect the different wavelengths ( $\lambda$ ) from the locations of the intensity maxima's. In Figure 5 shows the variation of intensity (I) *vs.* diffracted angle ( $\theta$ ) for the

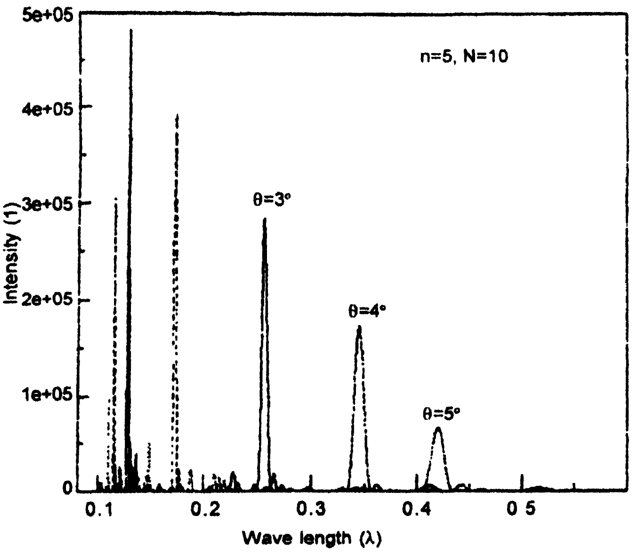


**Figure 4.** Shows the variation of intensity *vs* wave length for three different values of diffracted angle.

Glycine which have their wavelength ( $\lambda$ ) 2 46 mm and Glycolaldehyde 2 913 mm [9-10] and forms strong intense spectra near about $\theta$ = 3° and $\theta$ = 6° respectively Hence, these types of grating will be very much useful tool for detecting those molecules Therefore it is possible to detect those molecules Hence these types of mixed grating will be very much useful tool for detecting such organic and bio-molecules

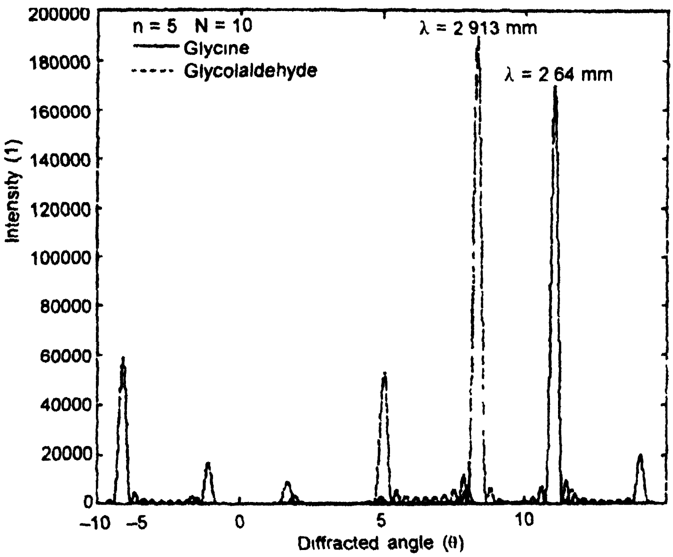


**Figure 5** Shows the plot of intensity *vs* diffracted angle ( $\theta$ ) for the Glycine and Glycolaldehyde molecules

## 4. Concluding remarks

Considering the geometrical configurations for obtaining satisfactory reproducible results it is found that $n$ = 5 and $N$ = 10, is quite suitable Many organic molecules and bio molecules have their wave length lying in the millimeter wave range, these gratings operating on millimeter and microwave bands as already said will be useful in astro-physics and astro-chemistry in the detection of such molecules As for example, glycine and glycolaldehyde have their wave lengths of 0 264 cm and 0 2913 cm respectively and therefore can be easily detectable From Figures 4, it is evident that angle of diffraction close to 0–10 degree is gives satisfactory results According to the desired diffraction angle parameters of the gratings elements may be chosen A common component used in the present day microwave and millimeter wave receivers in the wide band-width limiting amplifier which operates in the non-linear region They have the problem of 'capture effect' by which the weaker signals get suppresed by stronger signals Also the tuned oscillators in the microwave receivers have a phase noise problem We suggest that the use of a microwave echelon lamellar grating would be a much more straight forward method for instantaneous frequency measurement would be able to detect even very weak signals with no capture effect Furthermore these would be no power loss or time lag usually associated with conventional receivers

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