What can we learn by differentiating between the physical processes behind interference and diffraction phenomena?

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ABSTRACT

This paper extends and generalizes the principle of Non-Interference of Light (NIL) to diffracted secondary wavelets. In a previous series of papers,[1–14] we have demonstrated the NIL principle for well defined superposed light beams, which experience negligible diffracted spreading within the interferometers being used. NIL is consistent with quantum physics where emitted photons from material dipoles are considered non-interacting Bosons. Our NIL principle describes the formation of fringes (energy re-distribution) as patterned energy absorptions or scattering by "local" material dipoles proportional to the square modulus of the sum of all the superposed stimulating fields experienced by the dipoles.

Keywords: Non-interference of light or NIL; non-interference of secondary wavelets, non-interacting photons in diffraction; non-interacting photons in interference;

1. INTRODUCTION

In classical physics, interference phenomenon, with superposition of well defined optical beams (suffering negligible diffractive spreading within the interferometer), is mathematically represented by directly summing the electromagnetic fields to derive the resultant energy distribution (fringe pattern). The implied hypothesis is that the light beams, by themselves, interact with each other to create a new energy distribution. However, quantum physics defines light beams consist of photons, which are Bosons, and they do not interact with each other. They can occupy the same physical space when a light beam is tightly focused, or different beams cross each other or co-propagate through the same space. We agree with this position of quantum physics and hence consider non-interference of light beams (NIL) is a fundamental property of light beams[1–14] . Quantum physics is then forced to assume, as per Dirac, "a photon can interfere only with itself" to create fringes (redistribution of energy). We disagree with this hypothesis since in the model of quantum physics, photons being stable elementary particles, cannot make themselves "appear or disappear" without some physical interaction with themselves, or with some other materials, to create fringes. Our generalized hypothesis is that superposition effects can become manifest only as some measurable physical transformation in some detecting material dipoles. The transformations require energy, which is provided by all the superposed EM fields through simultaneous dipolar stimulations. The expression for the energy transfer $I(x)$ is given by the QM prescription, square modulus of the sum of all the dipolar complex amplitude stimulations[1] $\chi a_n E_n(x)$, due to all the superposed EM waves; where a_n are the real amplitudes of the individual EM fields, $E_n(x)$ are their sinusoidal complex undulations at the x-location and $^{(1)}\chi$ is the polarizability of the material dipoles containing their quantum properties:

$$I(x) =^{(1)} \chi^2 \left|a_1 E_1(x) + a_2 E_2(x)\right|^2 = \left|^{(1)}\chi a_1 E_1(x) +^{(1)} \chi a_2 E_2(x)\right|^2 . \tag{1}$$

Thus, the superposition phenomenon, being a physical energy exchange effect, must be represented by the summation of the simultaneous dipolar stimulations physically induced by all the simultaneously present fields. Notice that when $^{(1)}\chi$ can be assumed to be a constant, in Eq. 1, using a mathematical rule, it can be taken

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out of the square modulus sign. Then the remaining terms inside the square modulus sign appear as if one can literally sum the EM fields to produce the fringes (energy re-distribution); as if the role of $^{(1)}\chi^2$ is no more than a passive detector constant. This is a major mistake of classical physics. The same dipole, or the dipole complex, can sum all the stimulations simultaneously induced by multiple EM fields. But the EM fields cannot sum themselves. There is no interference of light. It is not just a mere semantics. The consequences are deep and extensive in all branches of optical physics wherever we measure some effects due to superposition of more than one EM fields[4–14].

Huygens-Fresnel model (including its Rayleigh-Sommerfeld modifications[15]) of diffraction works remarkably well, from macro optical phenomena (like imaging by Hubble telescope) to nano-photonic phenomena (like nano optical wave guides and plasmonic photonic manipulation of EM waves). The core assumption behind this diffraction model is fundamentally similar to that for the classical interference phenomenon - (diffracted) secondary wavelets sum themselves to re-arrange their energy distribution, generating the new diffracted intensity distribution. The objective of this paper is to extend our NIL hypothesis to diffraction phenomenon using the concept behind Eq. 1. We demonstrate that the registered rearrangement of diffracted intensity distribution, as in classical interference effects, is also a result of interactions between "detecting" material dipoles and the multitudes of diffracted wavelets. In the nanometer domains where the diffracted secondary wavelets and the perturbing material dipoles are inseparable, one can obtain new energy distributions, as in plasmonic photonics, which again conforms to our general hypothesis that only material dipoles can facilitate the creation of new energy distribution and hence facilitate the generation of new effective wave front immediately outside the plasmonic material medium.

This paper is organized as follows. Section 2 provides the supporting evidence for the NIL hypothesis. The hypothesis is extended to diffracted wavelets in section 3. The formulation and calculation of near field diffraction is developed in section 4. The conclusion is summarized section 5.
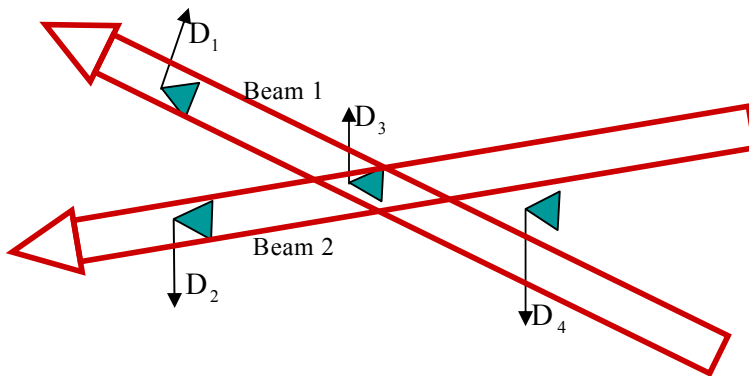
2. BRIEF REVIEW OF NON-INTERFERENCE OF LIGHT (NIL)

Figure 1. Non-interaction of laser beams cross through.

When two light beams pass through each other, they keep propagating unperturbed in their beam energy distributions. If two projectors project their images on two different screens while the path of the light beams cross through each other, it is obvious that the images on the screens remain unaffected. There is no spatial or temporal scintillations in the intensity patterns imaged by our retina even though the received light beam has to cross through innumerable other beams carrying different sceneries from different directions. WDM technology sends a good number of independent laser beams, each carrying separate data, having different wavelengths (frequencies) through many thousands of kilometers of single mode glass fibers. These beams can be easily de-multiplexed without loss of any data. WDM beams do not experience any heterodyne mixing. The data is never destroyed as heterodyne noise inside the single mode fiber. The hypothesis of expanding universe is reproducibly validated through the measurement of the Doppler shifts of characteristic line spectra from different stars at different distances. Many of these light beams have been traveling for billions of light

years while crossing through trillions of other light beams produced by all other stars. Yet, each beam preserves its unique distant-dependant Doppler shift characteristics. All these cases validate our NIL-hypothesis. It is obvious that light beams co-propagate or cross through each other unperturbed. So, in spite of mathematical correctness of time-frequency Fourier theorem, and in spite of acceptance of linear summation of sinusoids by Maxwell's wave equation, light beams cannot be summed directly to re-group beam energy since they do not interact with each other. Weakening a light beam to a very slow rate of photoelectron release cannot create a novel interference phenomenon! Superposition effects are always displayed through interactions between light and material dipoles! In other words, the non-interaction property of light is one of the key properties of light that makes it the most useful tool to gather and analyze information about the material world!

2.1 Non-interaction of laser beams

We propose an experiment that can be carried out in any modest laboratory to prove that crossing laser beams, as shown in Fig. 1, do not interact with each other. The crossing beams are collimated Gaussian beams of finite spatial size as depicted in the figure. D1, D2, D3, D4 are detectors. Detector D1 registers only the effect of beam-1 and remains unperturbed whether the beam-2 is on or off. In the same way, D2 registers only the effect of beam-2 and remains unperturbed whether the beam-1 is on or off. D4 is out of the region of either beam so D4 does not register anything. Only the detector D3, placed inside the volume of superposition of the two beams, can register the fringes due to superposition of the two beams. One can conclude from these observations and measurements that the two crossing laser beams do not interact with each other.

2.2 Non-interaction of crossing laser beams produced by a Fresnel bi-prism
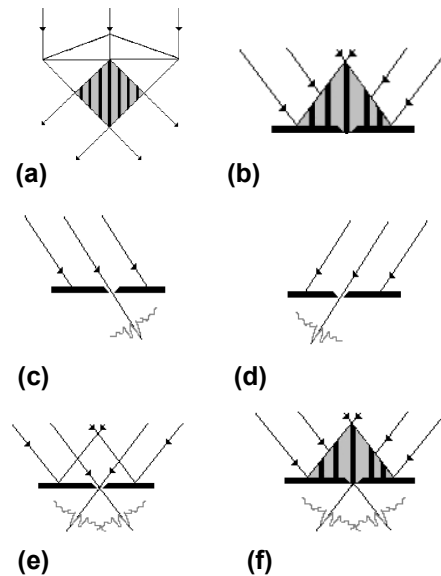

Figure 2. Non-interaction of laser beams. We propose an experiment with a Fresnel bi-prism and a single slit to underscore the non-interference of light beams. The two bi-prism beams will produce two independent diffraction patterns along the directions of the respective Poynting vectors, irrespective of whether the slit is placed on a potential dark or a potential bright fringe[8] .

In Fig. 2 we propose an experiment where a Fresnel bi-prism generates two beams that cross through each other. As per our NIL-hypothesis, the two beams will pass through each other un-perturbed as in Fig.2a; but fringes can be observed only if one places a detector array within the volume of superposition. Fig.2b shows a slit positioned on the location of a dark fringe. Fig.2 c and d show that if the two beams were sent separately, one at a time, we would have registered two diffraction patterns emerging along the directions of the Poynting vectors of the two beams, as underscored in Fig.2e. Fig.2f repeats the same concepts by dramatizing the point that two independent diffraction pattern will emerge even if the slit were located exactly on the location of a

potential dark fringe (if detector array was placed just before the slit). A dark fringe does not necessarily imply the absence of light energy (or non-arrival photons). Where the two electric vectors of the two superposed beams are 180° out of phase from each other, the local detecting dipoles would not be stimulated and hence they will register a "dark fringe". In-phase locations will register bright fringes since the two E-vector amplitudes will jointly and strongly stimulate the detecting dipoles.

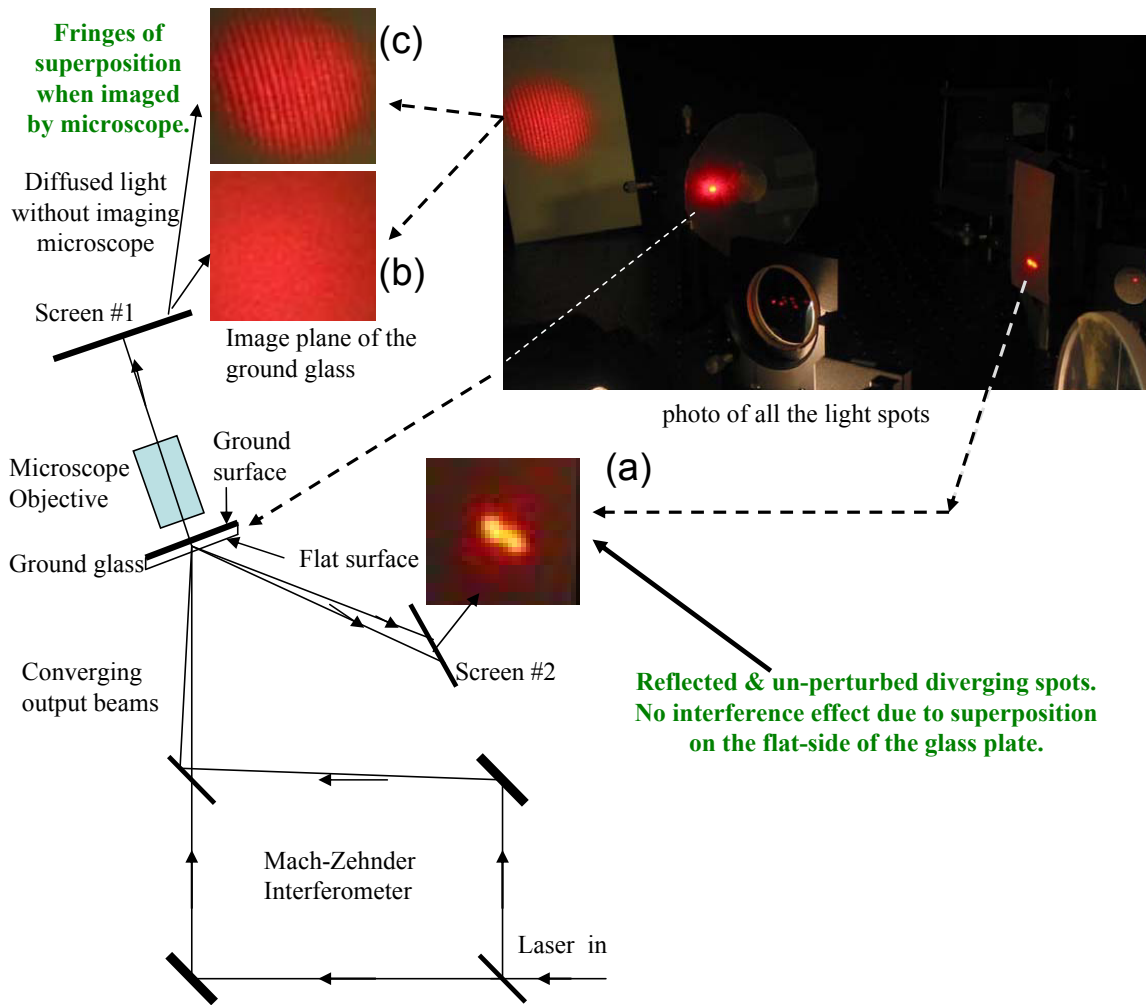## 2.3 Non-interaction of crossing laser beams produced by a Mach-Zehnder

Figure 3. Non-interference of convergent beam pair produced by a Mach-Zehnder interferometer. See text for details.

To demonstrate the non-interaction or non-interference between laser beams, we designed an experiment using a Mach-Zehnder interferometer (MZ).[16] The set-up is sketched in Fig.3 and the results are shown in Fig.3a,b,c. The MZ interferometer was given appropriate tilts to produce a pair of converging outgoing beams, as the Fresnel bi-prism does. A special ground glass was used which has flat surface in the front side and ground surface in the opposite side. When the two light beams, coming out of the MZ, converges on the ground glass, a part of the energy from both the light beams is reflected by the front flat surface and the rest pass through the ground surface (ignoring the absorption), which gets scattered. The reflected beams from the front flat surface of the ground glass emerge out totally unperturbed as a pair of divergent beams. As a result, there are two separated bright spots on screen #2 (photo on Fig.3a). This means that these two beams have not experienced any interaction with each other even though they were superposed on the same spot of the flat side of the glass plate (screen #1) and then got reflected unperturbed by each other. The part of the energy that passes through the ground

surface of the ground glass, hits the screen #1 and appears as a single divergent beam full of random speckle patters due to scattering (photo on Fig.3b). When a microscope objective was placed between the ground glass and the screen #1 to create an enlarged and sharp image of the ground surface, a clear interference fringe pattern was observed (photo in Fig.3c). This means that the interference fringe pattern exists on the ground surface of the ground glass. Obviously, the fringes are due to simultaneous response of the individual lumps of silica (glass) molecules to the two superposed beams. The physical locations where the small silica lumps experienced two electric vectors stimulating them out-of-phase, they could not make any forward scattering, producing dark fringes. Similarly, in-phase E-vector locations produced bright fringes. A high resolution photographic plate or a digital camera screen (photo detector array) placed directly at the convergence plane of the two MZ-beams would have also recorded these fringes.

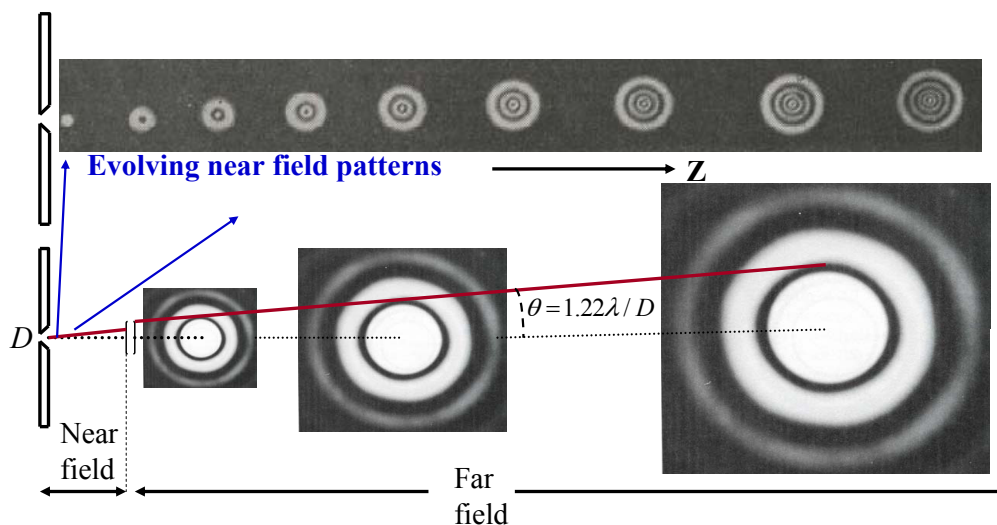## 3. NON-INTERACTION OF WAVELETS

Figure 4. Evolution of near field and far field diffraction pattern due to a small circular aperture. Note that the on-axis near field pattern goes through a series of dark spots indicating that they are the simultaneous superposition effects of HF wavelets on the recording Silver Bromide dipoles, rather than "interference" of light. In the far filed the relative phase variations between the HF wavelets are so small that the recorded intensity pattern remains identical in angular distributions [Photos taken from ref[17, 18]].

Huygens' Principle states that the wavefront of a propagating wave of light at any instant conforms to the envelope of spherical wavelets emanating from every point on the wavefront. The wavelet is more basic concept than the light beam. It is natural to extend the hypothesis of non-interaction of light beams to non-interaction of light wavelets. Since, even the best collimated light beams experience diffractive divergence and can be modeled accurately by Huygens-Fresnel Integral (HFI), we are assuming that HFI does model propagation of light at all stages of propagation. Here for example we consider the diffraction of light after a circular aperture with radius of D. The diffraction pattern consists of a central bright spot (Airy disk) surrounded by a series of bright and dark rings in far field. In the near field, the diffraction pattern varies with the distance from the aperture. The center spot is not always bright, but evolves through alternate bright, dark, bright, dark patterns and so on, as shown in Fig.4. On-axis dark and bright spots represent detector's response at that plane as the square-modulus of the sum of all the complex amplitudes of all the diffracted HF wavelets. So the dark spot on axis is not the absence of energy. Far field pattern evolves with unchanging angular distribution because the relative phase difference between the HF wavelets has become negligible along the propagation axis. This far field Bessel beam pattern remains un-altered even when one inserts a microscopic scattering center on axis, as in trapping of particles inside the beam.

Fig. 5 shows Talbot images in the near field domain formed due to superposition of rapidly evolving secondary wavelets emerging from the slits of a grating. Such images are observable only after being recorded by a
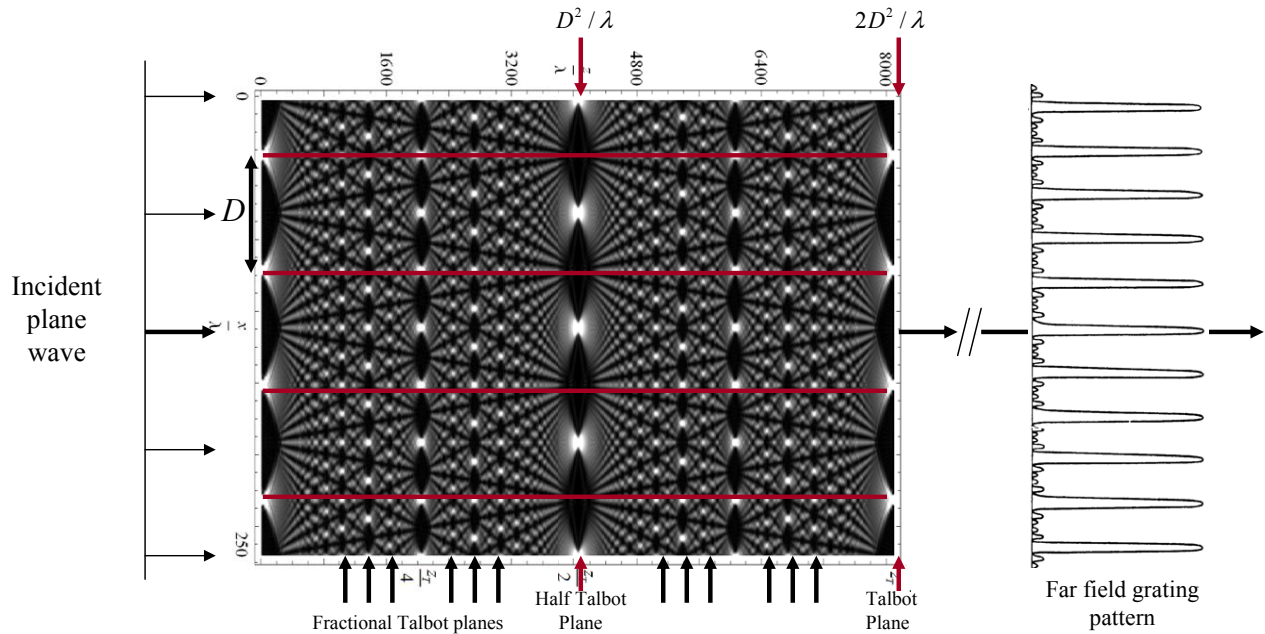
Figure 5. The optical Talbot Effect for monochromatic light. Appearance and disappearance of dark spots along any particular forward axis is not a sign of absence of EM field energy. Detectors in those spots experience absence of resultant E-vector stimulation. Diffracted wavelets propagate through each other unperturbed. [Adapted from Wikipedia http://en.wikipedia.org/wiki/Talbot_effect.]

photographic plate or a CCD array. Collectively, Talbot images represent an excellent example to appreciate that secondary wavelets pass through each other without perturbing the propagating energy distribution of each other. In Fig. 5 one can locate the exact Talbot image of the grating at a distance $2D^2/\lambda$. At the half Talbot distance D^2/λ, the grating image is inverted in its dark vs. bright position. In between these distances there is a large number of fractional Talbot images with double, triple, etc., number of spots compared to the number of actual slits in the grating. If one carefully observes the evolution of dark and bright spots along any forward axis, one can appreciate that the best way to explain such a complex and orderly registration of energy variation is due to the response of detecting dipoles in each local points. There is no operating force between EM waves to redistribute filed energy in a rapidly changing spatial pattern as they propagate through each other.
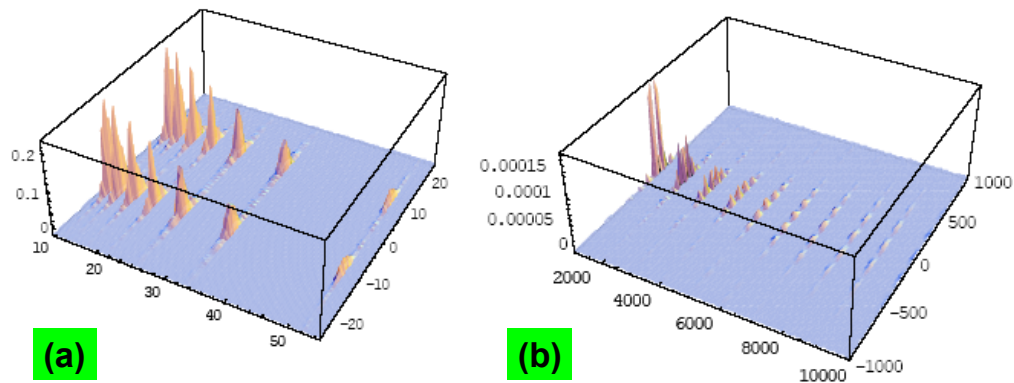

Figure 6. Intensity of light after the diffraction of the double-slit system, (a) near field, (b) far field.

The Fig. 6 shows the diffracted intensity of light (vertical scale) due to a double-slit system. We can see

that the traditional double-slit diffraction fringe pattern can not be formed in the near field, as the separation between the slits is too large for physical superposition (Fig. 6 a). But in far field, due to diffractive divergence, they start overlapping and start developing traditional double-slit pattern. All these diffraction patterns are response of the local detecting material dipoles, not rearrangement of intensities of the two light beams produced by their superposition only.

4. TIME-DIFFRACTION

It is no doubt that the real optical signals always have finite time duration. In another word, all the optical signals are pulsed signals of finite length. This raises the phenomenon of diffractive pulse broadening. The Huygens-Fresnel (HF) diffraction integral can be represented as:[19]

$$U(P_0) = \frac{-i}{\lambda} \int \int_{\Sigma} U(P_1) \frac{e^{ikr}}{r} \cos\theta ds, \tag{2}$$

where $U(P_0)$ is the calculated sum of the field at a point P_0 due to all the HF wavelets, $U(P_1)$ is the field strength at a point P_1 on the aperture, and r is the distance between P_0 and P_1. For a finite pulse, $U(P_1,t)$, since the HF wavelets with different delays, could be superposed with different amplitudes, we propose that we directly sum the delayed HF wavelets as shown in Fig. 7, showing the case for a rectangular pulse. The temporal delays between the wavelets are now explicitly recognized via $t = n(\nu)r/c$, where the refractive index $n(\nu)$ is introduced to underscore that the frequency dependent dispersive delays should be considered if the diffraction is taking place inside a homogeneous medium. One can now easily visualize that the effective measured pulse width will be different, especially in the near field, as the location of the observation point P_0 changes at any plane in the near field. If $U(P_1,t)$ contains many actual carrier frequencies, then the Eq.3 should be integrated further over the distribution of carrier frequencies,

$$U(P_0,t) = \frac{-i\nu}{c} \int \int_{\Sigma} U(P_1,t) \frac{e^{i2\pi\nu t}}{r} \cos\theta ds; t = \frac{n(\nu)r}{c}. \tag{3}$$

Since we can only detect intensity through the response of a detector to all the superposed HF wavelets, technically, one must convert all the HF wavelets $U(P_1)$ into corresponding stimulation of the detecting dipole amplitudes by multiplying them with the polarizability $^{(1)}\chi$, as shown in Eq.1, and then obtain the time varying intensity $I(P_0,t)$ as. Since $^{(1)}\chi$ is usually a constant, normalized computed value remains unchanged whether one explicitly considers "summing the dipole undulations" (NIL-hypothesis) or "summing the EM waves" (light interferes):

$$I(P_0,t) = \left| {}^{(1)}\chi U(P_0,t) \right|^2 = \left| \frac{-i\nu}{c} \int \int_{\Sigma} {}^{(1)}\chi U(P_1,t) \frac{e^{i2\pi\nu t}}{r} \cos\theta ds \right|^2. \tag{4}$$

Traditionally, we replace the time-dependent function $U(P,t)$ by the time-independent Fourier transform of the envelope function, which tends to work for free-space, since secondary wavelets do not "interfere" with each other. The Fourier frequencies of the envelope function can be written as

$$U(P_1,t) = \int_{-\infty}^{+\infty} \tilde{U}(P_1,f)e^{i2\pi ft}df, \tag{5}$$

where f if the Fourier frequency. And the traditional approach for the time-diffraction is to insert the Fourier frequencies in the CW diffraction formula of Eq.2:

$$U(P_0,t) = \frac{-i\nu}{c} \int \int_{\Sigma} \int_{-\infty}^{+\infty} \tilde{U}(P_1,f)e^{i2\pi ft} \frac{e^{i2\pi\nu t}}{r} \cos\theta ds df. \tag{6}$$

For free-space diffraction, either Eq. 3 or Eq. 6 will work. For diffraction inside a dispersive media, Eq. 3 should be used to avoid error due to material dispersion.

When a pulse signal diffracted by a single slit with slit width of $2b$, the light intensity of the point of (ξ, z) is the superposition of the diffractive wavelets from each point of the aperture. The distance between the point (ξ, z) on observation screen and the $(x, 0)$ on the aperture is $r_x = [z^2 + (\xi - x)^2]^{1/2}$. The time delayed is $\tau = \tau_{abs}(x, \xi, z) = r_x/c$, and $r_x = [z^2 + (x - \xi)^2]^{1/2}$. The minimum value in the near field is $\tau_{min} = \tau_{abs}(\xi, \xi, z) = z/c$, the maximum value is $\tau_{max} = r_{max}/c = [z^2 + (\xi + b)^2]^{1/2}/c$. $\tau_0 = \tau_{max} - \tau_{min}$ is a characteristic pulse evolving time constant. It is the diffractive pulse broadening at (ξ, z).
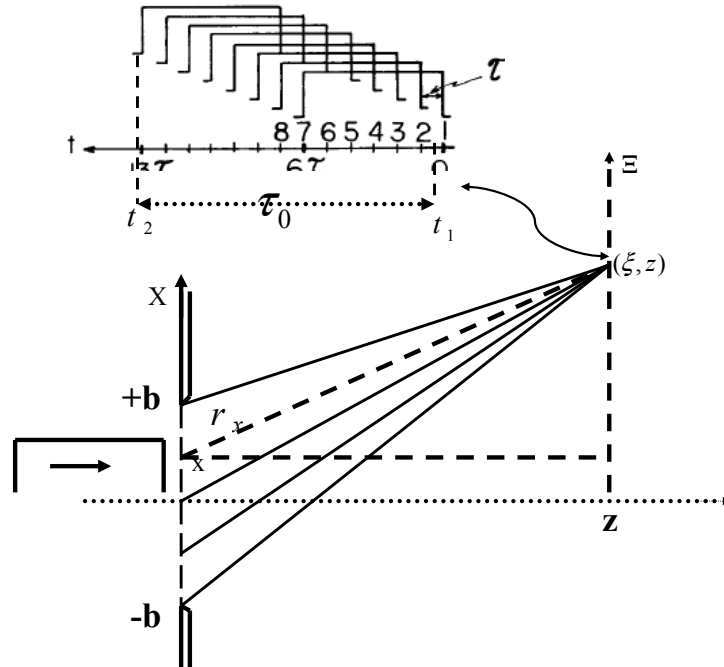

Figure 7. The origin of the pulse stretching in the time diffraction.

For the near-field time diffraction of a single slit with the slit width of $2b$, the time evolving intensity is

$$i_p(t, \xi, z) = \left| \int_{-b}^{b} a(t - \tau) \frac{e^{i2\pi\nu(t-\tau)}}{r_x} \cos\theta dx \right|^2, \tag{7}$$

where $a(t) = \frac{-i\nu}{c} U(P_1, t)$ assuming the intensity of each point at the single slit is identical.

The time integrated intensity is

$$I(\xi, z) = \int_{t1}^{t2} i_p(t, \xi, z)dt; (t2 - t1) \geq 2\tau_0. \tag{8}$$

The effects of time-diffraction as differential pulse broadening at on-axis vs. off-axis points in the near field, will be published elsewhere. Such effects will not be observable in the far-field, since the differential delays between the secondary wavelets become negligible.

5. CONCLUSION

We have generalized the hypothesis - Non-Interference of Light (NIL) beams - to diffracted wavelets and hence to the diffraction phenomenon. This concept is also supported by the analysis presented in a recent paper[20] . Due to propagation delays, diffracted wavelets stretch the incident pulse, generating a broader pulse at the output. This effect will be most dominant in the near field between on-axis and off-axis points. We have presented a simple method of formulating tine-diffraction and consequent diffractive pulse broadening. Detailed analysis will be presented elsewhere.

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