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Determination of the characteristic frequency of two–level system in the modulated optical field

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Introduction

Interaction between a two-level system and strong nonmonochromatic electromagnetic field has been the focus of attention of the laser technique and fiber optics for a long time. The influence of the modulated optical signal on the active medium, when the amplitude and phase (or frequency) vary arbitrary in time, is important in many problems, such as interaction of ultrashort pulses with the resonant amplifier, change of the line shape, the emission perturbation theory, self-focusing of light etc. [1].

The two-level approach is especially useful in the photoemission technology. The shorter the wavelength the greater the energy of quantum system, so that photoemission is most easily produced by ultraviolet radiation; with the development of special surfaces, photoemission can be generated by radiant power throughout the visible and even infrared region. It is possible to determine the most effective modulation depth for light-beam control applications, by combining this data with radiated laser characteristics. When light beams are objectionable, or secrecy is required, use may be made of the infrared region.

In this article, a new computational procedure is proposed for a two-level system in the strong harmonically modulated optical field.

Subject and Methods

A behaviour of a resonant medium in the modulated optical field may be described by the help of Bloch equations

$$\dot{P} = EN + \Delta\omega Q, \tag{1}$$

$$\dot{N} = -EP, \tag{2}$$

$$\dot{Q} = -\Delta\omega P,\ \Delta\omega = \omega - \omega_0 . \tag{3}$$

where N is the density of active atoms, P, Q – real and imaginary parts of polarization, ω - optical frequency of the field E, ω_0 – resonant frequency of the medium. The dipole moment of the transition d_0 and Planck's constant h are assumed to be equal to unity so that Rabbi's frequency $d_0 E/h$ coincides with E .

In the case of AM modulation

$$E = E_0 + E_1 \cos\Omega t,\quad \Omega\langle\langle\omega. \tag{4}$$

If $\Delta\omega = 0$ the system of Eq. (1)-(3) may be solved exactly. For $\Delta\omega \neq 0$ only various numerical methods are in use. Therefore from the methodical and practical points of view the cases when Bloch equations may be solved analytically are of considerable importance.

From Eq. (1)-(3) we have

$$\dot{P} = (E_0 + E_1 \cos\Omega t)N - \Delta\omega^2 \int P dt, \tag{5}$$

$$\dot{N} = -(E_0 + E_1 \cos\Omega t)P, \tag{6}$$

or in a dimensionless form

$$\left(t \to \Omega t,\ m \to \frac{E_0}{\Omega},\ 2q \to \frac{E_1}{\Omega},\ \alpha \to \frac{\Delta\omega}{\Omega}\right)$$

$$\dot{P} = (m + 2q\cos t)N - \alpha^2 \int P dt\ , \tag{7}$$

$$\dot{N} = -(m + 2q\cos t)P\ . \tag{8}$$

Results

The solutions for P and N were sought in the form

$$P = \exp i\beta t \sum_{n=-\infty}^{\infty} a_n \exp int \ , \qquad (9)$$

$$N = i \exp i\beta t \sum_{n=-\infty}^{\infty} b_n \exp int \ . \qquad (10)$$

In order to determine the expansion coefficients a_n and b_n, we must substitute the series into Eq. (7), (8) and compare the expressions for the same exponents. In this way the set of recurrent equations for the coefficients an and *bn* was obtained

$$\left(\beta + n\Omega - \frac{\alpha^2}{\beta + n\Omega}\right) a_n = q(b_{n-1} + b_{n+1}) + mb_n , \qquad (11)$$

$$(\beta + n\Omega) b_n = q(a_{n-1} + a_{n+1}) + ma_n . \qquad (12)$$

The condition

$$0 \le \beta \le 1 \qquad (13)$$

may be always realized by the change of summation index *n*.

$$|D| = 0. \qquad (14)$$

The determinant *D* is written explicitly in Table 1.

Table 1. System determinant *D*

..b_{-3}	a_{-2}	b_{-2}	a_{-1}	b_{-1}	a_0	b_0	a_1	b_1	a_2	b_2	a_3...
…											
q	$(\beta-2)-\frac{\alpha^2}{(\beta-2)}$	m		q							
	m	$(\beta-2)$	q								
		q	$(\beta-1)-\frac{\alpha^2}{(\beta-1)}$	m		q					
	q		m	$(\beta-1)$	q						
				q	$\beta-\frac{\alpha^2}{\beta}$	m		q			
			q		m	β	q				
						q	$(\beta+1)-\frac{\alpha^2}{(\beta+1)}$	m		q	
					q		m	$(\beta+1)$	q		
								q	$(\beta+2)-\frac{\alpha^2}{(\beta+2)}$	m	
							q		m	$(\beta+2)$	q
											…

The zeros of this determinant were sought for various real values of the parameters *m*, *q*, and α, and from this the corresponding real characteristic frequency β was determined.

For example, in Fig.1 – Fig.6 the curves with β = const are given on the α -*q* plane for *m*=0 and *m*=1 respectively.

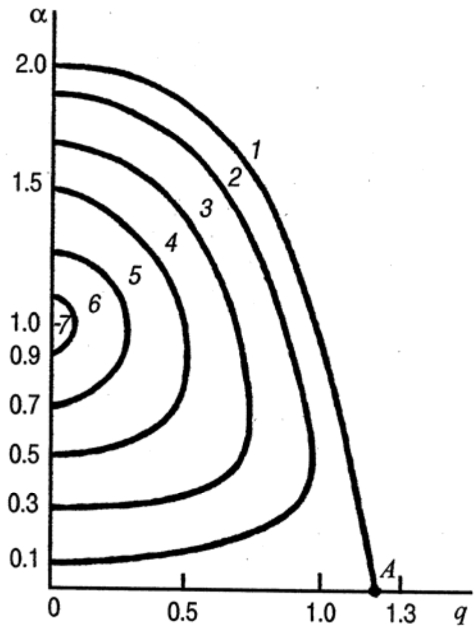

Fig. 1. The dependence of detuning α = Δω/ Ω upon the modulation depth 2q = E_1 / Ω at the constant characteristic frequency β : (1) 0.0, (2) ± 0.1, (3) ± 0.3,

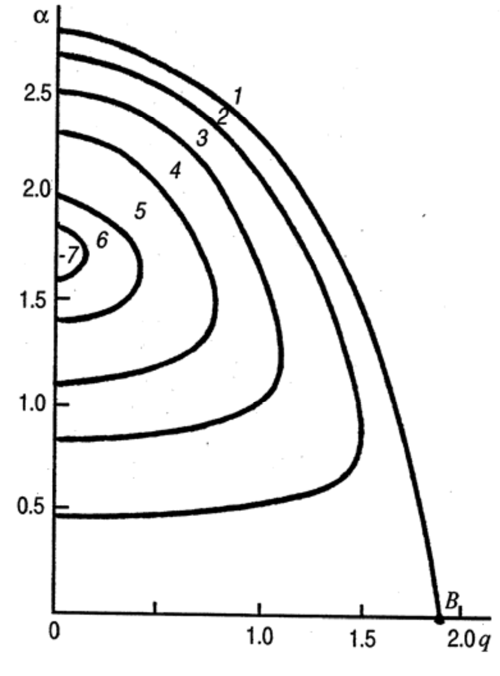

Fig. 2. The dependence of detuning α = Δω/Ω upon the modulation depth 2q = E_1 / Ω at the constant characteristic frequency β : (1) 0.0, (2) ± 0.1, (3) ± 0.3, (4) ± 0.5, (5) ± 0.7, (6) ± 0.9, and (7) ±1.0. Intensity of the carrier wave is $m = E_0 /\Omega = 1$ (4) ± 0.5, (5) ± 0.7, (6) ± 0.9, and (7) ±1.0

When β is determined coefficients a_n and b_n may be calculated by the help of recurrent equations (11), (12) taking into account that for $n > 7a$

$$a_n \approx b_n \approx J_n(2q),$$

where $J_n(2q)$ are n^{th} order Bessel functions of the kind. (Points A and B in Fig.1, 2 are the first zeros of $J_0(2q)$ and $J_1(2q)$ respectively).

In the case of FM modulation

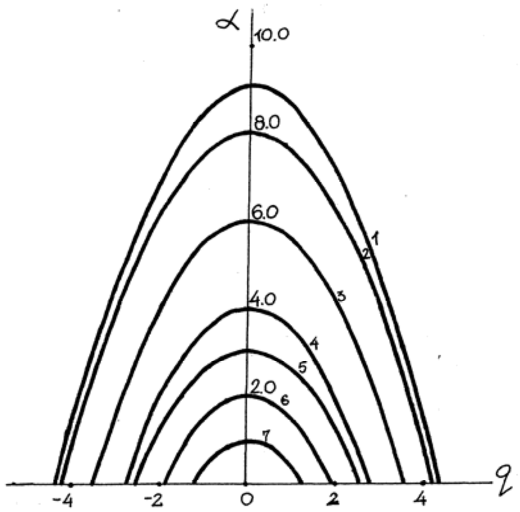

Fig. 3. The dependence of detuning $\alpha = \Delta\omega/\Omega$ upon the modulation depth $2q = E_1/\Omega$ at the various intensities of the carrier wave $m = E_0/\Omega$: 1 – 1.0; 2 – 2.0; 3 – 3.0; 4 – 4.0; 5 – 5.0; 6 – 6.0; 7 – 7.0

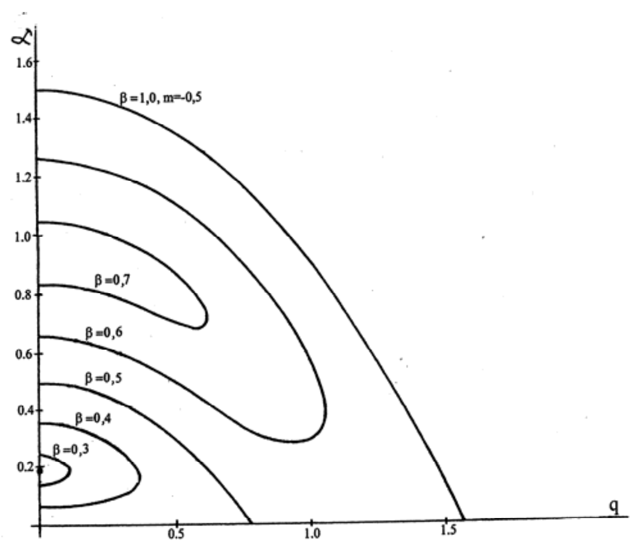

Fig. 4. The dependence of detuning $\alpha = \Delta\omega/\Omega$ upon the modulation depth $2q = E_1/\Omega$ at the constant characteristic frequencies β. Intensity of the carrier wave is $m = E_0/\Omega = -0.5$.

$$\Delta\omega = \Delta\omega_0 + \omega' \cos \Omega t , \quad (15)$$

$$E = E_0 . \quad (16)$$

Eq.(1)-(3) may by written then as follows

$$\dot{P} = (\Delta\omega_0 + \omega' \cos \Omega t)Q - E_0^2 \int P dt , \quad (17)$$

$$\dot{Q} = -(\Delta\omega_0 + \omega' \cos \Omega t)P . \quad (18)$$

Eq.(17), (18) are equivalent [2, 3] to Eq.(5), (6), and aforementioned calculations may be applied to the FM as well as to the AM modulated fields.

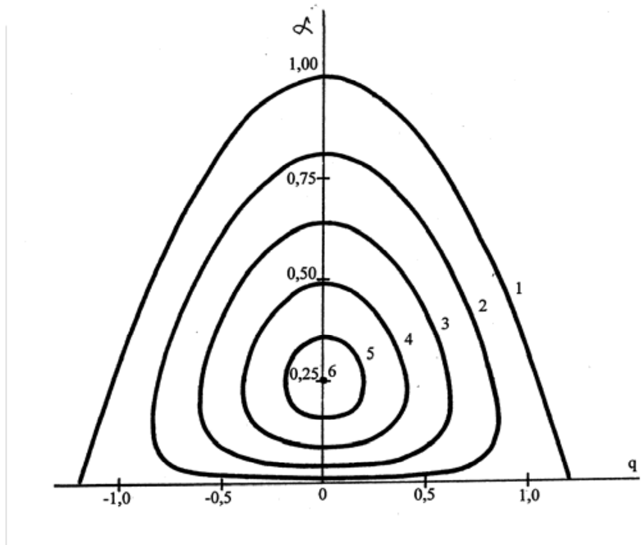

Fig. 5. The dependence of detuning $\alpha = \Delta\omega/\Omega$ upon the modulation depth $2q = E_1/\Omega$ at the constant characteristic frequencies β: 1 – 0.1; 2 – 0.3; 3 – 0.4; 4 – 0.7; 5 – 0.9; 6 – 1.0

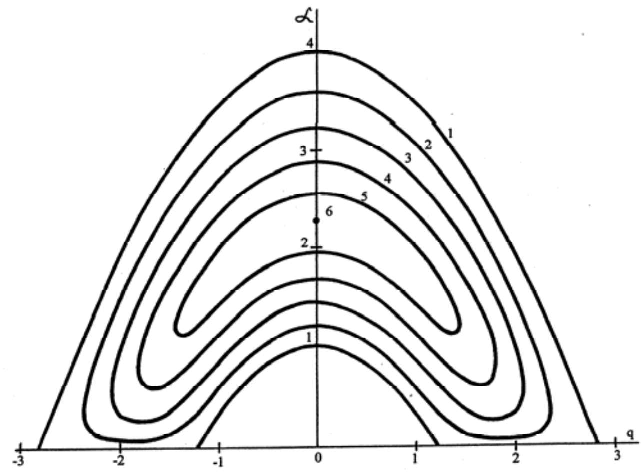

Fig. 6. The dependence of detuning $\alpha = \Delta\omega/\Omega$ upon the modulation depth $2q = E_1/\Omega$ at the constant characteristic frequencies β: 1 – 0.0; 2 – ±0.1; 3 – ±0.2; 4 – ±0.3; 5 – ±0.4; 6 – ±0.6

Conclusions

In the modulated optical field the direct determination of the characteristic frequency β (an analog of the Rabbi frequency) are practically impossible. The set of special nomograms allow to use the numerical procedure, which depends upon amplitudes of modulation, detuning and modulation frequency. The set of nomograms may be employed in the case of both amplitude and frequency modulation.

Space exploration has intensified the need for precise knowledge of the radiated power outside the earth's atmosphere; since satellites are subjected to this radiated power on the side facing the sun, in an environment, which, excepting for reflections of this power from the earth, or other planets, corresponds almost to perfect darkness. As the whole satellite is virtually in a vacuum, it attains temperature stability only by re-radiating power into space. It is obviously desirable to check the many calculations which are made to predict such conditions, by submitting the unit to simulated solar radiation in evacuated low temperature test chambers, on earth. Since light has to be beamed towards the satellite, high-brightness lasers of great power in accurate optical systems are needed. Suitable radiation has been provided by the use of high power carbon laser or compact xenon laser, which may have some of the extensive near infrared radiation filtered.

For studies of photochemical deterioration, much more attention has to be paid to the detailed spectral power distribution of the visible and ultraviolet regions. The close approximation of xenon laser radiation to sunlight, in the ultraviolet and visible regions makes them particularly effective for such studies. Their constancy and the nonconsumable nature of their electrodes, makes them convenient for thermal tests.

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Z. Jankauskas, V. Kvedaras, V.Zaveckas. Determination of the Ccharacteristic Frequency of Two–Level System in the Modulated Optical Field // Electronics and Elektrical Engineering. – Kaunas: Technologija, 2006. – No. 3(67). – P. 61–64.

Interaction between a two-level system and strong nonmonochromatic electromagnetic field has been the focus of attention of the laser technique and fiber optics for a long time. The influence of the modulated optical signal on the active medium, when the amplitude and phase (or frequency) vary arbitrary in time, is important in many problems, such as interaction of ultrashort pulses with the resonant amplifier, change of the line shape, the emission perturbation theory, self-focusing of light, etc.

In this article, a new computational procedure is proposed for a two-level system in the strong harmonically modulated optical field. Expressions for polarization and population difference of a quantum system have been obtained in the form of the Fourier series. The characteristic frequency has been determined numerically. It depends not only upon the intensity of the carrier wave and the detuning magnitude but also upon the depth and frequency of modulation. The computational technique is applicable both for amplitude and phase modulation. Ill. 6, bibl. 3 (in English; summaries in English, Russian and Lithuanian).

З. Янкаускас, В. Квядарас, В. Завяцкас. Определение характеристической частоты двухуровневой системы в модулированном оптическом поле // Электроника и электротехника. – Каунас: Технология, 2006. – № 3(67). – С. 61–64.

Взаимодействие двухуровневой системы с сильным немонохроматическим электромагнитным полем давно находится в центре внимания лазерной техники и волоконной оптики. Влияние модулированного оптического сигнала на активную среду, когда амплитуда и фаза (или частота) произвольно меняются во времени, актуально для многих задач, таких как взаимодействие сверхкоротких импульсов с нелинейным резонансным поглотителем или усилителем в лазерах, изменение формы линии в поле мощного спонтанного излучения, самовоздействие и самофокусировка света и др.

Предложена новая расчетная методика двухуровневой системы в сильном гармонически модулированном оптическом поле. В виде рядов Фурье получены выражения для поляризации и разности населенности. Ил. 6, библ. 3 (на ангийском языке; рефераты на английском русском и литовском яз.)

Z. Jankauskas, V. Kvedaras, V.Zaveckas. Dviejų lygmenų sistemos būdingojo dažnio nustatymas moduliuotame optiniame lauke // Elektronika ir elektrotechnika.– Kaunas: Technologija, 2006. – Nr. 3(67). – P. 61–64.

Dviejų lygmenų sistemos sąveika stipriu moduliuotu elektromagnetiniu lauku jau seniai yra pluoštinės optikos ir lazerinės technikos dėmesio centre. Moduliuoto optinio signalo poveikis dviejų lygmenų sistemai, kai amplitudė ir dažnis nėra pastovūs, aktualus nagrinėjant daugelį uždavinių, pavyzdžiui, trumpųjų šviesos impulsų sąveiką su netiesine rezonansine sistema lazeriuose, linijos formos pokyčius savaiminės spinduliuotės lauke, šviesos pluošto savaiminį fokusavimą, šuolių relaksacinių dydžių matavimą ir kt. Dažniausiai tokios rūšies uždaviniai nėra analiziškai tiksliai išspręsti.

Šiame straipsnyje kvantinė rezonansinė sistema aprašyta Bloch'o lygtimis. Poliarizacijos ir aktyviųjų atomų koncentracijos išraiškų ieškota Fourier eilučių pavidalu. Išvestos Fourier harmonikų rekurentinės lygtys. Sistemos būdingasis dažnis priklauso nuo moduliacijos dažnio ir intensyvumo. Skaitinės būdingojo dažnio vertės randamos prilyginant nuliui algebrinių lygčių determinantą. Pateiktoji skaičiavimo metodika gali būti naudojama ir amplitudinės, ir dažninės moduliacijos atvejais. Il. 6, bibl. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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