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Can we get any better information about the nature of light by comparing radio and light wave detection processes?

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Abstract

Comparing the radio and the light wave detection processes, this paper clarifies that what we normally call "interference" of EM waves, is actually the summation of the field induced signals carried out by the detectors. We have also presented a generalized definition of the superposition effects as measured (SEM) due to multiple physical steps behind any detection process. Thus the manipulation of the various physical properties of the detectors to various parameters of the EM waves can yield different "interference" effects for the same set of superposed waves. If EM waves interfered by themselves, such manipulation would not have been possible. We also give simple examples of visibility degradations due to rotation of the states of polarization and underscore that such degradation should not be assigned to degradation of coherence properties of the EM waves. It is due to the change in the stimulating amplitude, reduced by Malus'cosθ law, which is accessible to the uniaxial dipole like response of the detecting molecules.

[Key Words: differentiating radio & light wave detection, superposition effects for radio and light waves, physics of measurement process]

1. Introduction

Substantial investments in research and opening new companies are currently being made for quantum communications (QCom) and encryptions using the quantum properties of visible and infrared light (photons). Interestingly, even though radio and light wave "photons" are both solutions to the same Maxwell's wave equation, we have not come across any equivalent investment in QCom using traditional radio waves. However, some active interests are there in the microwave domain using microwave cavity QED, which clearly consists of quantum devices. The fundamental difference between the radio and light wave communication systems could be understood by analyzing the key common operational system steps: (i) generation, (ii) modulation, (iii) propagation, and (iv) detection of the carrier signals. In this paper we will focus only on the detection processes. The energy transforming receivers for the radio waves are very classical (dominated by macro LCR circuits and devices) in contrast to light wave systems where we must use quantized energy states of dipole-like atoms and molecules or their assemblies. For radio waves, the LCR-receiver produces undulatory (AC) current exactly replicating the carrier frequency with the application of any external voltage. For light waves, the photo detector transfers discrete valance-band electrons to the conduction-band as a one-way (DC) electric current extractable with applied external voltage; the carrier frequency information of the light wave is completely lost. The differences in the behavior of these two receivers become even more dramatic when two or more different carriers frequencies are present simultaneously. For an LCR circuit with broad frequency response, the induced current literally becomes a linear superposition of *AC currents* replicating all the incident frequencies and hence the current can be analyzed using the Fourier time-frequency superposition theorem. The photo detector in contrast produces a complex undulatory *DC current* that is given by the square modulus of the linear sum of all the complex oscillatory signals. The individual absolute frequency information is lost permanently. They are available only as all-possible difference frequency currents and hence cannot be expressed as proportional to the summation of the individual amplitude signals as in the case of radio frequency induced currents. Is the popular emphasis on the quantum-ness for EM wave packets (photons) with frequencies much higher than radio waves due to the quantum-ness of the photo detector? Does visible light really constitute indivisible entities we tend to loosely call "photons"? Why do we ignore the quantum-ness of the radio photons? Is it only because the energy of the radio photon is eight orders of magnitude smaller than that for the visible photon, $\nu_{rad} / \nu_{vis} = 10^6 s^{-1} / 10^{14} s^{-1} = 10^{-8}$? Should one then invest time to invent some novel noise-free photo detectors for the radio frequency domain? Would that allow radio wave communication become equally amenable to quantum communication? The key question remains unsettled as to whether Dirac's second quantization have really resolved the "wave-particle duality" of electromagnetic waves across the entire spectrum, from long radio waves to the extremely high frequency gamma rays.

2. Is the 'photon' an indivisible packet of energy?

Non-interference of light and causality violation. Our position is that there is no wave-particle duality. When atoms and molecules undergo energy level transitions releasing a discrete packet of energy $\Delta E = h\nu$ ('photons'), it emerges out as a space and time finite EM wave packet with a carrier frequency ν and propagate out as a classical wave packet following diffraction principle [1]. Newton's hunch that light is some how "corpuscular" but not "particle" was correct.

The literature is full of claims of dual behavior of 'photons' simply based on different experimental arrangements. If inanimate entities in this universe were really to behave differently for different experimental set up by us, we could not have understood so much of the workings of this evolving universe that appear to be systematically logical independent of our conscious attempt to understand the processes. The correct force law of interaction between the sensors and the sensees (detectors and detectees) must apply for all measurement (detection) processes. First, let us take note of our daily visual observations. It clearly indicates that well-formed ("far-field" from source or disturbance) light beams simply do not re-distribute their energy (or, interfere with each other to create fringes by themselves) when the beams contain energy equivalent to trillions of 'photons' [2-7]. Otherwise we could not have recognized the face of our loved ones by imaging the wave front coming from their faces while being crossed by billions of other unwanted sight carrying waves. If the reduction of intensity of a light beam to the level of a single photon ($h\nu = 6.626 \times 10^{-34} J.s$) per millisecond or second endows them with the new property of self-interference, then we need to find the cause of such a strange behavior when they are isolated from the original beam. In general, if a single particle can make itself appear and disappear from measurements, then it is strange to rationalize how a macro universe can keep on evolving causally out of interactions between elementary particles which are never causal. Dirac's claim of "Each photon then interferes only with itself" [8] and more recent claims of teleportation of single photons through interferometry [9, 10] violate causality besides neglecting the obvious fact that EM waves cannot generate "interfere fringes" in the absence of material dipoles, at least not within the linear domain of our routine laboratory environments.

Non-equivalency of photons and "clicks". Second, most of the claims of single photon detection for almost a century come from the misplaced interpretation of the discrete "clicks" as discrete 'photons'. In photographic records of fringes, it is the Silver halide crystallites that create the graininess. Wave or quantum nature of light has nothing to do with it. However, the Silver halide molecules themselves are quantum mechanical devices requiring discrete amounts of energy absorption dictated by the requirement for the correct optical frequency, $\Delta E = h\nu$ for proper exposure. Further, irrespective of the wave-particle duality, the general principle of superposition does not bar quantum devices from absorbing the right amount of energy ΔE from an assembly of multiple superposed fields as long as they provide the right dipole stimulating frequency ν. Very similar logic applies to the origin of electronic "clicks" from photo detectors. Electrons are indivisible elementary particles and their binding energies are quantized by a similar constraint $\Delta E = h\nu$. So, when an assembly of detecting dipole molecules experiences the stimulation by the correct frequency ν, the assembly can release, from the valance to the conduction band, only a discrete number of n-electrons by absorbing $n.\Delta E$ quantity of energy from the superposed light beams. The rate will be dictated by the flux of light. This discrete property of displaying "clicks" by various light detectors should not be assigned to the electromagnetic filed. The correctness of quantum mechanics assures us that the "clicks" necessarily correspond to the absorption of ΔE quantity of energy from the field, but it is not sufficient to claim that photons are indivisible entities.

Successes of semi-classical model. Third, E. T. Jaynes [11] and W. Lamb [12] have shown that photo electric emission can be accurately modeled by semi-classical approach (classical EM field and quantized dipoles), without the need to quantize the EM wave.

Light diffraction, a classical process. Fourth, light propagation by diffraction process is highly matured field that accurately predicts the design properties of even the most modern nano photonic wave guides and devices. Explaining the behavior of a passive convergence or divergence of a plane wave as quantum mechanical scattering is a very difficult mathematical task. Quantization of atoms helped us to uncover a staggering amount of new information about the micro universe. In contrast, quantization of EM fields has only confused us about the nature of EM radiation, rather than giving us any substantial amount of new information.

More than one 'photon' needed for single electron emission. Finally, we would like to refer the readers to a paper by E. Panarella [13] where he demonstrated with a meticulous set of experiments that one needs a minimum amount of EM wave energy that is equivalent to at least four 'photons' to trigger a photo electron emission.

3. Formalizing detection processes

Let's first establish the universality of the process behind registering the "superposition effects as measured" (SEM) that is at the core of doing physics through experimental validations [14]. We divide the process in four steps. (i) A *Transformation:* We can scientifically measure only re-producible quantitative *transformations* that are experienced by our interactants (or detector-detectee, or sensor-sensee). (ii) *Energy exchange*: Any transformation in measurable physical parameters requires *energy exchange* between the interactants. (iii) A *force of interaction*: The energy exchange must be guided by a *force of interaction* between the interactants and it must be strong enough to facilitate the exchange of energy, which are usually constrained by the characteristic limitations of each interactants. (iv) *Physical superposition* and *locality*: Since the effectiveness of all force rules dies with distance, energy exchange between the interactants requires that they must experience each other as *local* influence, implying that they must be *physically superposed* entities (experience each other within their sphere of influence). (v) *Nothing is known completely*: At the current state of our science we do not know the complete set of parameters and their rules of variations of either of the interactants. Thus, drawing objective conclusions as to some new intrinsic properties of either of the interactants based on one experimental observation will be limited inspite of help from mathematical logic and "leap of imagination". We also must always be extra careful not to assign the intrinsic property of one of the interactants on to the other and claim objectivity. We believe that we are assigning the intrinsic quantum properties of photo detectors (quantized electrons and their discrete energy requirements) on to the diffractible and divisible EM wave packets.

Let us re-construct the steps behind SEM again as the evidence of its universality (or causation rule): Interactants must be sufficiently *local* to be able to experience each other as physically *superposed* within the range of the *interacting force* that will allow some *energy exchange* followed by some t*ransformations* that is amenable to measurements for us. Thus, any materialized superposition effect is necessarily an *active* and a universally *local process*, not a passive mathematical principle that our consciousness can influence! Mathematical methodology must recognize this Reality Ontology (RO) [5].

Thus the same pair of interactants under the same spatial environment must interact under the influence of the same force. Then they will undergo the same reproducible transformation preceded by energy exchange amongst each other. However, if we try to detect the same type of detectee (in our case, EM waves) with different types of detectors, the energy exchange process and the consequent measurable transformations will be different. We do not believe that such causally different effects due to the same type of detectee should be ascribed as duality of the detectee. A photo detector will always release discrete electrons without the information about the detectee frequency, while an LCR circuit will generate "classical" current along with the detectee frequency.

4. Differentiating radio and light wave detection

4.1. Detecting radio 'photons'. Let us compare and contrast the detection of a pair of radio waves and a pair of optical waves, both pair having two distinctly different carrier frequencies. Standard radio wave detectors are tuned (resonant) LCR circuits whose resonance width can be manipulated to accept only one of the two frequencies, or both as depicted in Fig.1a. For, optical wave detection, we chose resonant atoms in gaseous state for sharp resonance to only one optical frequency and a solid state detector like APD with broad valence-conduction bands to accommodate simultaneous response to two frequencies (Fig.1b).

The free conduction electrons in an LCR circuit directly respond to electromotive force induced on the circuit at the radio wave frequency and collectively undulate back and forth at the same radio frequency within the LCR circuit by absorbing energy from the radio wave. The measurable transformation is this AC current in the circuit, which exactly resembles the radio wave in all aspect except for a possible fixed phase shift.

$$E(t,\nu_1) = a\cos 2\pi\nu_1 t; \quad I_{LCR}(t,\nu_1) = \eta a\cos(2\pi\nu_1 t + \varphi) \tag{1}$$

Where $E(t,\nu)$ is an EM wave; η is the energy transfer coefficient; and $I_{LCR}(t,\nu)$ is the AC current induced in the LCR circuit by the radio wave. Note that the frequency information is preserved perfectly bb the linear LCR circuit that can be read out by a suitable oscilloscope. Note that the constant η actually contains the information regarding the real physical processes behind the field-LCR circuit interaction and the energy transfer.

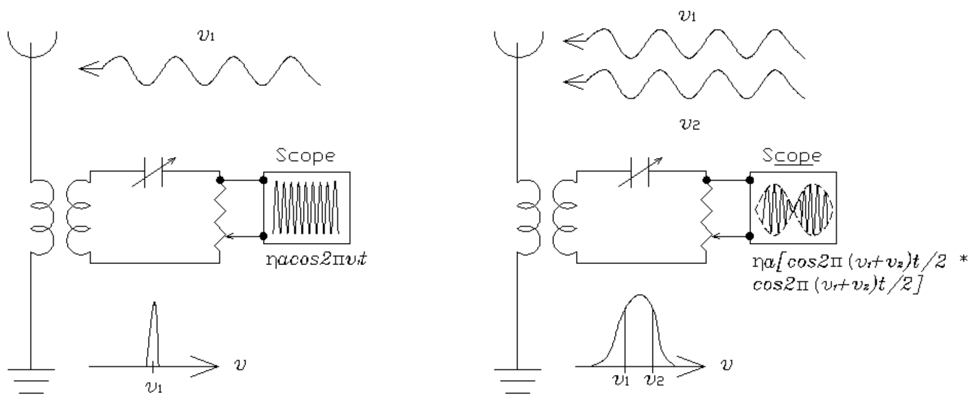

Figure 1. Comparing the response characteristics of two resonant LCR circuits to pure radio waves. LCR-1 on the left is resonant only to one frequency ν_1 and can measure it as an oscillatory current at frequency ν_1 . LCR-2 on the right shows the superposition effect due to two radio waves. It has a broader resonance and can respond to two frequencies simultaneously by producing two superposed currents at ν_1 & ν_2 producing an undulatory beat current as if the two radio waves interfered by themselves.

Now consider two radio waves with two distinct frequencies with fairly close values. While propagating through the free space, they do not interfere or redistribute each others energy. Otherwise we could never have received clear radio signals from far away stations. However, they do produce superposition effects within the detecting LCR-2 circuit.

$$E_{1,2}(t,\nu_{1,2}) = a\cos 2\pi\nu_{1,2}t; \quad I_{LCR}(t,\nu_1,\nu_2) = \eta a[\cos 2\pi\nu_1 t + \cos 2\pi\nu_2 t]$$
$$= 2\eta a\cos 2\pi\frac{\nu_2+\nu_1}{2}t \bullet \cos 2\pi\frac{\nu_2-\nu_1}{2}t \qquad (2)$$

We have assumed that the amplitudes of both the incident radio waves have the same amplitude a. Notice that the measurable current in the circuit appears exactly as the linear superposition of the two radio waves as if they interfered by themselves until we pay careful attention that the summation implied by the superposition principle has actually been carried out by the LCR-2 circuit indicated by the common constant ηa. If we normalize Eq.2 to eliminate the constant. ηa , we can easily confuse ourselves that two radio waves have interfered with each other (summed themselves). Many different studies are required to fathom the depth of physics that lies buried inside η & a. The LCR-1 circuit, having sharp response capability only to frequency ν_1, would report to us that there was no other radio wave at frequency ν_2. Our capability to extract knowledge out of nature is very much limited by our invented sensors and the intrinsic limitations of the sensors themselves, some of which we may still be unaware of.

4.2. Detecting optical 'photons'. Let us now reconsider the above experiments but in the optical frequency domain that requires quantum detectors like atoms in gaseous state for sharp resonance or assembly of atoms for broad band resonance. As of now, it appears that the necessity of quantum detectors for optical frequencies is a fundamental limit of nature based on our current technological knowledge. It is as yet unknown to us whether in future we might be able to invent some nano LCR circuits that can directly generate measurable currents at optical frequencies. Optical photo detectors follow square law. Measurable currents that can be extracted from photo detectors is experimentally found to be proportional to the short time integration of the square of the electric field strength of the incident optical wave, which has later been validate by quantum mechanics.

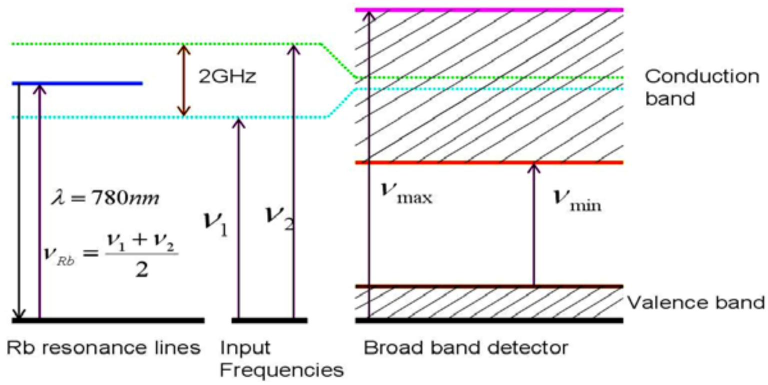

Figure 2. Comparing quantum detectors for light waves with sharp resonance and broad band resonance. Rb-atoms at the left can respond only at the ν_{Rb} frequency. The spontaneously emitted intensity cannot tell us the original frequency without other comparative knowledge. A broad band detector on the right can respond simultaneously to two, $\nu_1 \& \nu_2$, or more frequencies and generate all possible difference frequencies (heterodyne signal). We cannot recover the absolute values of the frequencies, which is in contrast to the case of radio wave detection by LCR-2 of Fig.1 that gives the beat signal allowing inverse Fourier transform to recover the absolute frequencies.

Let us now expose a Rb-gas cell [2] to an optical wave of carrier frequency ν_{Rb} containing atoms with resonant energy levels matching the quantum rule $\Delta E = h\nu_{Rb}$. Due to resonance matching, the atoms will be strongly stimulated as dipoles at the frequency ν_{Rb} and each atom will absorb an amount of energy ΔE from the field and then reemit the energy as a spontaneously emitted wave packet. The corresponding linear susceptibility (polarizability) of the atoms is represented by $\chi_1(\nu_{Rb})$ and we can represent the absorption process as (see Fig.2, left segment):

$$E(t,\nu_{Rb}) = a\cos 2\pi\nu_{Rb}t; \quad I_{SP} = \frac{\chi_1^2(\nu_{Rb})a^2}{T}\int_0^T \cos^2(2\pi\nu_{Rb}t+\varphi)dt = \chi_1^2(\nu_{Rb})a^2/2 \qquad (3)$$

The measurable transformation in this case is I_{SP} that is proportional to the intensity of the spontaneously emitted light from the gas cell. The value of $\chi_1(\nu_{Rb})$ is zero for all other frequencies. Notice that because of the "quadratic law" behavior of the quantum photo detectors, we have completely lost direct information regarding the carrier frequency of the incident optical wave. Only by knowing the "resonance" behavior $\chi_1(\nu_{Rb})$ of the atoms from various other experiments and by doing spectroscopy of the spontaneous emission, we may indirectly gather some limited information regarding the carrier frequency of the original optical wave. Even an ordinary broad band photo detector with $\chi_1(\nu_{\max.},\nu_{\min.})$ non-zero for a band of frequencies between $\nu_{\max.} \& \nu_{\min.}$ would give us a DC current proportional to I_{SP} without any carrier frequency information. We have used resonance atoms to illustrate the point that the simultaneous presence of a pair of optical wave at frequencies $\nu_1 \& \nu_2$ would have gone completely un-reported by these atoms (see Fig.2, middle segment). In other words, the gas cell would report that there were no optical beams at all simply because the atoms would not be stimulated by the frequencies $\nu_1 \& \nu_2$. Note again that χ_1 contains a lot of details (physics) regarding the actual dipolar stimulation processes by the EM wave. It will become partially apparent in the next experiment.

Let us now use the broad band detector along with fast response electronics and shine both the optical beams by making them incident collinearly on the detector. The extractable current now sinusoidally undulates at the difference or the beat frequency:

$$E_{1,2}(t,\nu_{1,2}) = a\cos 2\pi\nu_{1,2}t;$$
$$I_{PD}(t,\nu_1-\nu_2) = \frac{\chi_1(\nu_{\max.},\nu_{\min.})a^2}{T}\int_0^T[\cos 2\pi\nu_1 t + \cos 2\pi\nu_2 t]tdt = \frac{\chi_1^2 a^2}{2}\cos 2\pi(\nu_1-\nu_2)t \tag{4}$$

Unlike the sharply resonant quantum detector, the broad band detector reports the presence of two optical frequencies but only as their difference; the absolute values of the frequencies are still lost as in the last case (Eq.3). Further, the undulatory beat current of Eq.4 gets lost if the time constant of the electronic circuitry is much longer than the inverse of the beat frequency. The slow circuit then makes second time average of the undulatory current of Eq.4 and presents it as an average DC current. This is a "classical' instrumental effect in contrast to the first short time average over the period T, which is inherently quantum mechanical. First, the dipolar response properties of the detecting molecules (singly or collectively depending upon the detector structure, gas or solid state, etc.) determine the initial quantum mechanical response to the superposed beams that are buried inside $\chi_1(\nu_n, \hat{p}, \hat{P}, ...)$, where ν_n corresponds to the quantum mechanically allowed transitions levels and $\hat{p}, \hat{P}$ are unit polarization and Poynting vectors, respectively. In reality, dipolar stimulation is induced to any atoms and molecules irrespective of whether the incident filed matches the frequencies ν_n allowed by the quantum levels, which has been extensively studied by the field of non-linear optics [15]. The generalized dipolar stimulation is given by

$$\vec{d}(\nu) = \sum_n \chi_n \left[\vec{E}(\nu)\right]^n \tag{5}$$

Where χ_n is the n-th order susceptibility of the molecule to be polarized by the n-th power electric vector of the incident wave. All materials respond as dipoles to all frequencies besides the quantum mechanically allowed set of frequencies. Only the strength of polarization and the consequent energy exchange (conversion) is limited by the strengths of χ_n that is normally very weak.

4.3. Roles of $\hat{p} \& \hat{P}$ in superposition effects. The roles played by the polarization and the Poynting vectors in superposition effects are very instructive to appreciate in the context of joint stimulation by multiple fields with different values for $\hat{p} \& \hat{P}$. Usual literature does not connect unique roles in the context of measuring superposition effects.

Consider first the role of the polarization vector $\hat{p}$. We know from classical optics that light polarized parallel to the plane of incidence does not get reflected at the Brewster angle. Under this condition, the boundary molecules are stimulated as dipole along the refracted ray (direction), which is precisely orthogonal to the potential direction of reflection; and we know that dipoles do not emit any radiation along its axes. When a 50% beam splitter in an interferometer experiences two coherent and same frequency collimated beams of equal amplitudes and same state of polarization from opposite direction with the conditions that the Poynting vectors for the two reflected and the two transmitted directions are collinear, 100% energy of both the beams can be redirected in one or the other direction based on the choice of the phases on the dielectric boundary [4]. In the absence of the beams splitter, the two beams simply cross through each other without any perturbations since light beams by themselves do not interfere. If the two beams have non-parallel polarizations, then the $\cos\theta$ projections of the amplitudes on each others directions will determine the strengths of the re-directed energies for each polarization. However, if the Poynting vector directions $\hat{P}$ for the reflected and the transmitted directions are non-collinear, then each beam will generate its own pair of transmitted and reflected beams, irrespective of their states of polarizations. No superposition effects (or re-direction of energies) are imposed by the beam splitter! However, a detector array after the beam splitter will register intensity variations (fringes) whose spatial frequency will be given by the tilt between the two wave fronts. We do not believe that these rules of classical physics that makes the boundary molecules of a beam splitter material an inseparable part of the observed superposition effects can be ignored when the intensity flux of the beams are reduced to that which is equivalent to a few photons per second.

4.4. Field coherency vs. simultaneous detectivity of detectors behind visibility degradation. Suppose a Mach-Zehnder interferometer (MZI) is set up to produce beautiful fringes with a linearly polarized CW laser beam. If we now insert two orthogonally oriented linear polarizers in the two MZI arms, the original fringes are replaced by a uniform intensity that is the simple sum of the two intensities [5]. If we now slowly rotate back one of the polarizers slowly and eventually make it parallel to the polarizer in the other arm, we will see the emergence of the fringes with continuously enhanced visibility (contrast) from zero to the original unity. If we claim that light interferes with light, then we need to explain the continuous variation of the fringe visibility as continuous variation of the degree of coherence between the beams in the two arms of the MZI even though they have been produced by splitting the same CW coherent beam. This is a rather artificial definition of coherence for waves. In contrast, we have proposed a simpler and yet logically more sound definition based on Malus' law. Material dipoles, even when they are intrinsically isotropic, they first respond as a dipole to the strongest E-vector and carries out polarized undulation along that direction. The dipolar undulation being a uniaxial process, the same dipole cannot simultaneously respond to another weaker E-vector if it is exactly orthogonal to the other E-vector. Effectively it is forced to ignore the presence of the weaker field. Thus it is unable to sum the effects of the joint stimulation. Therefore the superposition effect cannot become manifest. When the second linear polarizer is at an angle less than 90^{o}, the dipole now combines its response to $\cos\theta$ component of this filed with the original stronger E-field, giving rise to variable contrast changing with θ. We believe that this new hypothesis is operationally a better one than claiming that the degree of coherence between coherent laser fields changes with altered polarization angle as $\cos\theta$.

We have similar confusion regarding coherency between optical beams of different frequencies. Michelson's Fourier transform spectroscopy (FTS) works with the assumption that different frequencies are incoherent, which is obviously not true in general since heterodyne effects are now standard engineering tool for many measurements. A passive beam splitter, as in Michelson's FTS system, responds separately to each optical frequency, not to the joint stimulation due to the superposed fields of different frequencies. So Michelson's assumption was functionally correct for his particular arrangements. When the assembly of the dipole molecules is active detectors and if their quantum properties allow them to respond to all the frequencies, they respond to the joint stimulation (or sum of all the allowed stimulations) and the absorbed energy becomes proportional to the square modulus of the joint amplitude stimulation, as shown in Eq.4 for a two frequency case.

Explicit discussion of the roles of $\hat{p}$ & $\hat{P}$ is also interesting for heterodyne superposition effects. Eq.4 is correct only under the assumption that the polarizing vectors $\hat{p}$ for both the beams are collinear; otherwise the factor cosθ as per Malus' law has to be applied. Further, the two Poynting vectors for the two superposed beams should also be collinear. Coherence theory cannot provide any explanation why the observed collinearity of the Poynting vector is critical for the heterodyne superposition effects to become manifest. This collinearity is not required when the superposed beams are of same frequency. Further, we experimentally found that while perfect collinearity of the Poynting vectors produce the best contrast heterodyne fringes, they still remain visible (measurable) for a small angle between the vectors for up to about 4^{o} and the decay in the beat current is almost exponential [16]. The determination of the Poynting vector requires the identification of both the E and B vectors. So we must conclude that the strength of joint dipolar stimulation due to different frequencies and the corresponding absorption of energies from all the fields are influenced by both the E and the B vectors of the impinged fields.

5. Conclusions

It is critical to appreciate the real physical steps behind any measurements. We have presented a generalized description of measurements by identifying the multiple steps behind superposition effects as measured (SEM), which can be appreciated as the universality of causation rule. Interactants must be sufficiently (i) *local* to be able to experience each other as physically (ii) *superposed* within the range of the (iii) *interacting force* that will allow some (iv) *energy exchange* followed by some (v) t*ransformations* that is *amenable to measurements* for us. Thus, any materialized superposition effect is necessarily an *active* and a universally *local process*, not a passive mathematical principle that our consciousness can influence! We call this Reality Ontology (RO).

We hope that it is clear as to why electrical engineers would interpret the "interference' of EM waves as directly a wave-wave interaction. For multi frequency radio waves received by a broad band LCR receiver gives a current that is precisely proportional to the sum of the individual frequencies of the radio waves as shown by Eq.2. These LCR detectors have linear response to the incident infrequencies. The resultant time varying (pulsed) current in the circuit can be correctly modeled by the time-frequency Fourier theorem. However, for higher frequency EM waves from infrared and up, our detectors are square law. The registered current is a "DC" current because of "one way" transfer of electrons from the valance to the conduction band. These detectors thus loose the information regarding the absolute value of the incident frequency. Beyond these differences, critical analysis of the detection processes teach us that the superposition effects due to EM waves become manifest through the detectors response. In other words, the summation implied by the superposition effect is physically carried out by the detectors response properties. This is why for the same set of superposed waves, the superposition effects can be made to produce different "interference" effects by changing the response characteristics of the detecting dipoles to various intrinsic properties of light waves like frequency, polarization and Poynting vectors as discussed in section 4.3 and 4.4. Thus recognition of "interference" as superposition effects as experienced by detectors, opens potentials for newer engineering innovations by manipulating the electromagnetic and crystal properties of the detecting medium by imposing external and internal fields.

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