Visualization of non-linear continuous wave dispersion effects on fiber grating with spreadsheets in online learning

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Spreadsheet software is a practical and straightforward computing and graphics tool. The use of Spreadsheets can reduce the risk of practicum in class and can be used remotely. This research presents a simple way to build a physics simulation based on mathematical equations in spreadsheet software. The simulation aims to visualize the effect of non-linear continuous wave dispersion on fiber gratings. Simulations can visualize different modes. The mathematical equations in fiber optics for non-linear effects are quite complex. Visualization can assist students in interpreting mathematical equations and making connections between theoretical and experimental modeling.

Keywords: Spreadsheet; dispersion; linear and nonlinear.

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1. Introduction

The Coronavirus Pandemic, or Coronavirus Disease (Covid-19), has tremendously affected various fields, including the economy, tourism, education, and others. Furthermore, another impact on educators is experiencing digital migration marked by the ongoing resurgence of online learning. Education globally must have a learning strategy during a pandemic, which we know as distance learning. This condition will hamper the physics learning process in the laboratory's practicum content, so physics concepts require visualization and simulation, and there will be active interaction in learning activities. An alternative to simulating and visualizing physical phenomena can be used with spreadsheets because spreadsheet applications can be used to represent models, perform sampling, perform model calculations, and report results with easy use by users without having to use complicated programming languages.

The simulation integrated with learning physics benefits students, such as a growing understanding of science content, stimulating inquiry skills [1], and increasing metamodeling knowledge [2]. By manipulating variables and observing physical effects in simulations, the learning process becomes more applicable to real-world problems [3]. Using simulation in teaching physics can save costs, time, and risks that arise from a practicum in the classroom and laboratory.

Spreadsheets can be used as learning tools for elementary and middle school students [4]. The use of spreadsheets makes lessons more practical and interesting; giving students more significant opportunities to verify results and make connections between spreadsheet formulas, quadratic functions, and graphs [5]. Educational programs developed with spreadsheets effectively improve students' Computational Thinking [6]. Spreadsheets that have been used in introductory physics materials, for example, provide a clear geometric picture of the lens beam [7]. Implementation of media based on visual basic analysis (VBA) Excel spreadsheets on potential harmonic oscillator material [8]. A projectile movement simulation has been built in the spreadsheet [9]. The trajectory of charged particles can also be visualized using a spreadsheet [10].

The use of spreadsheets in introductory physics has been widely practiced, but in advanced physics, it is still limited, such as non-linear effects in fiber optics; this could be due to more complex mathematical equations. Visualization using spreadsheets can help students when interpreting complex equations and the relationship between theory and experiment. This paper will present a spreadsheet simulation for teaching physics. It uses a spreadsheet to visualize the Dispersion Effect of Non-Linear Continuous Waves on Fiber Grating. This visualization may be helpful for students in physics learning that is carried out online or during laboratory limitations in carrying out practicums.

2. Theory

Diffraction gratings, which are used routinely in optical instruments such as spectrometers, are standard optical components. A diffraction grating is defined as an optical element capable of imposing periodic variations in the amplitude or phase of the incident light [11].

Optical media whose index of refraction varies periodically can act as a lattice, due to the influence of the periodic phase differences of light propagating in it; this is an index lattice. Periodic refractive index variations in the fiber core form Bragg Lattice fibers. The distribution of Bragg reflectors built in a short time on optical fiber can reflect specific wavelengths of light and send those wavelengths of light in other directions. Bragg Lattice Fibers have strong dispersion

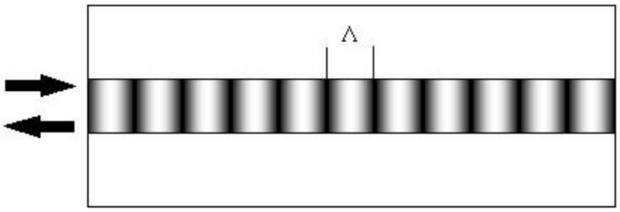

FIGURE 1. Schematic illustration of fiber lattice. Dark and light show periodic variations of the refractive index.

in both reflection and transmission [12]. Bragg's non-linearity with low reflectivity makes it possible to obtain compressed pulses with very low layer intensities [13].

A general theory has been developed to describe a mathematical model for the periodic structure, taking into account non-linear effects. Lattice diffraction states when the angle of incidence of light is θ_i with a reflection angle of θ_r so [11]:

$$\sin\theta_i - \sin\theta_r = m\lambda, \tag{1}$$

where m is the lattice period and λ is the wavelength of light in the medium, r is the average refractive index, and m is the Bragg diffraction order. This can be a phase-matching condition similar to the Brillouin scattering case.

$$\kappa_i - \kappa_d = m\kappa_g, \tag{2}$$

where κ_i and κ_d are incident and reflected light wave vectors. Meanwhile, κ_g is a lattice wave vector with magnitude $2\pi = \Lambda$ and is related to the refractive index of the medium, which changes periodically, as shown in Fig. 1. With the fiber lattice acting as a reflector for specific wavelengths.

The angles in Eq. (1) $\theta_i = \pi/2$ and $\theta_d = -\pi/2$. If $m = 1$, the lattice period is related to the vacuum wavelength as = 2, this is the Bragg condition [11].

Non-linear effects can be accounted for by solving the following non-linear pairwise mode equations:

$$\frac{\partial A_f}{\partial_2} + \beta_1 \frac{\partial A_f}{\partial t} + \frac{i\beta_2}{2}\frac{\partial^2 A_f}{\partial t^2} = m, \tag{3}$$

$$\frac{\partial A_b}{\partial_2} + \beta_1 \frac{\partial A_b}{\partial t} + \frac{i\beta_2}{2}\frac{\partial^2 A_b}{\partial t^2} = n, \tag{4}$$

when,

$$m = i\delta A_f + ikA_b + i\gamma(|A_f|^2 + 2|A_b|^2)A_f, \tag{5}$$

$$n = i\delta A_f + ikA_b + i\gamma(|A_f|^2 + 2|A_b|^2)A_f. \tag{6}$$

In certain cases, β_2 can be neglected in Eqs. (3) and (4) for practical purposes. For a typical lattice length $(< 1m)$, setting $\alpha = 0$. So the non-linear pairwise mode equation becomes:

$$i\frac{\partial A_f}{\partial z} + \frac{i}{v_g}\frac{\partial A_f}{\partial t} + \partial A_f + kA_b + \gamma(|A_f|^2 + 2|A_b|^2)A_f = 0, \tag{7}$$

$$-i\frac{\partial A_b}{\partial z} + \frac{i}{v_g}\frac{\partial A_b}{\partial t} + \partial A_b + kA_f + \gamma(|A_b|^2 + 2|A_f|^2)A_b = 0, \tag{8}$$

where V_g is the group velocity, δ is the detuning factor, and k is the coupling coefficient which is the cause of the dispersion effect. The solution to Eqs. (7) and (8) within the continuous wave (CW) limit of time-derived terms can be neglected, and the solution becomes:

$$A_f = u_f \exp(iqz), \qquad A_b = u_b \exp(iqz), \tag{9}$$

where u_f and u_b are constant along the lattice, by entering the parameter $f = u_b/u_f$, it is clear that the total power $P_0 = u_f^2 + u_b^2$ is divided between the waves propagating forward and those propagating backward. For u_b and u_f can be written:

$$u_f = \sqrt{\frac{P_0}{1+f^2}},$$

$$u_b = \sqrt{\frac{P_0}{1+f^2}}f. \tag{10}$$

From Eqs. (7)-(10), both q and depend on f and are produced by:

$$q = -\frac{k(1-f^2)}{sf} - \frac{\gamma P_0}{2}\frac{1-f^2}{1+f^2},$$

$$\delta = -\frac{k(1+f^2)}{sf} - \frac{3\gamma P_0}{2}. \tag{11}$$

Using a spreadsheet, we will see the relationship between q and δ . There are two types of effects, namely linear and non-linear. If $\delta = 0$ is in Eq. (11) above, there will be a linear effect. Meanwhile, the non-linear effect $\gamma P_0/k$ has a particular value. For the linear case, Eq. (9) becomes:

$$q = -\frac{k(1-f^2)}{sf}, \qquad \delta = -\frac{k(1+f^2)}{sf}. \tag{12}$$

The value of f can be positive or negative. For $|f| > 1$ dominating wave retreat.

3. Research method

This paper uses a spreadsheet to visualize the relationship between q and δ in non-linear and linear dispersion. In the spreadsheet, the researcher creates one row as the input value for δ. For example, from -13.2 to 13.2. Then, the researcher calculate q and δ for the non-linear case according to Eq. (11). As for the linear case, the researcher use Eq. (12).

The formula used to visualize the relationship q with δ in the spreadsheet is given in Table I. Figure 2 shows the spreadsheet window used.

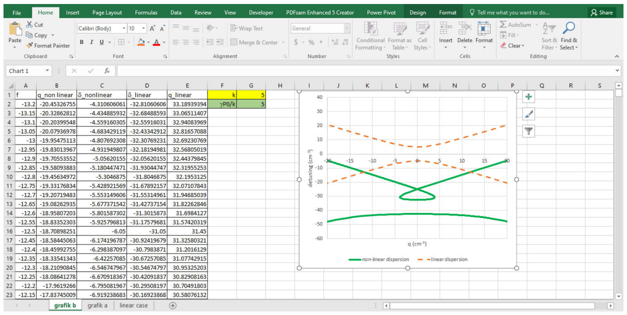

FIGURE 2. Spreadsheet view.

Cell	Variable	Formula
A	f	Input range (-13.2, 13.2), interval 0.05
G1	κ	5
G2	γP_0	2 atau 5
B	q (Non linier)	=-G1*(1-A2^2)/(2*A2)-G2*G1/2*(1-A2^2)/(1+A2^2)
C	δ (Non linier)	=-G1*(1+A2^2)/(2*A2)-3/2*G2*G1
D	q (linier)	=-G1*(1-A2^2)/(2*A2)
E	δ (linier)	=-G1*(1+A2^2)/(2*A2)

FIGURE 3. Table of formulas used in spreadsheets.

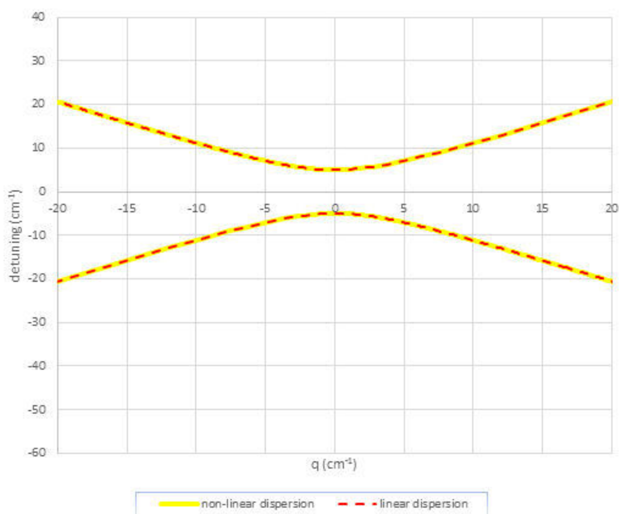

FIGURE 4. The non-linear dispersion curve shows the variation of δ with respect to $\gamma P_0/\kappa = 0$ (yellow curve). The yellow curve shows the relationship for the linear $(\gamma = 0)$ case.

4. Result and disscussion

To understand the physical meaning of Eq. (11), consider the low-power case so that non-linear effects can be neglected. By setting $\gamma = 0 = 0$ in the Eq. (11) to show $q^2 = \delta^2 - \kappa^2$. The results of the visualization of the relationship of q and δ on non-linear and linear dispersion are in Figs. 2-8.

Figures 3-9 explains the relationship of δ to q dispersion from linear to non-linear, the process from linear turns into

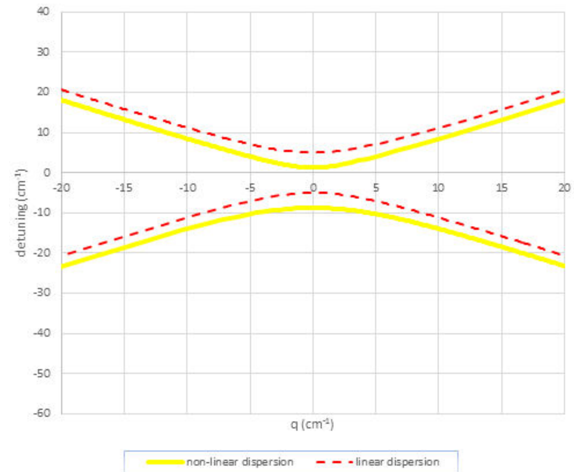

FIGURE 5. The non-linear dispersion curve shows the variation of δ with respect to q for $\gamma P_0/\kappa = 0,5$ (red curve). The red curve shows the relationship for the linear y case.

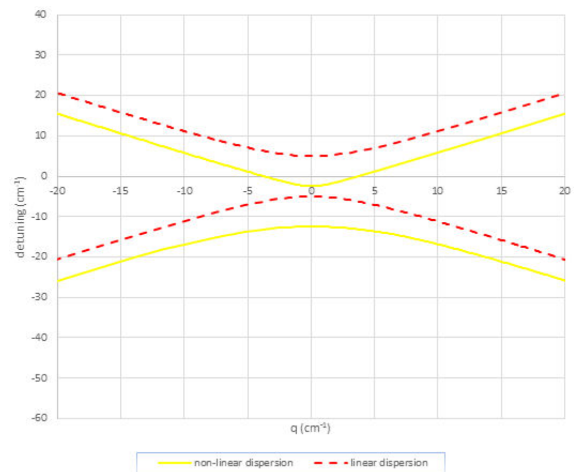

FIGURE 6. The non-linear dispersion curve shows the variation of δ with respect to q for $\gamma P_0/\kappa = 1$ (yellow curve). The red curve shows the relationship for the linear $(\gamma = 0)$ case.

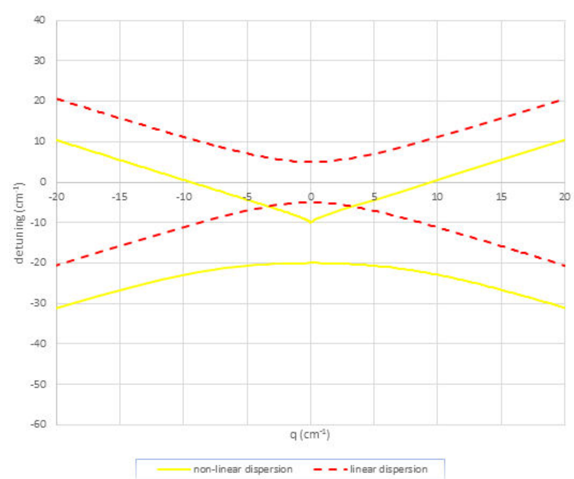

FIGURE 7. The non-linear dispersion curve shows the variation of δ againt to q for $\gamma P_0/\kappa = 2$ (yellow). The yellow curve shows the red for the linear $(\gamma = 0)$ case.

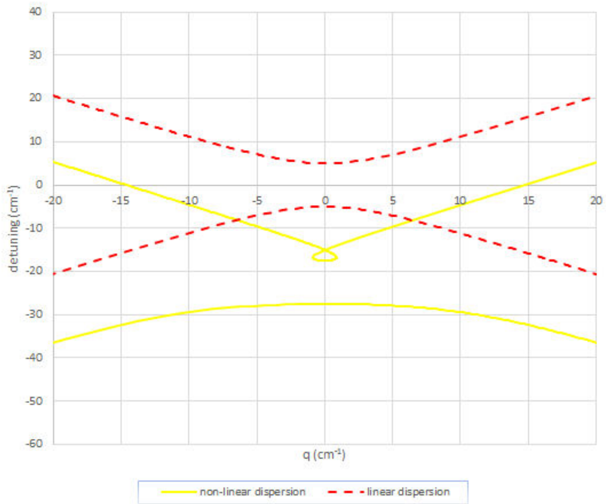

FIGURE 8. The non-linear dispersion curve shows the variation of δ to q for $\gamma P_0/\kappa = 3$ (yellow curve). The yellow curve shows the red for the linear $(\gamma = 0)$ case.

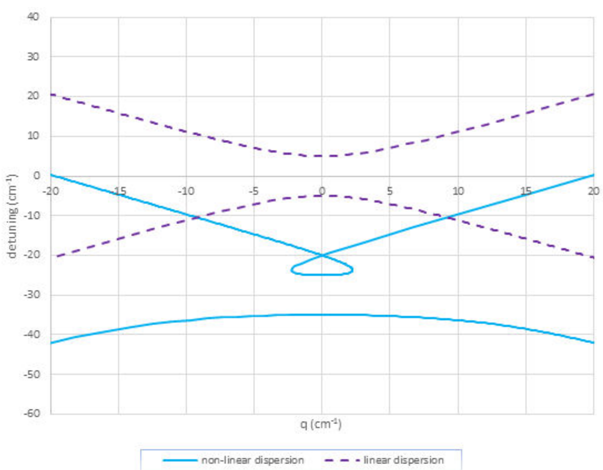

FIGURE 9. The non-linear dispersion curve shows the variation of δ concerning q for $\gamma P_0/\kappa = 4$ (yellow curve). The blue curve shows the red for the linear $(\gamma = 0)$ case.

linear. It can be seen from Figs. 3-5 where there is no difference in non-linear changes, for example, in Fig. 2 where $\gamma P_0/\kappa$ becomes 0 (zero) so that the non-linear graph is the same as the linear graph. When y is replaced by 0.5, the graph of the non-linear process goes down. When $\gamma P_0/\kappa$ becomes 1, the graph is beyond its shift; the critical value of P_0 can be determined by calculating the value of f where q is set to zero while $f \neq 1$ [11]. This is because $\gamma P_0/\kappa$ is more extensive, and the graph shift is more significant.

The non-linear process occurs when $(\gamma P_0/\kappa) > 1$; this can be seen in Figs. 6 - 8, where non-linear dispersion shifts play a more significant role. Figures 8 and 9 for $(\gamma P_0/\kappa) = 4$ and $(\gamma P_0/\kappa) - 4$ with negative values indicate the position

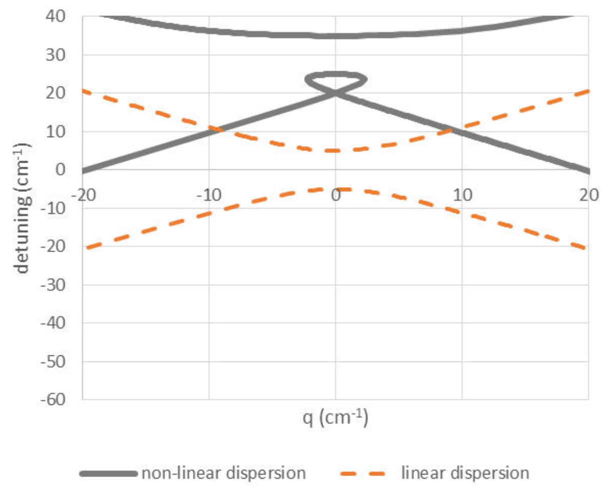

FIGURE 10. The non-linear dispersion curve shows the variation of δ to q for $\gamma P_0/\kappa = -4$ (gray curve). The orange curve shows the relationship for the linear $(\gamma = 0)$ case.

of the wave propagating backward [11]. Non-linear effects cause signal shrinkage and cause large dispersion [14] in fiber optics, therefore, a way is needed to minimize these effects.

Non-linear and linear dispersion simulations using simple spreadsheets can be carried out in class when studying optical material on the topic of wave propagation. By starting to derive mathematical equations from the teacher, then continuing the simulation to visualize with a spreadsheet based on the equations obtained. Simulation can bridge the gap between theoretical and experimental modelling. Students and teachers can experiment with fiber optic modes in the laboratory and then compare their observations with theoretical modelling-based simulations. Experiments can be replaced with video demonstrations when dealing with distance learning, especially during a pandemic. Video demonstrations of fiber optic mode are available for free on several websites, such as MIT `OpenCourseWare` [15] or `Wolfram Mathematics` can also be used to build the visualization. Simulation can help students and teachers interpret mathematical equations and understand physics concepts using spreadsheets because many teachers and students already know and understand them and act as an intermediary for modelling and experimenting by simulating them.

5. Conclusion

This article shows that offices or the financial sector often use spreadsheet software applications but can be used in advanced physics classes. Build spreadsheet-assisted physics simulations to visualize linear and nonlinear dispersion effects, and can assist teachers in conducting online learning as a substitute for experiment results.

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