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FLASH[1]—A Superluminal Communicator Based Upon a New Kind of Quantum Measurement

Nick Herbert[2]

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The FLASH communicator consists of an apparatus which can distinguish between plane unpolarized (PUP) and circularly unpolarized (CUP) light plus a simple EPR arrangement. FLASH exploits the peculiar properties of "measurements of the Third Kind." One purpose of this article is to focus attention on the operation of idealized laser gain tubes at the one-photon limit.

1. INTRODUCTION

The theorem of Bell guarantees that two quantum systems which have interacted in the past can no longer be regarded as independent systems.(1) The mathematical inseparability of the quantum theoretical representation is an essential part of nature, not a mere accident of the formalism. These once interacting systems—which in general may be space-like separated, hence truly isolated according to special relativity—remain in some sense connected in a manner unmediated, unmitigated, and immediate. If this instant quantum connection were directly observable—rather than indirectly verified via Bell's argument—it would put quantum mechanics into conflict with special relativity by permitting faster-than-light signaling.

Can Quantum Connectedness Act as a Medium for Superluminal Communication?

This question has been considered by physicists at Berkeley(2) and Trieste,(3) and answered in the negative. A typical scheme imagines systems

[1] FLASH: acronym for First Laser-Amplified Superluminal Hookup.

[2] Box 261, Boulder Creek, California.

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I and II correlated at source O and traveling to detectors A and B, respectively, where various measurements may be performed upon them at the experimenter's pleasure.

If the observer at B can discover, by some measurement made on system II alone, what measurement A has chosen to make on system I, it is easy to construct a superluminal signaling scheme which connects A and B.

Demonstrations of the impossibility of superluminal signaling proceed by showing that the value of any quantum mechanical observable at B is independent of the choice of measurement performed at A. These proofs are straightforward and elementary, do not involve any exotic—possibly questionable—axioms. The easiest way a determined superluminal signaler might hope to circumvent such clear-cut prohibitions would be to widen the notion of "observable" to include events not explicitly covered by the concept of "quantum mechanical observable" as used in these proofs.

In particular, quantum mechanical observables are always *average values* (or expectation values) of a large number of similarly prepared experimental situations. Quantum mechanics does not in general predict the occurrence of individual events but only statistical aggregates formed by such events. There are many possible ways that individual events can realize the same quantum averages. Quantum theory regards all these ways as equivalent, as indistinguishable outcomes.

Now it is precisely the occurrence of these individual events (but not their averages) which Bell proves to be instant connected.

What seems to be happening here is that one choice of apparatus at A will lead to certain individual events at B, while another choice of apparatus at A will lead (superluminally?) to another set of individual events at B. However although the particular individual events at B must be different in each case (as we are assured by Bell), any average we might form from these events will not differ in the two cases. The pattern remains the same as its elements change and any message must be coded in the pattern. Another way of picturing this situation is to say that one setting at A leads to a particular random sequence a B; another setting at A leads to a different random sequence at B. But two truly random sequences are indistinguishable. Superluminal message (alterations of individual events) can be *sent* but not *decoded.*

2. SUPERLUMINAL SIGNALLING VIA THE FLASH PROCESS

Previous schemes[4] to exploit quantum connectedness for faster-than-light (FTL) signaling relied on a canonical EPR setup: A source O emits back-to-back S-state photons I and II which are detected by polarization sensitive maximal detectors (calcite prisms plus wave-plates when appropriate) at distant detection sites A and B. The photon correlation is such that when photon I is observed (at A) to have polarization state X, photon II will be observed (at B) to be in the orthogonal polarization state.

Choosing to measure "plane polarized photons" at A will "collapse" the state at B into "plane polarized photons" while chosing to measure "circularly polarized photons" at A "collapses" the state at B into "circularly polarized photons." The crucial question for superluminal signaling is: "Can you detect a difference between a collection of "circularly polarized photons" and a collection of "plane polarized photons"?" Both beams are *unpolarized* which means that in each case the two orthogonal pure polarization states occur at random in the beam. Another way of phrasing this question is: "Can an experimental distinction be made between plane unpolarized (PUP) light and circularly unpolarized (CUP) light or is there only one kind of unpolarized light?" If such an experimental distinction can be made, then superluminal signaling becomes possible in principle.

The quantum mechanical description of unpolarized light does not recognize the PUP/CUP distinction. As far as quantum theory is concerned, there is only *one* kind of unpolarized light. If quantum theory is a complete description of nature—as is often asserted—that would be the end of the story. An experiment in which PUP and CUP could be distinguished would not only permit superluminal signaling, it would reveal that quantum theory is incomplete—incidently realizing the goal of the orginal EPR thought experiment.

The FLASH process consists of an S-wave photon source at O and a calcite/wave-plate combination at A. Without the wave-plate, the calcite prism separates light into plane polarized eigenstates (H & V) and the light at B is, because of its correlation with the light at A, plane unpolarized (PUP). With the wave-plate inserted at A, the calcite prism separates the light into circularly polarized eigenstates and the light at B is circularly unpolarized (CUP).

If the observer at B used a similar detection scheme, she could sort photons into either circular or plane polarization categories but not both: the maximal measurement you can perform on photons is a dichotomous one, according the usual ways of thinking. The choice of which dichotomy to force is up to you. However no matter what the choice, a random sequence of Horiz/Vert or Right/Left photons would be observed giving no clue as to what measurement A is making on her photons. To distinguish CUP from PUP, B must be able to make more complex measurements than are possible with passive optical devices.

The FLASH scheme uses a nonselective laser gain tube to multiply single photons into bursts of identically polarized photons, whose collective

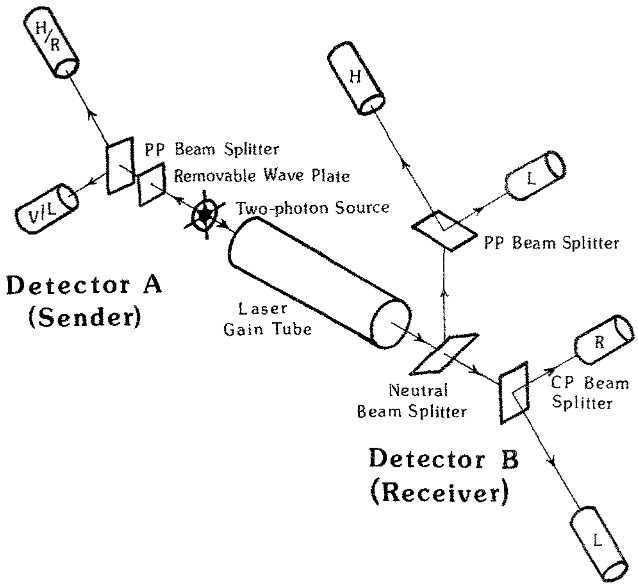

Fig. 1. The FLASH detection process. Photons in beam B (traveling to the right) are rendered either circularly unpolarized (CUP) or plane unpolarized (PUP) by positioning of the quarter wave plate in beam A (traveling to the left). Each B photon is amplified by a nonselective laser gain tube and the resulting isopolarized burst of light is examined for counting asymmetry in either the CP or PP channel.

polarization can now be measured with a beam-splitter arrangement. Fig. 1 illustrates one polarimeter possibility.

Imagine that a plane polarized (H) photon has been detected at A. This means that a plane polarized (V) photon is incident on the B subsystem. This photon is amplified by the gain tube into N V-polarized photons which are separated by the neutral beam splitter into two packets of roughly $N/2$ photons each—all plane polarized in the vertical plane. One of these subbeams is directed to a CP splitter where it is divided equally into R and L beams, and detected. The other subbeam is directed to a PP splitter and all $N/2$ photons are deflected into the V detector. The signature of a vertically polarized photon is:

H: 0 photons

V: $N/2$ photons

R: $N/4$ photons

L: $N/4$ photons

In a similar manner RCP and LCP photons leave a unique signature. It is easy to see how a PUP beam could be distinguished from a CUP beam by this apparatus.

A serious objection to FLASH concerns the *noise* of the laser process. The rate of spontaneous noise can be calculated by assuming *one stimulating photon per mode* continually present.[5] This condition assures us that if the incoming (CUP or PUP) beam is nondegenerate (less than one photon per mode), the noise will always be greater than the signal.[6] On the other hand, if the incoming beam is degenerate and thus able to overcome the quantum noise, the photons will "tread on one another's heels" and scramble the polarization message (CUP or PUP). There is no range of input beam intensity where FLASH will give a signal/noise ratio greater than unity. The objections considered here apply to all laser-amplified FTL proposals.

So for each "photon burst" the signal of the input photon will be masked by noise. However by looking at many bursts we can average out the noise and extract the appropriate signal signature (either an $|H-V|$ excess is the case of a PUP signal, or an $|R-L|$ excess in the case of a CUP signal). The number of bursts necessary to establish the nature of the signal at a given confidence level will depend on the degeneracy of the EPR source: the higher the degeneracy parameter—but always less than one to avoid signal scrambling—the fewer bursts must be analyzed to recognize each signal bit.

In contrast to traditional *Gedankenapparat* involving Compton-recoiling slits, single photon weighing devices, etc., realization of the FLASH proposal with practical equipment is not out of the question. Although sufficient for a thought experiment, the single photon polarimeter (detector B in Fig. 1) involving as it does the detection of a *lack of counts* in a particular channel, would be difficult to implement. A design (suggested by J. Cramer) based on coincidence techniques is better.[15]

In the Cramer scheme, detector B does not consist of a CP splitter and a PP splitter but of two beam splitters of the same type. Suppose two PP splitters are used (P-mode). Four kinds of triple coincidences are possible: THH, THV, TVH, and TVV, where T represents the trigger pulse, HH means a count in each H channel of the two PP beam splitters, etc. If the incoming beam is CUP, these four kinds of coincidence will occur with equal frequency. However if PUP light is incident on the gain tube, there will be an excess of THH, TVV responses.

Similarly when two CP splitters are used (C-mode), with responses: TRR, TRL, TLR, and TLL, an incident CUP beam signals its presence by an excess of TRR, TLL events and a PUP beam gives a uniform response. Cramer envisions transmitting a single signal bit (PUP or CUP) for a fixed time T, running in P-mode for $T/2$ sec, in C-mode for $T/2$ sec and deciding the nature of the signal by whichever mode leads to excess coincidences of either (THH, TVV) or (TRR, TLL) type.

Given that a state consisting of two or more identically polarized photons exists, other schemes can be imagined for determination of the photons' common polarization to a precision better than those permitted by the Heisenberg uncertainty principle (for one photon). A third receiver realization (Harvard's scheme) uses neither PP nor CP beam splitters but a pair of elliptical splitters whose polarization axes are equidistant from the H–V and R–L axes on the Poincaré polarization sphere.[16] In all other respects save type of splitters this scheme is identical to Cramer's. One advantage of the Harvard scheme is that no alternation of apparatuses is necessary to decode the PUP/CUP signal: one set of beam splitters suffices.

3. DISCUSSION OF THE FLASH PROPOSAL

A subtle objection to FLASH is contained in the work of D. Scarl and collaborators.[7] Scarl attempted to measure the temporal correlation between the stimulating and induced photons in a Helium–Neon laser gain tube. For both spontaneous and stimulated emission, Scarl found *no time correlation* in excess of that predicted by the Hanbury–Brown–Twiss effect. The naively expected correlation time (line width Fourier transform) is 0.22 *ns* and Scarl was able to detect correlation times as large as 3.4 *ns*.

The "Scarl effect" if taken at face value would shut down FLASH immediately because it eliminates the *photon bursts* which are essential for its operation. According to Scarl's results, the incident photon does not produce a burst of stimulated light like an electron pulse in a Geiger counter but instead a temporally broad wash of light. Scarl's results seem to contradict the demonstrated ability of laser gain tubes to amplify picosecond pulses[13] with no appreciable temporal broadening—a gain tube property exploited in the laser fusion effort.[14] In this case stimulated photons must be time correlated with stimulating photons to within 10^{-12} sec. Together these results suggest that the laser amplification process is delocalized throughout the *time envelope* of the input wave function. This means that, for a uniform nonmodulated beam (Scarl's case), there will be no correlation between stimulated and stimulating photon. To get a *narrow burst* of laser amplification, a pulsed input (as in laser fusion) is necessary.

To achieve time modulation of the input beam, the EPR source must be pulsed with a technique which does not introduce a preferential polarization. One possible modulation method uses a *three-photon cascade* as an EPR source—the third photon (detected by 4π-sensor to avoid polarization selection) serves to alert B's detectors to an imminent flash of signal light. The EPR photons emerge from small apertures located at opposite poles of the trigger sphere. To eliminate false alarms, the trigger pulse is disabled if one of the EPR photons strikes the trigger sphere. This trigger pulse imposes an exponential time modulation on the input light, with time constant a function of the widths of the cascade states. For simplicity, apparatus for source modulation is not shown in Fig. 1.

We note that for coincidence detection (e.g., the Cramer scheme) the Scarl effect far from being detrimental actually operates in our favor. According to Scarl the spontaneous noise and spontaneous noise induced photons *are not time correlated* while signal and signal induced photons *are time correlated* within the input pulse envelope. Hence laser-amplified noise is suppressed relative to laser-amplified signal by coincidence detection.

The gain tube in the FLASH detector acts like a photomultiplier tube—producing a *burst* of particles in response to a single photon. The difference between a gain tube and a phototube is that in the gain tube the particles are identical copies of the input photon while the phototube produces a burst of electrons uncorrelated with the input photon's polarization. Photons and electrons differ in a more fundamental way. Although the signal and noise are independent processes, the wave nature of light will cause them to interfere (see Ref. 17). This interference will shift the output polarization in a random direction at each signal event but the output will always be biased in favor of the input polarization, a bias that is detected (over a period of time) by the polarization selective coincidence detectors.

How Does FLASH Evade the FTL Impossibility Proofs? In what Sense is Quantum Theory Incomplete?

The answer to these two questions is the same. FLASH does not really deal with statistical aggregates of photons but—with the aid of perfect photon xeroxing provided by the laser effect—is able to examine the polarization of each individual photon. FLASH finds a way to "personalize" a random sequence of photons. Note that if we average over all bursts before performing our statistical search for counting asymmetries, the counts in all four channels become the same; for long term averages, all signatures vanish. The conventional density matrix description evidently applies to this sort of long term average.

All proofs of the impossibility of using EPR to signal FTL[2,3] assume that the *density matrix* is a complete description of nature. The density matrix for photons at B is just the 2×2 diagonal matrix for unpolarized light and does not depend on what kind of measurement is performed on photon A. FLASH realizes a finer distinction: resolving this matrix into a sum of pure CP matrices or pure PP matrices depending on the setting of the distant quarter wave plate. These pure state components of the "unpolarized"

B beam occur in a pseudorandom sequence. This sequence is not random because a copy of it exists somewhere else in the universe—namely at detector A. Information present at A allows us to uniquely resolve the "random" sequence at B into its pure components and accordingly to perfectly predict the behavior of an "unpolarized" beam on a polarizing beam splitter of the proper type.

The possibility of dissecting a density matrix into a pseudorandom sequence of component matrices has been already described by Peres.[8] To distinguish them from pure states or mixtures—which together exhaust the state descriptive vocabulary of conventional quantum theory—Peres calls these finer dissections "quantum compounds." FLASH works at a deeper level than the usual quantum description, operates by remotely resolving the density matrix into its "compounds" without direct access to the information at A.

FLASH does not challenge the *results* of ordinary quantum theory—in fact they are necessary for its operation. However it describes these results in a *larger language*—a language widened to include *quantum compounds*—justifying Einstein's suspicions that the usual quantum formalism fails to capture completely the subtle behavior of correlated systems.

Pauli in his classic article[9] on measurement theory distinguishes two kinds of measurement: a measurement of the First Kind leaves the measured state in the eigenstate of the measured eigenvalue; a measurement of the Second Kind leaves the measured state in some other eigenstate. We deal here with a third kind of measurement—a measurement which *duplicates* the measured state exactly. While measurements of the First and Second Kinds may be said to *preserve* or *change* the state respectively, a measurement of the Third Kind *copies* it.

Nowhere is there a larger communication gap between theorists and experimentalists than over the problem of quantum measurement. Almost every paper on measurement theory for the past 50 years, following in the footsteps of von Neumann, has assumed First Kind measurements to adequately picture the critical system-apparatus link. Yet few experimentalists can imagine a measurement in which the observed system is left in its original state. Recently it has been rediscovered that measurements of the First Kind do not even conserve angular momentum,[10] a development which suggests that First Kind processes occur more rarely in nature than might be inferred from their representation in the physics literature.

A handful of papers have been published on Second Kind measurements,[11] but processes of the Third Kind—FLASH feasible processes—remain so far unexplored.

The weakest link in the FLASH scheme is the assumption that a laser gain tube is able to exactly duplicate single photons. What is needed here is a good description of an idealized laser gain tube in the spirit of a *Gedankenapparat*. Just as the idealized double slit experiment still continues to provide new insights into conventional quantum theory, so the idealized gain tube will act as a valuable conceptual tool for exploration of Third Kind measurement processes. It is hoped that studies of Third Kind measurements—a type of gentle natural xerography—will be spurred by the possibility of a practical faster-than-light communicator and/or an extended quantum theory.

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