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Invited Paper

A critical look at the source characteristics used for time varying fringe interferometry

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ABSTRACT

Interference fringes are registered by detectors. All detectors absorb energy from a single or multiple superposed fields through the process of "square modulus" of the sum of the complex amplitudes. The detected energy becomes proportional to the total relative phase difference for all the superposed fields. The process creates ambiguity in discerning the effects due to frequency and phase modulations. We underscore that fringe detection being a physical interaction process between superposed fields and detecting molecules (including beam splitter boundary), the dipolar properties of atoms and molecules should be used to help us discern the effects due to frequency and phase modulations. We traditionally accept that orthogonally polarized light beams do not "interfere". Or, light beams of different frequencies are "incoherent" to each other; but we have highly developed heterodyne interferometry for which the wave fronts of the superposed beams must be matched. Yet, we do not explicitly recognize the roles of the molecules of detectors and beam splitters that really carry out the real functions. Besides, understanding the various processes behind their dipolar response can help us innovate more precision interferometric techniques. As for examples: (i) How precisely the polarization should be parallel to produce perfect visibility fringes? (ii) How precisely equal the optical frequencies of superposed beams should be to create perfectly steady-state energy re-direction by a beam splitter in an interferometer with collimated and collinear beams. (iii) How small the wave front mis-match can be tolerated to produce perfect heterodyne fringes while superposing beams of different frequencies?

Keywords: Interferometry, Frequency modulation interferometry, Phase modulation interferometry, Heterodyne interferometry, Distinguishing between frequency and phase modulation in interferometry

1. INTRODUCTION

Time varying-fringe interferometry (through phase and frequency variations) has evolved into a matured engineering field and is still producing new innovations toward nanometric precisions to keep pace with the evolution of nano technologies [1, 2]. The key objective of this paper is to underscore various subtle physics behind the operational processes that lie behind the production and detection of "moving" fringes in space and time due to superposition of modulated beams in two-beam interferometers. The conceptual origin of the paper derives from three obvious facts that are not "coherently" integrated in many interferometry books.

Let us recognize that all recorded fringes are energy variations produced by the total resultant phase variations due to the superposed fields that tend to mask the separate contributions by the frequency (-ies) of the optical field(s) and the pure phase delay(s). This is because the energy exchange between the superposed fields and the operating molecules follows the well-validated phase-driven process that can be stated as taking the "square modulus of the sum of the superposed complex amplitudes". In the optical domain, we can discern only the

relative phase information recorded as energy (intensity) variations. All interferometric measurements and holograms tell us the same story. This point is especially relevant for experiments that generate and register time varying fringes since one must design the experiment to be able to distinguish between the contributions to the time varying phase of the fringes due to frequency and phase modulations along with the propagation delay in the two arms of the interferometer. Let us consider a generic situation where an input optical field is replicated as two equal amplitude signals with a relative time delay of τ . If they are represented as $a\exp[i2\pi\nu(t)t + i\phi(t)]$ and $a\exp[i2\pi\nu(t+\tau)(t+\tau) + i\phi(t+\tau)]$, which are superposed to register fringes, the intensity variations can be represented as:

$$I(t) = 2 + 2\cos[2\pi\{\nu(t)t - \nu(t+\tau)(t+\tau)\} + \{\phi(t) - \phi(t+\tau)\}] \quad (1)$$

It becomes difficult to discern between the contributions by the frequency and the phase of the original fields from the measured time varying phase of the fringe intensity. Is it at all possible to make such a distinction?

The first key is to recognize that well formed light beams can propagate collinearly, or by crossing each other at an angle, without operating on (or interfering with) each other. Light beams do not "see" each other! We do not "see" light directly either. We "see" light only through the "eyes" of the material detectors that respond to the EM fields as physical dipoles before absorbing any energy from the fields and then reporting that to us through some measurable transformations. Thus, the observed "interference fringes" (which are re-distribution or re-direction of superposed field energies) are produced by the actions of the material molecules (acting as dipoles) of the detectors and of the boundary layers of beam splitters (as the case may be). Hence, the information these molecules give us is "colored by the quantum goggles they wear"! It is important to acknowledge that all photo detection and superposition effects are the results of some physical process, various interactions between the superposed fields and the dipole like molecules of the detectors and of the boundary layers of beam splitters. The physical properties of these molecules, collectively and separately, determine the outcome of the superposition effects. Dark fringes cannot be interpreted always as the non-arrival of indivisible energy packets of photons. Light beams need to pick up the diverse information from each of the arms of an interferometer and then present all those information on the detectors or beam splitters. They dictate through the "square modulus" response process as to what we are allowed to "see". We call the imposition of such a physical process on the photoelectric equation behind detecting superposition effects as *Reality Ontology* (RO) [3].

We will discuss several situations relevant to two-beam interferometry to illustrate our above points. We hope that a deeper understanding of these processes behind producing superposition fringes by the detectors (active process of energy absorption) and beam splitters (passive process of energy re-direction) will inspire novel innovations toward newer techniques and higher precisions.

2. OBSERVED SUPERPOSITION FRINGES ARE DICTATED BY THE PROPERTIES OF THE SENSING MOLECULES

We have underscored that we do not "see" light beams; and light beams do not "see" each other, at least not until the cosmic medium itself becomes nonlinear. In the language of QM, light constitutes photons and they are Bosons; they can occupy the same space without feeling "crowded". Then who does the energy re-distribution and re-direction that we measure as fringes in interferometry? It is the detector and beam splitter – the constituent atoms or molecules that respond to the superposed EM fields as electric dipoles. The first step behind producing superposition effect begins with the summation of the superposed amplitudes. It is the atoms and molecules, as energy absorbers or re-directors, which carry out the amplitude summation process, but only when they are quantum mechanically allowed (QMA) to respond to all the superposed fields carrying different information simultaneously. The resultant amplitude stimulation constitutes the summation step. Recognizing this summation step, which is carried out by the atoms and molecules, is the most important contribution by quantum mechanics. The next step is energy absorption or re-direction. This photo-induced reaction is successfully represented by the square modulus of the superposed fields on them.

2.1 Brewster angle, superposition of orthogonally polarized light and the physics of molecules

Let us apply the QMA conditions to some specific examples. It is an observed phenomenon that plane polarized light cannot be reflected by the molecules of a dielectric boundary at the Brewster angle. This is

because the direction of reflection coincides with the axis of the dipolar undulation of the boundary molecules – a dipole cannot send radiation along the axis of its undulation [4]. Another observed phenomenon is that two orthogonally polarized beams produced from the same coherent beam do not produce superposition fringes. This is because the detector molecules cannot be induced to carry out uniaxial dipolar undulations along two orthogonal axes at the same moment. They choose to undulate in response to one or the other state of polarization. So, they fail to sum or respond to the resultant amplitude summation and register fringes of energy variation.

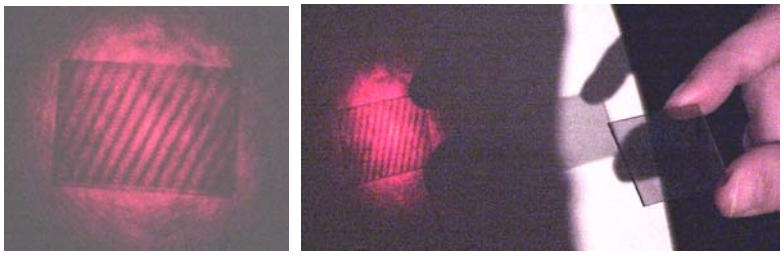

Figure 1. Two beams of orthogonally polarized light have been superposed with a very small angle. Then a polarizer has been inserted within a portion of the beam. Only those segments of the light beams that pass through the polarizer show superposition fringes. The scattering molecules of the screen (paper) cannot respond simultaneously to two orthogonal E-vectors stimulations. Hence they cannot sum the superposition effects and we do not see any fringes in the beam which is outside that intercepted by the polaroid. Light beams transmitted by the polaroid are polarized parallel. So, the scattering molecules now can sum the induced stimulations due to both the E-vector amplitudes. Now, where the E-vectors are in phase, we have strong scattering and bright fringes and wherever the amplitudes are in opposite phase, the scattering molecules are not stimulated at all and hence they do not scatter any light; those regions appear as dark fringes.

Mathematically one can represent the linear response of a dipole to an incident EM filed, $\vec{a}\exp[i2\pi\nu t]$ as $\vec{d}\exp[i2\pi\nu t]$ where $\vec{a}$ and $\vec{d}$ are related by $\vec{d} = \chi_{(1)}\vec{a}$, where $\chi_{(1)}$ is the first order (linear) polarizability of the detecting dipole. If the detector experiences the superposition of two phase-delayed fields of parallel polarizations $\vec{a}\exp[i2\pi\nu t]$ and $\vec{a}\exp[i2\pi\nu(t+\tau)]$, then the energy transfer can be written as:

$$\begin{aligned} D(\tau) &= \left|\vec{d}\exp[i2\pi\nu t] + \vec{d}\exp[i2\pi\nu(t+\tau)]\right|^2 \\ &= 2(\vec{d}\cdot\vec{d}) + 2(\vec{d}\cdot\vec{d})\cos 2\pi\nu\tau = 2d^2(1+\cos 2\pi\nu\tau) \end{aligned} \tag{2}$$

But, if one of the polarizations is rotated by 90^0 before superposition then $\vec{d}\cdot\vec{d} = 0$ and there will be no energy transfer.

2.2 Michelson interferometer with multiple frequencies in "filter mode"

It is a well documented phenomenon that a Michelson interferometer (MI) produces intensity fringes from an incident multi-frequency beam corresponding to each frequency separately, as if the beams of different frequencies are always "incoherent" to each other. The boundary layer molecules of the beam splitter of a perfectly aligned Michelson interferometer, illuminated by such multi-frequency collimated beam, will transmit (re-direct) the input energy based on the phase conditions for each frequency independent of the amplitudes of the other frequencies. The boundary layer molecules respond to the pair of superposed beams corresponding to each frequency separately; as if different optical frequencies cannot experience each others presence. This is at the root of success of Michelson's Fourier transform spectrometry (FTS). Consider the MI in Fig.2 set in the "filter mode" with the incident beam collimated and the output beams are combined collinearly. "Filter-mode" implies that in this alignment, the MI can completely block the transmittance of any one frequency at a time when the phase delay $2\pi\nu\tau$ is set equal to odd multiple of π. If we send a CW beam containing two frequencies ν_1 & ν_2, the transmitted intensity can be written as:

$$
\begin{aligned}
D_{filter}(\tau) &= \left| e^{i2\pi\nu_1 t} + e^{i2\pi\nu_2 t} + e^{i2\pi\nu_1(t+\tau)} + e^{i2\pi\nu_2(t+\tau)} \right|^2 \\
&= \left| e^{i2\pi\nu_1 t} + e^{i2\pi\nu_1(t+\tau)} \right|^2 + \left| e^{i2\pi\nu_2 t} + e^{i2\pi\nu_2(t+\tau)} \right|^2 \\
&= 4 + 2(\cos 2\pi\nu_1\tau + \cos 2\pi\nu_2\tau) = 4\left[1 + \cos 2\pi \frac{\nu_1 + \nu_2}{2} \cos 2\pi \frac{\nu_1 - \nu_2}{2} \right]
\end{aligned}
\tag{3}
$$

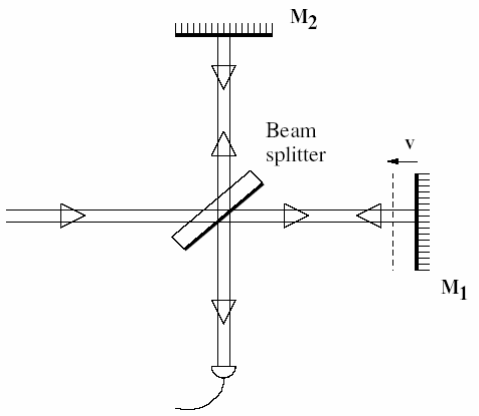

Figure 2. A Michelson interferometer (MI) in "filter mode" implying that it is illuminated by a collimated beam and the MI is aligned to generate the output beam as perfectly coincident on the beam splitter and emerging collinearly.

Notice that the second line of Eq.3 is not a correct step if we apply only pure mathematical logic. The four amplitudes corresponding to the two frequencies have been re-grouped under two separate square-modulus operators based on the physical assumption that a passive beam splitter molecules cannot aid in summing the amplitudes corresponding to different optical frequencies. They can only sum amplitudes due to the same frequency incident from opposite directions such that the Poynting vectors of the two beams are collinear. The overall modulation of the fringe visibility or intensity modulation is produced due to summation of the two independent fringe systems, which is obvious from the last line. If we now represent by $D_{osc}(\tau)$ as the processed data of Eq.3 by eliminating the "dc" component and the constant and then Fourier transform it, conjugate variables being ν & τ , we get the Fourier transform spectrum $\tilde{D}(\nu)$ of the incident light:

$$
\begin{aligned}
D_{Osc.}(\tau) &= \cos 2\pi\nu_1\tau + \cos 2\pi\nu_2\tau \\
\tilde{D}(\nu) &= \delta(\nu - \nu_1) + \delta(\nu - \nu_2)
\end{aligned}
\tag{4}
$$

This is the simplest example of Fourier transform spectroscopy whose success depends on the absence of any mutual superposition effects between the amplitudes of the two frequencies. Are the two coherent single frequency light beams mutually "incoherent"? We think that it is not a question of coherency. It is the physical behavior of the molecules on which the fields are superposed.

We have assumed for Eq.3 & 4 that the signal $D_{osc}(\tau)$ has been registered by a detector that is electronically slow or it is a photographic plate. But, if the same light beam is received by a broad-band high-speed detector, it will generate an undulating DC current constituting all possible beat (difference frequency) signals due to all the constituent frequencies. Here, "broad-band" implies that the detector molecules must have the QMA property of responding to all the incident frequencies simultaneously by virtue of their broad valence-conduction transition bands. And "high-speed" implies that the detector is electrically designed with the ability to respond to oscillatory electric currents corresponding to the maximum frequency beat current, which is the difference between the two extreme frequencies of the incident light beam. Why does a high speed detector treat multiple frequencies in a light beam as "coherent", but a slow detector or a beam splitter of a Michelson interferometer does not? Again, the "coherency" is not the property of the fields alone. The superposed EM

fields by themselves cannot explain the reasons without reference to the process of physical and causal interactions between the fields and the material molecules. To find the electric current response by fast detector to the same input field of Eq.3 (two independent frequencies), we must first find the amplitudes transmitted by the beam splitter when the MI is set in the "filter mode". They are derived by taking the square root of the transmitted intensities for each of the frequencies:

$$E_1(\nu_1) = a_1\, e^{i2\pi\nu_1 t + i\phi_1} \;\&\; E_2(\nu_2) = a_2\, e^{i2\pi\nu_2 t + i\phi_2}$$
$$\text{Where, } a_1 = \sqrt{2}(1+\cos 2\pi\nu_1\tau)^{1/2} \;\&\; a_2 = \sqrt{2}(1+\cos 2\pi\nu_2\tau)^{1/2} \tag{5}$$

Note that the beam splitter that is normally designed to be a 50/50 energy (or intensity) splitter is now functioning as an energy re-director with all possible ratios between 0 to 1 depending upon the phase delay $\nu\tau$. It can function as a 100% reflector or a 100% transmitter simply based on the phase conditions for the two beams arriving with their Poynting vectors collinear on the beam splitter from the opposite directions [5]. Without the physical and causal presence of both the fields from the opposite directions, the beam splitter cannot function as a variable energy splitter. The current that will be registered by a high speed detector placed after the beam splitter is now given by:

$$D_{fast}(t) = \left|a_1 e^{i2\pi\nu_1 t + i\phi_1} + a_2 e^{i2\pi\nu_2 t + i\phi_2}\right|^2 = a_1^{\,2} + a_2^{\,2} + 2a_1 a_2 \cos\{2\pi(\nu_1 - \nu_2)t + (\phi_1 - \phi_2)\}$$
$$= (a_1^{\,2} + a_2^{\,2})\left[1 + \frac{2a_1 a_2}{a_1^{\,2} + a_2^{\,2}} \cos\{2\pi(\nu_1 - \nu_2)t + (\phi_1 - \phi_2)\}\right] \tag{6}$$

The "fringe visibility" of the beat current is now modulated depending on the value of τ. But, if we put the fast detector to receive the two collinear frequencies of equal amplitudes directly (before the MI), we have a sinusoidal beat current that does not suffer from the "visibility" degradation that happens to the current if detected after the MI:

$$D_{fast}(t) = \left|e^{i2\pi\nu_1 t} + e^{i2\pi\nu_2 t}\right|^2 = 2[1 + \cos 2\pi(\nu_1 - \nu_2)t] \tag{7}$$

The fringe visibility is now perfect and it is unity due to equal amplitudes of the input signals.

2.3 Michelson interferometer with multiple frequencies in "fringe mode"

We now consider the case when the MI is in a "fringe mode", i.e., the collimated output beams emerge through the beam splitter at an angle due to a deliberate tilt in one of the MI mirrors (Fig.3). The beam splitter boundary molecules loose their collective property of re-directing the energy based on the phases of the same frequency beam from the opposite directions. When the Poynting vectors of the two beams are at an angle, the beam splitter boundary condition treats them as non-interacting independent beams, and the energy is split 50/50 (or any other value as originally designed). This is very much like the way a beams splitter always treats beams of different frequencies irrespective of their Poynting vectors. The fringes that will be registered by a slow detector can now be described as:

$$D_{fringe,slow}(\tau_1, \tau_2) = 4 + 2[\cos 2\pi\nu_1(\tau_1 + \tau_2) + \cos 2\pi\nu_2(\tau_1 + \tau_2)] \tag{8}$$

We have introduced two variable delays, τ_1 & τ_2, corresponding to the delay introduced by the MI mirrors and along the spatial fringe axis, respectively. If we now replace the slow detector by a fast detector, we will get the same spatial variation of the fringes as above without any temporal beat current. This is again because the conditions of physical interactions with the superposed fields set by the molecules of the broad band fast detectors for absorbing energy. They release the proportionate number of time-varying electron from the valence to the conduction band, which is detected as a time varying current under the influence of external voltage applied on the detector.

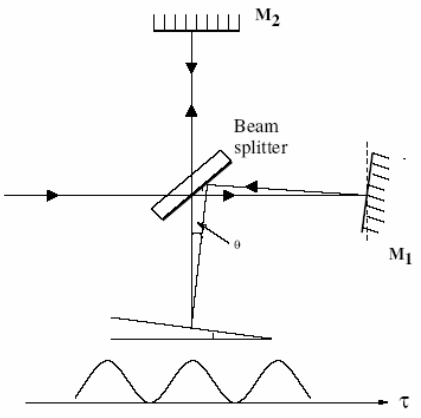

Figure 3. Michelson interferometer in "fringe mode" where the input collimated beam is emerging as a pair of tilted wave fronts giving rise to spatial fringes.

2.4. Heterodyne beat signal generation requires both parallel polarizations and collinear Poynting vectors.

In this section we present a simple yet elegant experiment that can be potentially very accurate to check the degree of collinearity required for the two wave fronts containing different frequencies to efficiently produce the heterodyne beat signal. That the two independent wave fronts for heterodyne mixing should be matched perfectly has been well known by experimentalists in the fields of radar and LIDAR for quite some time [6]. The experimental arrangement for mixing two He-Ne lasers to find the conditions for beat signal generation is shown in Fig.4 along with a photo of the actual experiment.

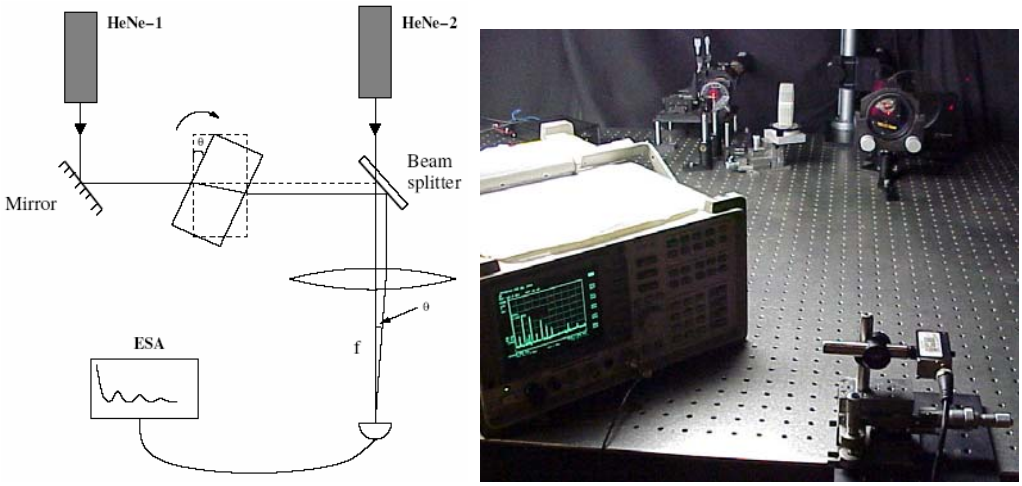

Figure 4. An experimental set up and the actual photograph to measure the angular sensitivity of heterodyne beat signal when two beams carrying different frequencies are combined on a fast detector.

The two lasers were running in multiple longitudinal modes (frequencies) given by ($c/2L_{1,2}$) which also slowly drift in time due to temperature instability. The two laser beams were combined by a beam splitter and then focused by a long focal length lens (75cm) on a fast detector to keep both the beam focused on the same spot (a small 2GHz detector) even when the two laser beams were not collinear but parallel. Laser-1 was folded by a mirror to pass its beam through a thick glass plate, which can be accurately rotated by a graduated turn-table to introduce lateral translation of beam-1 on the beam splitter. The combined beams were passed through a polarizer to assure the parallelism of the states of polarizations of all the modes. When the glass plate was slowly rotated, the beam was translated parallel to its original direction. The process introduced a controllable small angle between the two laser beams on the detector and yet they hit the same spot on the detector before the glass plate was rotated. A careful measurement showed that an angle of about 4 minutes introduced

between the two laser beams was sufficient to stop the beat between the two independent lasers. The value "4 minutes" may not be as accurate as we would like because the optical components and the thick glass plates were all off-the-shelf simple components mostly $\lambda/2$ quality or worse. Consequently, some portions of the aberrated wave fronts may have remained matched as the angle between the two beams was increased. The results are shown in Fig.5 and the figure caption describes further details.

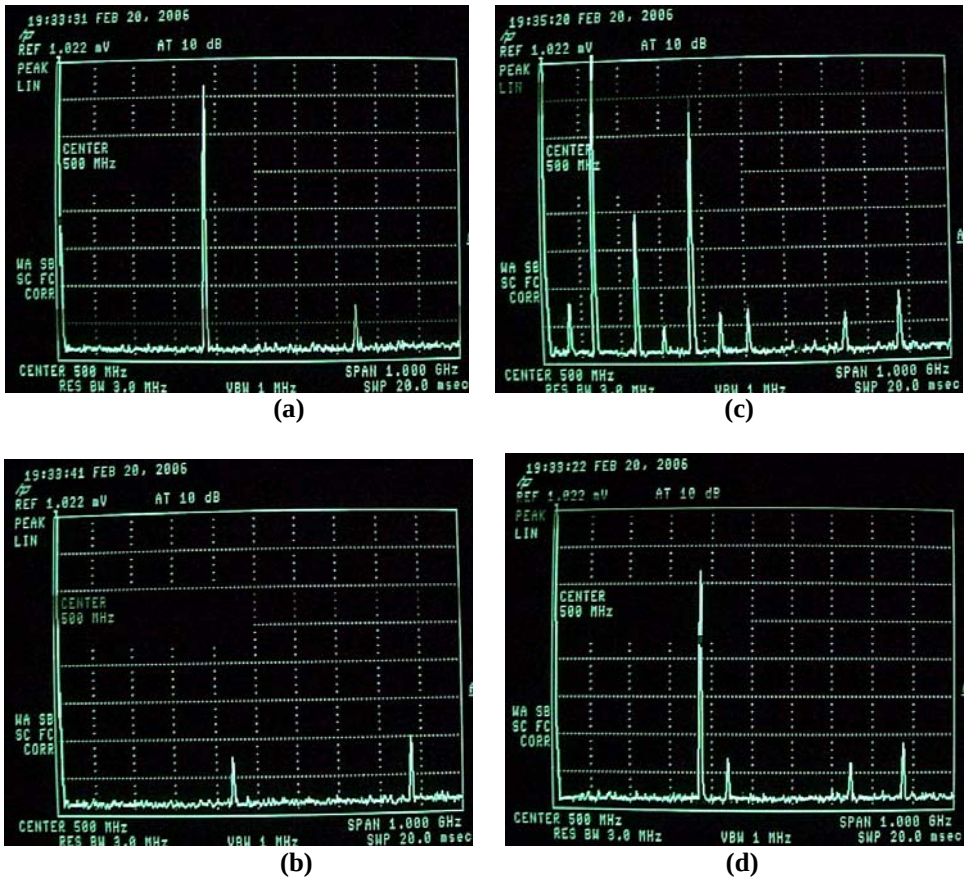

Figure 5. Multiple beat signals due to multiple longitudinal modes (frequencies) produced by two separate He-Ne lasers as shown in (a) and (b); the locations of the beat signal are slightly different due to different laser cavity lengths. Then the two laser beams were combined with perfect collinearity by a beam splitter and focused on the same detector. This is achieved by maximizing the beat signals between the two laser modes, as shown in (c). Then the glass plate was rotated just enough to eliminate the signals corresponding to the beat between the two lasers and gave only the four lines corresponding to each laser separately, as shown in (d), which is effectively a superposition of (a) and (b). The corresponding angular tilt between the two laser beams was found to be about 4 minutes.

3. HOW TO DISTINGUISH BETWEEN THE CONTRIBUTIONS BY FREQUENCY AND PHASE PARAMETERS OF SUPERPOSED FIELDS IN TIME VARYING FRINGES

We are now in a position to discuss the issue raised by Eq.1 in the introduction, viz., how to distinguish between the contributions by frequency and phase parameters of superposed fields in time varying fringes. The cases for time varying fringes due to a pure phase undulation introduced in one of the arms of a two-beam interferometer by a phase modulator is straight forward. The rate of fringe shift will correspond to the phase shift introduced by the modulator, whether electro-optic or mirror translation (vibration). The electronic speed of the detector needs to match the speed of the phase modulator, which rarely goes to GHz domain. If the temporal fringe modulation is due to pure beat signal between different frequencies contained in the input beam itself, again it is easy to discern the situation from the knowledge of the conditions required for beat signal

generation – the two superposed beams must be collinear along with matched wave fronts and their polarizations must also be parallel. So, the beat signals can be detected through an interferometer only if it is set up in the "filter mode". If the interferometer is set up in the 'fringe mode" to create spatial fringes and they are time varying, it is only due to relative phase variations between the beams that are superposed at an angle. For very small angles between the beams, there may be some ambiguity that can be resolved by repeating the experiment with much more care.

3.1. Does a moving mirror generate Doppler frequency shift or a simple phase delay?

In some books [7] and papers [8], it is customary to describe the translation of a mirror as giving rise to Doppler frequency shift. In a simple Michelson interferometer (MI), these authors correctly show that the rate of fringe movement corresponds mathematically to the Doppler shift that would be observed by a detectors moving with a constant velocity relative to the source. A simple MI with a unit amplitude signal of frequency ν will give rise to fringe intensity:

$$D(\nu) = 2(1+\cos 2\pi\nu\tau) \tag{9}$$

Consider, as in Fig.2 that one of the MI mirror is undergoing a translation at a velocity v, then the total delay per second is $\tau = 2\mathrm{v}/\mathrm{c}$, which allows us to rewrite the above equation as:

$$D(\nu) = 2\{1+\cos 2\pi(2\nu\ \mathrm{v}/\mathrm{c})\} \tag{10}$$

The factor $(2\nu\mathrm{v}/\mathrm{c})$ determines the number of fringe shift per second. If we equate this with $(\nu_1 - \nu_2)$ as in actual beat signal per second, then the interpretation mathematically becomes equivalent to the traditional Doppler shift frequency [7, 8]:

$$(\nu_{Doppler} - \nu_{Original}) \simeq (2\nu\ \mathrm{v}/c),\ \mathrm{v} \ll \mathrm{c}. \tag{11}$$

Inspite of this mathematical equivalency, we will simply underscore that a specularly reflecting moving mirror can introduce only phase delay or phase advancement on an electromagnetic field. We will avoid going into the details of physical argument to resolve the issue in this paper. The fact that the spectral measurements by Michelson's Fourier transform spectrometers (FTS) [9] have been giving us the correct results for over a century is an excellent engineering proof of our point. When one uses MI in "filter mode" with one of the mirrors moving, the 50/50 beam splitter would always transmit 50% of the energy for each frequency without any superposition effect. The boundary layer of a beam splitter, the active part of the interferometer in the "filter mode" cannot simultaneously respond to the phases of different optical frequencies. If the MI is set up in the "fringe mode" with the wave fronts superposed at an angle to produce spatial fringes, no detector will respond to the heterodyne beat signal.

4. DISCUSSIONS

The fundamental physical behavior of an EM field is characterized by its intrinsic frequency of undulation of $\vec{E}$ & $\vec{B}$ vectors. This frequency is the repetitive steady rate of cycling of its undulatory phase between 0 and 2π . Thus, the frequency and phase are almost inseparable. However, exploiting the physical processes of detecting light, one can distinguish between the intrinsic frequency of field and the associated phase delay due to propagation.

In this paper we have described concepts and experiments that could help interferometrists to gainfully distinguish between the effects produced by frequency modulation and phase modulation and how to separate the two effects if they are entangled in a single experiment. The key is to appreciate that the fringes we detect are re-distribution and/or re-direction of superposed field energies. This registered change in field energy is a physical process. Accordingly, the quantum (electrical dipole) properties of atoms and molecules (in isolation, in nano clusters and in uniform bulk) present distinguishable unique characteristics when they interact with single or multiple superposed fields. Simple examples are: (i) Isolated atoms can respond to EM fields of very sharply defined frequency that matches with its quantum transition levels. The atoms can respond to this field and absorb energy from it even when it is phase modulated until the modulation rate gets close to the fundamental frequency of the original filed. But an atom cannot sum the effects of stimulation by two fields of same frequency matched to its quantum transition levels if the two fields are orthogonally polarized. This is

because an atom responds to EM field as a uniaxial dipole; it cannot physically execute two orthogonal dipole-like undulations at the same time. (ii) The same logic applies for detecting molecules in the solid state, but because of their broad transition bands (valence to conduction), they can (unlike free atoms or molecules) respond simultaneously to two frequencies at the same time, which allows them to be good temporal beat frequency sensors. However, they cannot keep on recycling themselves to transfer electrons from valence to conduction bands, absorbing energy at a sinusoidal rate of difference frequency, unless the Poynting vectors of the two fields are highly collinear. This clearly indicates that both the $\vec{E}$ & $\vec{B}$ vectors are playing physical roles in beat signal detection because stationary spatial fringe detection by an array of same detectors do not require Poynting vector collinearity. Otherwise, we would have been totally deprived of ever inventing and registering interference fringes. Thus, one can appreciate that "coherence" [10] of electromagnetic fields should not be defined without incorporating the physical properties of the detectors that determine the detectability of fringes. This point is obvious from the following questions: (i) Why do not two orthogonally polarized beams generated from the same "coherent" light produce interference fringes? (ii) Why two beams of different frequencies do not "interfere" with each other on the beam splitter of a Michelson interferometer, but they do on a high-speed broad-band detector?

We have discussed and shown some experimental results regarding possible flexibility in the collinearity requirement of Poynting vectors to produce beat signals. We have also underscored the requirement of same frequency for a MI-beam splitter's capability in re-directing beam energy. And, we all know that superposition effects require polarization to be parallel. How sharply do these three conditions need to be met in the real world of atoms and molecules? Need the angles be matched within milli- or micro or nano-radians? Need the frequencies be matched within Hz, milli-Hz, nano-Hz? Clearly some fundamental physics experiments can open up super-precision measurements once we determine these limits!

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REFERENCES

1. (a) H. Akiyama, O. Sasaki, and T. Suzuki, Opt. Express, **13**(25), p.10066 (2005); "Sinusoidal wavelength-scanning interferometer using an acousto-optic tunable filter for measurement of thickness and surface profile of a thin film". (b) O. Sasaki & H. Okazaki, Appl. Opt. **25**(18), p.3137 (1986),"Sinusoidal phase modulating interferometry for surface profile measurement".
2. SPIE Proc. Vol. **5531** (2004); "Interferometry XII: Techniques and Analysis."
3. C. Roychoudhuri, Phys. Essays, **19** (3), September 2006; to be published, "Locality of superposition principle is dictated by detection processes".
4. (a) M. V. Klein, *Optics*, John Wiley (1970). (b) E. Hecht, *Optics*, Addison-Wesley (1998). (c) F.A. Jenkins and H. E. White, *Fundamentals of Optics*, McGraw Hill (1957).
5. C. Roychoudhuri, SPIE Proceedings **Vol. 6108**, paper 1E (2006), *Reality of superposition principle and autocorrelation function for short pulses*.
6. R. G. Frehlich and M. J. Kavaya, Appl. Opt. **30**, 5325 (1991); "Coherent laser radar performance for general atmospheric refractive turbulence".
7. M. V. Klein, *Optics*, John Wiley (1970).
8. A. Stefanov et al., Phys. Rev. Lett. **88** (12), 120404 (2002), "Quantum correlations with spacelike separated beam splitters in motion: experimental test of multisimultaneity".
9. A. A. Michelson, *Studies in Optics*, University of Chicago Press (1962).
10. L. Mandel and E. Wolf, *Optical Coherence and Quantum Optics*, Cambridge U. Press (1995).