

# Qubit state represented by pendulum oscillations

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Abstract: As a qubit can be a polarization division multiplexed (PDM) quadrature amplitude modulated (QAM) symbol of light, its state has direct correspondence with polarization state of classical light. Even more intuitively, the state may be represented by pendulum oscillations. Also, it is noted that phase can be transmitted over classical channels to carry information.

## 1. Introduction

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Quantum physicists had been considering quantum superposition were beyond any classical intuition. For example, in [1], it is stated: “A left circularly polarized photon can encode a 0, for example, while a right-circularly polarized photon can encode a 1. Quantum systems can also register information in ways that classical digital systems cannot: a transversely polarized photon is in a quantum superposition of left and right polarization, and in some sense encodes both 0 and 1 at the same time.”. For another example, in [2], it is stated: “Unlike the classical bit, the qubit can exist in coherent superpositions of its two states, denoted as  $|0\rangle$  and  $|1\rangle$ .”

For us communication engineers/scientists, however, it is intuitively obvious that transversely polarized classical/quantum light is obtained by multiplexing left-circularly and right-circularly polarized classical/quantum light with proper relative phase, which means so called “quantum” superpositioned state is just a polarization state and can be classical. While bits are digital, the bits may be carried by analog symbols, which may be superpositioned.

Fundamental misunderstanding of most, if not all, quantum physicists on quantum state is, seemingly, that they thought phase unique to quantum state, even though classical radio waves, as solutions of Maxwell’s equations, do have phase, which may be modulated to carry information. For example, in [1], it is stated “the channel that randomizes the phases of input states” “transmits classical information perfectly, but transmits no quantum information at all”, though the channel destroys classical information encoded in phase. For another example, in [2], it is stated “Unlike classical information, qubits are susceptible to both traditional bit errors  $|0\rangle \leftrightarrow |1\rangle$ , and also

phase errors  $|0\rangle \leftrightarrow |0\rangle$ ,  $|1\rangle \leftrightarrow -|1\rangle$ .”, though classical symbols do suffer from amplitude errors and phase errors. That decoherence means loss of phase relationships does not mean classical channels destroy the phase relationships.

As a qubit, in this case, is superposition of a left-circularly and right-circularly (or vertically and horizontally) polarized photon state with various relative amplitude and relative phase, which are analog, and we can use QAM (Quadrature Amplitude Modulation) to modulate amplitude and phase of a photon, such a qubit is a QAM PDM (Polarization Division Multiplexed) symbol of light. While quantum physicists often state “the unit of quantum information is the quantum bit or qubit” [1], it is as metaphysical as stating “the unit of quantum energy is quantum Joule or quJ”. Just as quantum energy is energy, quantum information is information, unit for which is “bit”. A qubit is not a bit but an analog symbol.

A superpositioned state of a qubit is a unit vector in two dimensional Hilbert space over  $\mathbf{C}$  as  $ae^{i\theta_0}|0\rangle + be^{i\theta_1}|1\rangle$  ( $a, b, \theta_0, \theta_1 \in \mathbf{R}$ ,  $a^2 + b^2 = 1$ ,  $0 \leq \theta_0, \theta_1 < 2\pi$ ). Though quantum physicists often ignore absolute phase and only consider relative phase of  $\theta_0 - \theta_1$  important, absolute phase is retained in this letter, because correspondence to classical state is more obvious.

Classical polarization state, on the other hand, is represented as  $ae^{i\theta_H}E_H + be^{i\theta_V}E_V$  ( $a, b, \theta_H, \theta_V \in \mathbf{R}$ ,  $0 \leq \theta_H, \theta_V < 2\pi$ ), where  $E_H$  and  $E_V$  are vectors of horizontally and vertically polarized electric field, respectively. For electric field with unit strength,  $a^2 + b^2 = 1$ . Space of classical polarization state becomes a Hilbert space by introducing inner product as  $E_H \cdot E_H = E_V \cdot E_V = 1$  and  $E_H \cdot E_V = 0$ .

Thus, it is obvious that there is one to one correspondence between superpositioned state of a qubit:  $ae^{i\theta_0}|0\rangle + be^{i\theta_1}|1\rangle$  and classical polarization state of unit strength:  $ae^{i\theta_H}E_H + be^{i\theta_V}E_V$ . That is, superposition is not something specific to quantum state and can be classical.

If “superposition” means multiplications of some coefficients followed by additions, elements of modules over coefficient groups, in general, can be superpositioned. For example, velocity toward northeast is superposition of velocity toward north and velocity toward east and, in a sense, simultaneously represents velocity toward north and velocity toward east.

## 2. Intuitive representation of superpositioned state of a qubit or classical polarization state

While superpositioned qubit state can be represented by polarization state of classical radio waves, polarization state is very poorly intuitive, which should be the reason why quantum physicists misunderstood it something classically impossible.

If, instead of radio waves, visible light is used, we can see polarization state by our eyes. However, what we see is very remote that we can merely see changes in brightness of light

through various polarizers. We can't see something oscillating or, in case of circular polarization, circulating.

On the other hand, vectors representing position or velocity are mechanical and, thus, much more intuitive than polarization state of radio waves or light. However, as vector space of position or velocity is over  $\mathbf{R}$ , it is not appropriate to represent binary quantum states of oscillations, which needs a vector space over  $\mathbf{C}$ . To have such a vector space, we need something with phase, that is, something oscillating.

The simplest mechanically oscillating apparatus should be a pendulum. Fortunately, in the three dimensional real world, a pendulum has two orthogonal directions of oscillations, north/south and east/west (assuming we are not at north or south pole), which means vector space of its oscillating state is two dimensional over  $\mathbf{C}$ , which is just enough to represent binary quantum state of oscillations.

Qubit state  $ae^{i\theta_0}|0\rangle + be^{i\theta_1}|1\rangle$  can be represented by pendulum oscillation of  $(\text{Re}(ae^{i(\omega t + \theta_0)}), \text{Re}(be^{i(\omega t + \theta_1)}))$ . Linear oscillations of a pendulum represent linearly polarized qubit states. Oscillations of a pendulum in northeast/southwest direction is superposition of oscillations of the pendulum in north/south and east/west directions. So are left and right circular oscillations, though north/south and east/west oscillations are superpositioned at different relative phase from northeast/southwest linear oscillations.

With a pendulum, we can actually see the pendulum oscillating and, in case of circular oscillations, which represents circular polarization, circulating. Elliptic oscillations of the pendulum, which represents elliptic polarization, can also be seen.

If a pendulum oscillating in northeast/southwest direction or left or right circularly is viewed from north and east, people can see as if the pendulum is oscillating in east/west and north/south directions, respectively, with smaller amplitude, which corresponds to projection of quantum state. If north/south component of the oscillations of a diagonally or left or right circularly oscillating pendulum is dumped, the pendulum will oscillate linearly in east/west direction with smaller amplitude, which corresponds to passing diagonally or left or right circularly polarized photons through a horizontal linear polarizer.

### 3. Conclusions

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It is noted that classical state does have phase, which may be modulated to carry information. It is shown that qubit state can be represented by classical polarization state and, even more intuitively, two dimensional oscillations of a pendulum.

As "quantum" superposition is not really quantum, we should better say just "superposition". Moreover, as bit is the unit of quantum information and "qubit" is not a bit but an analog symbol, it should better be called "qusymbol".

## References

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- [1] S. Lloyd, “The capacity of the noisy quantum channel”, Phys. Rev. A55 (1997) 1613, <https://arxiv.org/abs/quant-ph/9604015>.
- [2] S. J. Devitt, K. Nemoto, W. J. Munro, “Quantum Error Correction for Beginners”, <https://arxiv.org/abs/0905.2794>,