

If superposed light beams do not re-distribute each others energy in the absence of detectors (material dipoles), can an indivisible single photon interfere by/with itself ?

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Abstract

The intention of this paper is to underscore that to understand fundamentally new properties of light beams, we must first find the limits of semi classical model to explain optical interference phenomena. We claim that we have not yet reached that limit. Careful analysis of the processes behind detecting fringes indicate that the effect of superposition of multiple optical beams can become manifest only through the mediation of the detecting dipoles. Since the detectors are quantum mechanical, (i) the observed effects are different for different detectors for the same superposed light beams, and further, (ii) they are only capable of registering discrete number of “clicks”, whose rate will vary with the incident intensity. A reduced rate of “clicks” at very low intensity does not prove that light consists of indivisible packets of energy. We have also experimentally demonstrated that (i) neither Fourier synthesis, nor, (ii) Fourier decomposition actually model the behavior of EM fields under all possible circumstances. Superposed light beams of different frequencies do not *synthesize* a new average optical frequency. A pure amplitude modulated pulse does not contain any of the mathematical, Fourier analyzed frequencies. The QED definition of photon being a Fourier mode in the vacuum, it necessarily becomes non-local. Since we have demonstrated that the Fourier theorem has various limitations in classical physics, its indiscriminate use in quantum mechanics should also be critically reviewed.

Key words: single photon interference; semi classical approach to interference; limitations of Fourier theorem; non-interference of light beams.

1. Introduction

It is not possible to provide a conclusive answer to a rather controversial question raised by the title of this paper. Our approach would be to highlight the conceptual continuity and differences between the use of the Principle of Superposition (PS) in classical and the quantum physics while carefully looking at the detection processes behind recording of optical interference phenomenon. The apparent conceptual break down occurs when one attempts to visualize “single photon interference” while reducing the intensity from classically comfortable values to arbitrarily low value. We will make an attempt to make the enquiring minds aware that in spite of staggering successes of both the classical and the quantum optics, the true nature of light still may not yet be completely revealed to us [1], because we “see” light only through the “eyes” of the detectors.

Our starting assumption is that the universe is one continuum and the nature is undergoing incessant, creative and causal evolution from micron-size single living cells to the inanimate galaxies spanning over many light-years based on the same set of laws of forces. Such a universe cannot be artificially divided into classical and quantum worlds. The apparent division is a reflection of our current limitation in our ability to create a unified mathematical formulation supported by visualizable model (paradigm) for the actual, causal and local processes (all forces exert influence over a finite range). The Principle of Superposition (PS) is the strongest operational principle that is common for both the Classical and the Quantum Physics. Interestingly, PS has been formulated, developed and validated in Classical Physics before the birth of Quantum Physics. Yet, unlike for Classical Physics, the PS is not only an essential driving force behind the entire Quantum Physics, but it also has a very different interpretation, almost to the level of mysticism, as

can be appreciated from the prevailing interpretations like, non-locality, non-causality, delayed choice, many-worlds, teleportation, etc., to interpret interference and diffraction fringes at very low light levels and particle flux levels.

Our long-term goal is to revisit the detailed detection processes behind the basic but the simplest classical and quantum measurement experiments. All phenomena evolve through superposition of two or more, similar or different real entities of nature (and their force fields) followed by energy exchange and some transformation. The measured (observed) transformations are the reports given to us by one or more of these entities which are “colored” by their own uniquely different characteristics of interactions. And, none of these entities are known to us completely. So, we are always challenged to continuously develop and extend conceptual continuities between the various classical and quantum phenomena. Fortunately, the PS provides the commonality between all interactions, although not all transformational energy exchanges are quantized, or requires initiation through the intrinsic amplitude of undulation of the entities concerned. In this paper, we will remain focused on the measurements of the effects of superposition of light beams since this provides the most important bridge between the classical and quantum PS. The classical world assumes light consists of spreading wave packets emitted by atoms and molecules that can shape and re-shape themselves as they propagate and evolve through diffraction and interference. While the quantum world assumes the photons to be discrete, independent, indivisible packets of energy those propagate as modes of the vacuum (cosmic medium). Thus we have a “clash of cultures” when the total intensity (flow of EM energy per unit time per unit area) in the interfering or diffracting beams is reduced equivalent to a single “click” in the detector at any particular moment. We can safely assume that both the cultures accept that when a single atom or a molecule undergoes a single de-excitation (transition), it emits a photon, a packet of EM energy given by $\Delta E = h\nu$. In classical physics, it is a space and time finite wave packet that evolves and propagates following Huygens-Fresnel principle validated by classical theory of diffraction, including van Cittert-Zernike theorem that correctly models the enhancement of spatial coherence by diffraction (propagation) of light from non-laser sources [2]. The wave packet has a precise carrier frequency ν , which was heuristically prescribed by Planck’s radiation law and later more systematically by quantum mechanics. However, in general, QED claims this wave packet to be simultaneously an indivisible packet of energy and a Fourier frequency mode of oscillation of the vacuum medium [1, 3-5] and hence it can behave both as a local and a non-local entity depending upon the design of the experiments [6]. However, there is some form of tacit commonality between the classical and quantum worlds’ assumptions as to how the energy is redistributed in the plane of recording of the interference or diffraction fringes. In classical physics, the tacit assumption is that the local field energy is redistributed due to the superposition of the fields themselves. In quantum mechanics, the explicit assumption is that the probability of the rate of arrival of the indivisible photons on the detector locations is dictated by the superposition equation determined by the entire instrument, inherently accepting interpretations like non-locality, delayed choice, etc. Both approaches have remained focused on interpreting the final mathematically predicted results, validated by the measurements, but ignoring the need to explore the actual processes (the real physics) behind detecting the EM energy. Our objective is to establish the fact that all measurements indicate that light beams, containing conveniently measurable energy, simply do not interfere by themselves to create fringes in the absence of detectors. Thus the various claims of single photon interference are fundamentally in doubt. However, the absorption of energy in the presence of EM fields in steps of discrete packets, $\Delta E (= h\nu)$, by any and all detectors, which are necessarily quantum mechanical, is not in question at all.

Publications in the mainstream literature [6 & references there] clearly imply that the issue of single photon interference is resolved, just as the definition of a photon is resolved. Let us first acknowledge that we never “see” light. What we observe or measure is what some transformation is experienced by a detector in the presence of light, which always constitute some quantum mechanical (QM) dipole (single or aggregate) in some form or another. In photo emissive devices, electrons are bound quantum mechanically and the released electrons are quantized particles and can never be fractional. In photo conducting devices, again discrete electrons are stimulated from the valence to the conduction band, which generate photo current under imposed potential difference. In photographic plates, the silver halide molecules in microscopic crystals, which are again quantum mechanical devices, are broken up and follow on chemical processing establishes silver atoms as discrete black spots. Thus, in the final analyses, any and all photo detection, whether at very low or at very high intensity, will always appear as summation of many discrete events, only the rate will be different. Such discreteness only validates that our model of atoms and molecules as

quantum mechanical devices is correct. This does not un-ambiguously validate the existence of EM field packets emitted by atoms as indivisible particle-like. The quantum condition of energy absorption $\Delta E = h\nu$ only dictates that ΔE amount of energy can be absorbed from any and all locally available E-fields undulating (and stimulating the detecting dipole) at the desired frequency ν . Further, different quantum detectors have different quantum properties with vary narrow or very broad frequency band passes of different central frequencies as in (i) fixed energy gaps defined by sharp energy levels for atoms in gaseous states, (ii) fixed but broad energy bands for photo conducting solid state detectors, or (iii) a fixed binding energy with allowed continuum as in photo induced ionizations, or molecular dissociations. This is why our retinal molecules or a silicon detector will report being in “dark” even when illuminated by γ -ray, x-ray or UV-photons, while suffering some damages. We claim that whether light exists only as indivisible and non-local states is not conclusively resolved by discrete “clicks” or “spots” that we observe at low light levels. We should be careful in separating the inherent properties of light from those of the detectors. We will also discuss the necessity of employing critical review in using the ever present Fourier theorem in optics underscoring pitfalls, as well as successes.

2. Does light really interfere with light as implied by Fourier Theorem & Maxwell’s wave equation?

Maxwell’s free space wave equation is given by:

$$\nabla^2 \vec{E} = (1/c^2) \partial^2 \vec{E} / \partial t^2 \quad (1)$$

A simple CW solution, neglecting the arbitrary phase factor, is $\exp[-i2\pi\nu t]$. Mathematically, any linear combination of this solution $\sum_n b_n \exp[-i2\pi\nu_n t]$ will also satisfy Maxwell’s wave equation. Well before Maxwell, Fourier established a very useful theorem for handling a time finite signal by its transform in the frequency space using the well-known integral,

$$a(t) = \int \tilde{a}(f) \exp[-i2\pi ft] df \quad (2)$$

Notice the similarity between the summation (integral) between the Fourier theorem and the acceptability by the Maxwell’s wave equation of the linear combination of its simple solutions. This congruency, as if, strengthens and validates the reality of the superposition of EM waves. Unfortunately, in the absence of any material medium and specifically, in the absence of detectors, well formed light beams pass through each other completely unperturbed. A well formed light beam can be defined as when the local diffraction effect is negligible. This is true when the spatial variation of the amplitude and phase on its wave front is much slower than the characteristic dimension of its wavelength. Such slowly diffracting light beams do not operate on each other to redistribute each others energy and/or frequencies, even when they physically cross through each other. But insertion of proper detector within the physical domain of superposition will record fringes as we do for holography and other interferometry. The bright and dark fringes represent the locations where the resultant electric vectors are in phase or out of phase. A dark fringe indicates that the detecting dipole cannot be stimulated to absorb energy from the fields as it is locally zero; it is not due to non-arrival of photons. If well formed light beams were to perturb each others energy distributions then, with light pouring in from trillions of stars from every directions, (i) the visual universe, instead of appearing steady, would have always been full of glittering speckles in space and time; (ii) the instrumental spectroscopy could not have discerned the Doppler shifts of individual star light crossed by trillions of other star light and predict the “expanding universe”. Or, terrestrially speaking, (iii) the wavelength domain multiplexed (WDM) communication, the back bone of our internet revolution, would not have worked; all the useful data would have evolved into random temporal, light beating pulses, and (iv) the Fourier transform spectroscopy would have never worked if light of different frequencies really interfered with each other on slow detector (we always drop the interference cross-terms between different frequencies). The effects of linear superposition of multiple light beams, supported by Fourier theorem and Maxwell’s wave equation, becomes manifest only in the presence of interacting materials (dipoles).

Here we should underscore the difference between the two phenomena of diffraction and “interference” of light beams. In classical optics, light always propagates through diffraction process, given by Huygens-Fresnel (H-F) diffraction integral [2]. It has been successfully predicting all possible propagation of light from the evolution of spatial coherence from distant star light, to the formation of simple or complex cavity modes in lasers, and to the evolution of wave fronts in most recent and complex nano photonics wave

guides. The H-F principle is mathematically congruent with Maxwell's wave equation since it accepts superposition of H-F secondary wavelets! Whether emitted by thermal sources or by laser cavities, the atomic and molecular emissions evolve by diffraction toward an angularly sustainable beam with increasing spatial coherence. The near field diffraction clearly indicates spatial re-grouping potential of EM field energies belonging to the same E-vector frequency, which becomes evident as the diffraction pattern evolves into the angularly stable far field pattern.

The confusing issue of diffraction vs, superposition of independent light beams can be further appreciated from the classic double slit "interference pattern", which is routinely used to underscore the "strange wave-particle duality" of "single photon interference". This "interference pattern" has always been studied in the far field where the two superposed single-slit far-field patterns are of the form given by (sinc/x) function. People tend to focus on the periodic cosine fringe pattern produced on a detector due to the superposition of the two "sinc" beams, ignoring the two a-periodic but well formed sinc diffraction patterns, which again evolved from very complex and rapidly changing near field patterns.

3. Do EM fields synthesize new composite fields under simple superposition?

We review [7] here a simple experiments that we have carried out by superposing two CW light beams carrying two distinctly different carrier frequencies separated by 2 GHz, symmetrically centered on one of the Rb-resonance lines. When the superposed beams are sent through an Rb-vapor tube, it did not show any resonance fluorescence, even though by simple trigonometry (according to two terms Fourier synthesis), we were supposed to get the matching resonance frequency (mean of the sum of the two superposed frequencies) [see also Fig.1]:

$$\vec{a}_{total}(t) = \vec{a}_1 \cos 2\pi\nu_1 t + \vec{a}_1 \cos 2\pi\nu_2 t = 2\vec{a}_1 \cos 2\pi \frac{\nu_1 - \nu_2}{2} t \cdot \cos 2\pi \frac{\nu_1 + \nu_2}{2} t \quad (3)$$

This revalidates that light beams do not operate on each other by themselves. However, when we sent this same superposed beam on to a high-speed photo conductor, we found the traditional AC current undulating at the difference (beat) frequency. The valence and the conduction bands of the photo detector are broad. This allows the detecting dipoles to simultaneously respond to all the allowed frequencies (here two), and the resultant current becomes:

$$I(t) = \left| \vec{d}e^{-i2\pi\nu_L t} + \vec{d}e^{-i2\pi\nu_S t} \right|^2 = 2d^2 [1 + \cos 2\pi(\nu_L - \nu_S)t] \quad (4)$$

Here \vec{d} is the dipole undulation vector induced on the detecting dipoles by the \vec{E} -vector (\vec{a}). The detailed detecting process ("picture") in our view is that the undulating electric vector of the EM field induces the material dipoles to undulate with it. If the frequency matches with the quantum mechanically allowed transition frequency, then only there is absorption of energy. For the superposition effects to be manifest, the detecting dipoles must be collectively allowed to respond to all the light beams simultaneously. When the superposed light beams have multiple frequencies, the detecting dipoles must have broad quantum mechanical bands to be able to register the superposition effects [see Fig.1]. If two superposed light beams are of orthogonal polarizations, the detectors cannot register the superposition effects. The dot product of orthogonal vectors is zero, whose "visual image" translation is that the same dipole (or, a collective set) cannot simultaneously carry out two independent and orthogonal undulations at the same instant in the linear regime of stimulation. Basically, the detecting dipoles always respond to the local resultant E-vector. If the E-vectors are orthogonal, then the dipoles respond to one or the other E-vector if they are embedded in isotropic medium. If the dipoles are embedded in a crystalline solid state, then the crystal axes dictate the allowed direction of dipole undulation.

There are important physical processes hidden behind the Eq.4. The final energy transfer during a photo detecting process is correctly given by the square modulus of the *linear superposition* of all possible (quantum mechanically allowed) dipole undulations in *complex representation* as in Eq.4. If we have a simple EM field represented by a real function, $\vec{a} \cos 2\pi\nu t$ the induced dipole undulation can be represented by $\vec{d} \cos 2\pi\nu t$. However, the measured detector current, for optical fields, is proportional to d^2 and not $d^2 \cos^2 2\pi\nu t$. The complex representation hides a short time averaging process that we normally tend to ignore. We are hypothesizing that this hidden time averaging process is physically real. The detecting

dipole is actually undulating under the influence of the E-vector while the mutual quantum compatibility for energy exchange is being ascertained (the availability of necessary amount of energy ΔE , and the right stimulating frequency ν). This point can be further supported from the following arguments. If the two superposed field amplitudes for the above experiment [Fig.1] are represented by real fields as in Eq.3, one gets two unphysical frequencies, mean of the sum and the mean of difference frequencies. We have carried out systematic measurements with very high resolution Fabry-Perot spectrometer in conjunction with very high speed detectors, scopes and electronics spectrum analyzers. We were not able to detect any of these two frequencies. They are not physically observable quantities. The two superposed light beam amplitudes did not interfere to synthesize new light field amplitude represented by the Eq.3. They remained as two non-interacting, independent fields ($\vec{a}_1 \cos 2\pi\nu_1 t; \vec{a}_1 \cos 2\pi\nu_2 t$), albeit being collinearly superposed. The

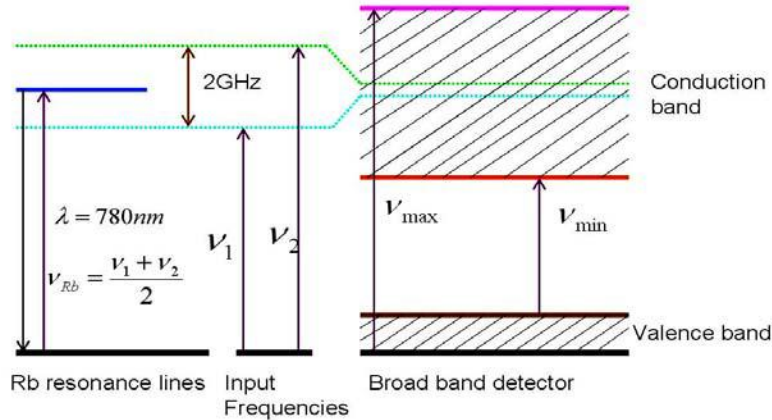


Figure 1. The above diagram compares the energy diagrams of one pair of the Rb-resonance lines, one pair of input frequencies and one pair of valence-conduction band diagrams of a photoconductor. When the input frequencies of the superposed light beams are symmetrically above and below the Rb-excitation line, Rb-dipoles do not experience their presence in the linear domain and fails to respond to the superposed light beams. In contrast, the assembly of the dipole molecules of the photo conductors is quantum mechanically allowed to respond to both the frequencies. As they do so, their amplitude of excitation undulates at the difference frequency (not the mean of the sum; see below), creating an undulatory rate of transfer of discrete number of electrons from the valence to the conduction band [7].

summation sign in Eq.3 does not represent a valid physical operation as these beams do not operate on (interact with) each other. However, in the presence of appropriate detector with broad excitation bands [Fig.1], the dipoles collectively attempt to respond to both the fields. When quantum mechanically allowed, they carry out the quantum compatibility sensing undulations simultaneously with both the fields and effectively sums their superposed effects while exchanging energy from both the fields. The result of Eq.4 can be recovered using the Eq.3 by time averaging the square of the superposed real dipole undulations induced by the two real fields:

$$I(t) = \frac{1}{T} \int_{-T/2}^{T/2} d_{total}^2(t) dt = \frac{d^2}{T} \int_{-T/2}^{T/2} [\cos 2\pi\nu_1 t + \cos 2\pi\nu_2 t]^2 dt \approx d^2 [1 + \cos 2\pi(\nu_1 - \nu_2)t] \quad (5)$$

Thus, (i) the superposition effect to become manifest (measurable), the multiple light beams have to be simultaneously present, both in space and in time, on the microscopic detecting dipoles. Further, (ii) the quantum rules (broad bands) of the detecting dipoles must allow them to simultaneously respond to all the superposed frequencies. And (iii) there is embedded time averaging in the detection step. Explicit recognition of all these detail processes behind detecting “photons” do not support the various mysterious interpretations like delayed choice (superposition), teleportation, etc. The detection process preserves the strict causality.

4. Do Amplitude modulated EM fields contain Fourier analyzed frequencies?

In the last section we demonstrated that the energy of light beams corresponding to different frequencies did not regroup as pulses on their own with a new average frequency. Fourier synthesis did not take place by simple physical superposition of light beams. In this section, we test the inverse process, the Fourier analysis – whether amplitude modulated light beams physically contains Fourier decomposed frequencies.

We tried a variety of high resolution spectrometric experiments, but the beat spectroscopy turned out to be the conceptually simplest [8-11]. We used two 1550 nm communication lasers. One laser had a fixed frequency, a DFB-type with about 20 MHz line width. The second laser was a tunable external cavity type with line width less than 100 KHz. The DFB laser was used both as a CW source and as an amplitude modulated source (by using an external, 10 GHz Mach-Zehnder modulator). The two laser beams were combined on to a very high speed, broad band (30 GHz) detector, connected parallel to a high speed scope and an electronic spectrum analyzer (ESA). The function of ESA is to present the oscillating currents it receives in terms of harmonics. Out of a wide variety of experiments on the basic theme, we are presenting two sets of data in Fig. 2a, b. For both the cases the optical frequencies of the two lasers were detuned from each other by about 15 GHz. For Fig.2a, both the lasers are running CW, and for Fig.2b, one of the lasers, the DFB, is undergoing AM at about 2.5 GHz [pseudo random super Gaussian (almost square) data pulses of width 0.4 ns]. When the two lasers are running CW, the beat spectrum is a narrow line located at 15 GHz as shown in Fig.2a since the detector current is literally a sinusoid at this 15 GHz difference frequency [see Eq.4]. When the DFB laser is amplitude modulated, the corresponding ESA display of the beat signal (Fig.2b) is again very much like that for the CW case. No new E-vector frequencies have been generated by the external AM. But, since the ESA now receives the 15 GHz sinusoid with random duration of 0.4 ns square pulses, it represents these random square pulses of current by its Fourier transformed spectral intensity distribution, which is a sinc^2 function with its first zero at 2.5 GHz.

If the modulation truly generated new Fourier frequencies, the half-width of the beat frequency line would have become 2.5 GHz; instead it has remained almost the same (probably 20 MHz, not discernable in the data presented). Notice that the vertical scale is logarithmic and the half-width point (3dB below the peak) for the beat signal line does not show any measurable change, especially compared to the first zero of the sinc^2 curve at 2.5 GHz. We must conclude that simple amplitude modulation does not generate new optical frequencies. The Fourier frequencies for a square pulse are not present at the optical beat signal location. Thus, the traditionally accepted ‘time frequency bandwidth product’, $\delta\nu\delta t \geq 1$, is not a fundamental limit of nature. We have validated that analytically [12, 13] and experimentally [10, 11]. One can recover the actual width of the carrier frequency content of a light pulse with ultra precision, limited only by the stability and intrinsic width of the CW reference signal. The width of $\delta\nu$ of the beat line in Fig.2b is orders of magnitude narrower than demanded by the Fourier analyzed width, 2.5 GHz. The mathematical representation of the detector current is very similar to Eq.4, but partially complicated by the fact that one of the superposed signals gets turned on and off intermittently; we are considering a single pulse for mathematical simplicity:

$$I(t) = \left| \vec{d}_{cw} e^{-i2\pi\nu_{cw}t} + \vec{d}_p e^{-i2\pi\nu_p t} \right|^2 = d_{cw}^2 + d_p^2 + 2\vec{d}_{cw} \cdot \vec{d}_p \cos 2\pi(\nu_{cw} - \nu_p)t \quad (6)$$

Here, \vec{d}_{cw}, \vec{d}_p are the dipole undulations induced by the CW reference signal (ν_{cw}) and the pulsed signal (ν_p) respectively. When the superposed light beams are of parallel polarizations, the magnitude of the dipole undulations induced by the super Gaussian (square-like) light pulses can be expressed by Eq.7, where m is an integer greater than 2 and τ is the pulse half width:

$$d_p(t) = \exp[-(t/2\tau)^{2m}] \quad (7)$$

The electrical signal of Eq.6 is analyzed by an HP-ESA (#8593E). It is able to discern the harmonic undulation, $\cos 2\pi(\nu_{cw} - \nu_p)t$ as a sharp line whether it is CW or cut off randomly by $d_p(t)$. The ESA is designed with memory and software to store the pulsating currents and analyze them in terms of sinusoids. Note that due to continuous and pseudo random (data) presence of $d_p(t)$, its ESA representation is a continuous sinc^2 -like function. If it were perfectly periodic, the ESA would have produced a periodic array of spikes under the sinc^2 envelope. We have recorded similar results when the input pulses were periodic.

The key significance of this experiment is that the Fourier decomposed frequencies of a pulse do not represent actual optical frequencies. We have directly demonstrated that a short optical pulse can carry its unique carrier frequency and is not burdened by the Fourier analyzed frequencies. Thus, when an excited atomic dipole spontaneously releases semi-classical ‘photon’ as a discrete packet of energy ΔE in the vacuum (cosmic medium), the classical model of the evolution of the photon as a time finite EM wave packet out of it with a uniquely defined carrier frequency ν , is congruent with the QM postulate $\Delta E = h\nu$.

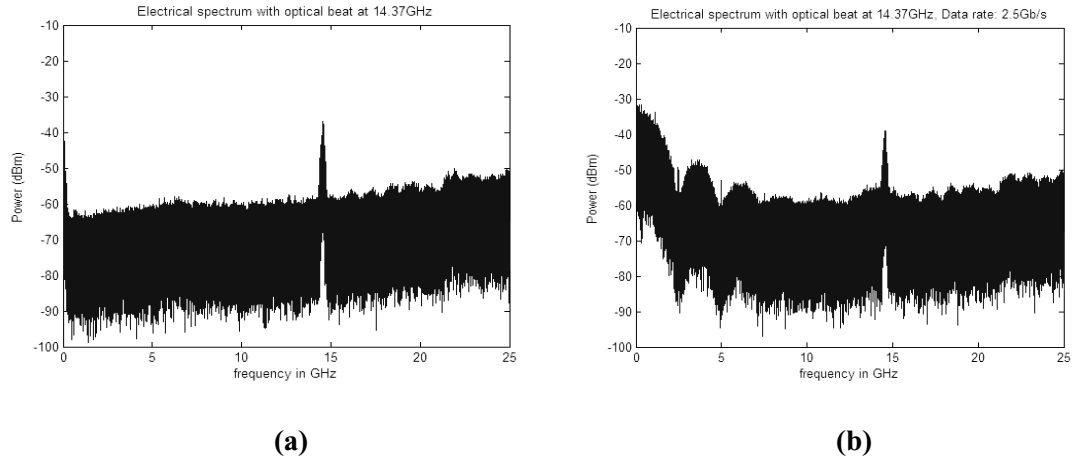


Figure 2. Out put from an electronic spectrum analyzer (ESA) fed by the photo current from a high speed detector illuminated by the superposed light beams of two different frequencies. The left photo corresponds to two CW light beams separated by ~ 15 GHz, the beat frequency. The right photo corresponds to the external amplitude modulation of one of the lasers by 0.4 ns super Gaussian (square-like) pulses (2.5 GHz pseudo random data). The carrier frequency (beat) signal remains essentially unchanged, while the presence of AM is separately displayed as the Fourier transform of the square-like pulses, sinc²-like harmonic distribution with the first zero close to 2.5 GHz location [10].

It is not necessary to define the photon as an indivisible, non-causal, non-local, Fourier frequency mode of the vacuum. However, we must rush to underscore that when the atoms and EM fields are confined inside a micro cavity by enforced boundary conditions, the situations are different from free space evolution of photons [14].

5. Discussions

The purpose of the paper has been to raise rational doubt on the current paradigm that light propagates as indivisible particle-like entities while preserving its wave behavior, requiring explicit acknowledgement that interference effects have to be explained as a non-local phenomenon. We have argued, through the exploration of the detection processes behind detecting superposition (“interference”) phenomenon that light beams really do not interfere with each other when it contains energy equivalent to trillions of photons. Then, phenomenologically, indivisible single photons cannot give rise to interference effects, unless one assumes that the single photon interference (at extreme low light level) is a distinctly different phenomenon compared to when one has abundant light energy. It is the paradigm of indivisible-photon that is forcing us to introduce a host of non-causal hypotheses.

The problems have been further complicated by the assumption that the Fourier theorem, although an elegant and very successful mathematical tool on its own right, represents actual physical processes experienced by light fields (interference). However, we have experimentally demonstrated that neither Fourier synthesis, nor Fourier decomposition represent physical realities for light. The Fourier theorem is extensively used in modeling natural processes both in classical and quantum physics. Because of its extended limits of integration, it has the potential to bring in non-causality into the analytical processes that people have been aware of [15] since its inception by Fourier. In fact, the definition of “what is a physical spectrum?” has been an evolving debate over a century, although, the prevailing view is that if the light is pulsed, the Fourier spectrum is the right representation [16-19]. But, this is probably the first time that we are claiming that superposing EM radiations of infinite extent, in the name of Fourier theorem, neglecting even causality violation, does not represent any physical reality. This is simply because light does not interfere with light. Thus, if the applicability of a mathematical theorem can be seriously questioned in one application, it should be critically reviewed for all other applications in physics that includes QED definition of a photon. Even the Uncertainty Principle should be revisited [20] since its essential platform is the product of the half-widths of a pair of functions related by Fourier transform. These widths may not necessarily represent any physical reality. Diffraction fringe patterns are analytically given when the

aperture function is known, and the de-convolution provides spatial super resolution [21]. For the classical time-frequency domain, we have shown analytically [22, 23] that the corresponding Fourier band width product, is not a fundamental limit in classical spectrometry in determining the carrier frequency content in a pulse. The experiment of Fig.2 above directly validates this assertion. Ref.23 shows that the extra width of the final time integrated “spectral” fringe is due to “time diffraction” and spatial spread of the energy corresponding to the same carrier frequency. This extra, time-integrated fringe width is mathematically shown to be derivable as the convolution of the CW intensity impulse response with the Fourier (transformed) spectral intensity function of the time pulse. This coincidence may have lulled us to accept the Fourier spectrum of an amplitude pulse as real “spectrum” without a critical review. The mathematical equivalency comes by using Parseval’s energy conservation theorem.

It is at the same time important to underscore at least two causally self consistent application of the Fourier theorem in optics. The first one is in diffraction. When the light duration is sufficiently long (effectively CW), the far-field diffraction pattern is correctly given by the spatial Fourier transform of the diffracting aperture [2]. However, this is based on the identification of the structural similarities between the Fourier transform integral and the Huygens-Fresnel space-space, diffraction integral (a recognized principle of physics) as it drops the quadratic curvatures of the Huygens’ secondary wavelets in the far-field in favor of plane waves. The Fourier transform conjugate variables are between two physical space coordinates (two spatial planes). Unlike for the time-frequency Fourier transform, no causality is violated in this space-space Fourier transform if the signal duration is much longer than the maximum relative phase delay between the center and the edge of the diffraction pattern. The second one is the Fourier transform spectroscopy, already mentioned in Section 2. Again, this is based on the identification of the fringe intensity pattern as Fourier inverse transformable sinusoidal undulations (after removal of the “dc” bias from the recorded intensity) based on the correct physics hypothesis that on slow detector there are no superposition effects between different optical frequencies (no cross terms). The two conjugate variables are the actual carrier frequency and the interferometer delay time (not the real running time) constituting the recorded sinusoidal fringe function [24].

The strength of our strictly causal and local model behind recording fringes due to superposition of multiple light beams is that it is congruent with the semi-classical model [25-27]. So, the possibility of extending this model to explain the superposition of truly indivisible quantum mechanical particles should be encouraging. Accordingly, the author is developing conceptual continuity in interpreting such superposition effects to be published elsewhere.

There may be readers who find the observations presented in this paper not to be sufficiently convincing and would insist on preserving the paradigms (i) that the EM energy packets emitted by atoms and molecules are simultaneously non-local and indivisible and (ii) that the indivisible single “photons” do interfere. For such readers, we would like to refer to the following references [28-31] where the authors argue against the single photon interference. The famous Bell’s inequality does not strengthen the case for non-locality either [32, 33]. Ref.28 has experimentally demonstrated that both the photographic plate and the photo detectors become sub-linear in their detecting efficiencies at very low light levels, clearly raising serious doubt as to the validity of the claim behind “single photon interference” and that only a “single photon” at a time was present in the entire interferometer system. In fact, it is well known that a minimum of 3 to 4 photons equivalent energy exposure is needed before a photographic grain can be successfully developed as a black grain.

We hope that this paper will inspire new developments in mathematical modeling of photons. Atoms and molecules being space and time finite, any form of energy released by them have also to be finite in space, time and energy value, if we simply accept conservation of energy, even if one is ignorant of the existence of atom quantization. It is no wonder that Newton insisted on “corpuscular” nature of light in its emission. The question is how does this space and time finite energy packet evolve and propagate in a causal fashion without the need to introduce any non-causal behavior?

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