Measurements clear the fog of quantum interference

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There are many quantum optical experiments whose effects are supposedly not classically explainable. In this paper, the experiments of Hong-Ou-Mandel and Franson are rebuild, measured and explained with classical radio frequency waves.

1. Introduction

The experiments described by Hong, Ou, Mandel [HOM87] and Franson [Fra89] show that two independent photons behave in the same way under certain conditions.

For example, a photon at a junction randomly chooses the left or right path. A similar but distant photon makes the same choice. Both photons take the left path. Or both take the right path.

In classical physics, there should be no such similar behavior. Light cannot communicate.

The two experiments are therefore regarded as prime examples of the incompatibility of quantum mechanics with classical physics.

The author doubted similar claims in his previous papers [Stu23]: Entanglement and Bell's inequality are "demystified" and the findings are used to build a real $2-computer that calculates like quanta.

In this paper both QM experiments are reproduced with classical waves and their functional equivalence is demonstrated.

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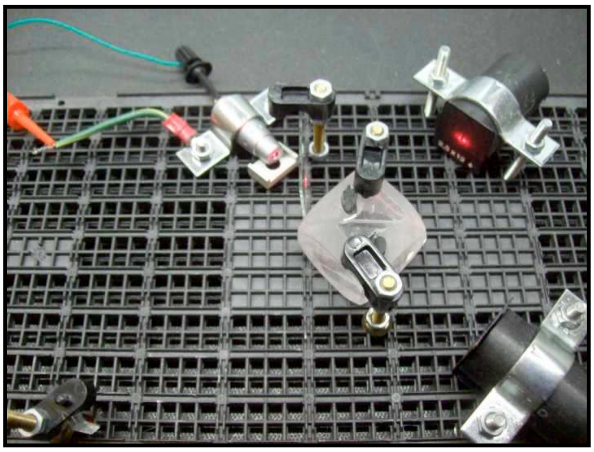
2. Development of a measuring environment



In principle, the experiments to be investigated consist of light sources, time delays, beam splitters, filters, diaphragms and detectors.

Fig. 1: Typical light experiment

Light with wavelengths of 700 nm, for example, oscillates at around 400 THz. At such high frequencies, only the photon energy (squared field amplitude) can be determined. As individual photons emit their energy in the detector, only destroying measurements are possible.

With such measurement limitations, it would be impossible to understand the function of a mains socket. The problematic quantum optics should therefore be converted to easily measurable radio waves:

Detail	**Quantum optics**	**Radio waves**
Frequency	Terahertz [THz]	Kilohertz [kHz]
Time	Femtoseconds [fs]	Microseconds [µs]
Sources	Laser + parametric Converter	Oscillators
Delays	Light propagation time	Delay lines
Branches	Beam splitter	Directional coupler
Measurement object	Photon energy	Wave amplitude
Measurement	destroying	not destroying

Table 1: Quantum optics vs. radio waves

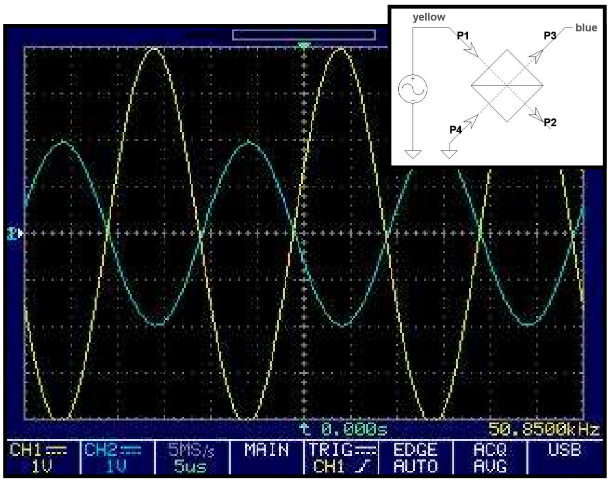
This implementation is first practiced on the beam splitter.

3. Conversion of the beam splitter to radio waves

The counterpart to the optical beam splitter with two inputs and two outputs is the 4-port directional coupler for radio waves. In our case, a 1:1 toroidal transformer with two termination resistors is sufficient.

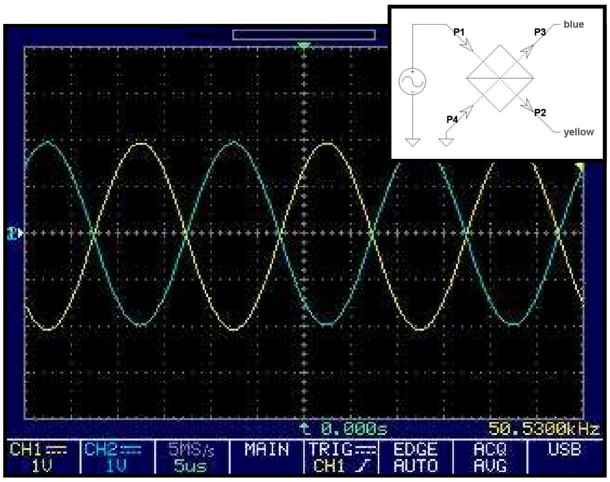
This directional coupler is carefully checked for functional consistency.

Fig. 2: Optical beam splitter vs. directional coupler



The directional coupler input P1 is fed with AC voltage (yellow curve). In blue the reflected (180" rotated) output P3 with halved amplitude.

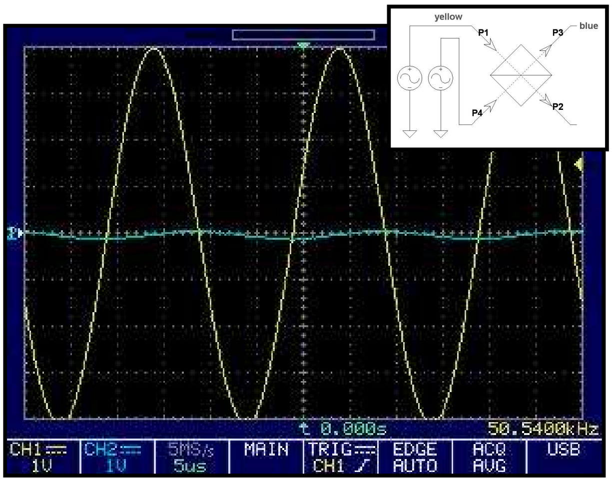
Fig. 3: Directional coupler P1 to P3



The two outputs are in phase opposition. P2 (yellow) has the same phase as the input voltage at P1 (transmitting).

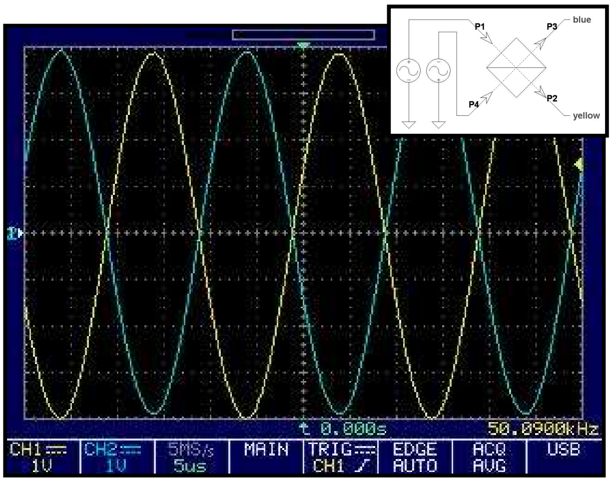
Fig. 4: Directional coupler P1 to P2 and P3

The function of a directional coupler with one input voltage corresponds to the behavior of an optical 50:50 beam splitter. The directional coupler is now tested with two input voltages.



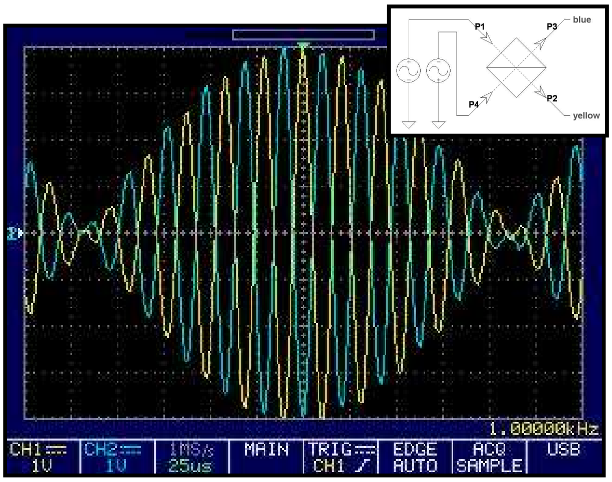
If both inputs P1 and P4 are supplied with the same voltages, destructive interference occurs at both outputs P2 and P3.

Fig. 5: Directional coupler with destructive interference



If both inputs P1 and P4 are supplied with antiphase voltages, constructive interference with full output voltage occurs at both outputs P2 and P3.

Fig. 6: Directional coupler with constructive interference



If inputs P1 and P4 are fed with different frequencies, interference beats can be observed at the outputs due to the sliding transitions between destructive and constructive interference.

Fig. 7: Directional coupler interference beats

These measurements prove that a directional coupler behaves in exactly the same way as an optical beam splitter.

The next step is to check whether the free "LTSpice" simulation software can represent the real directional coupler.

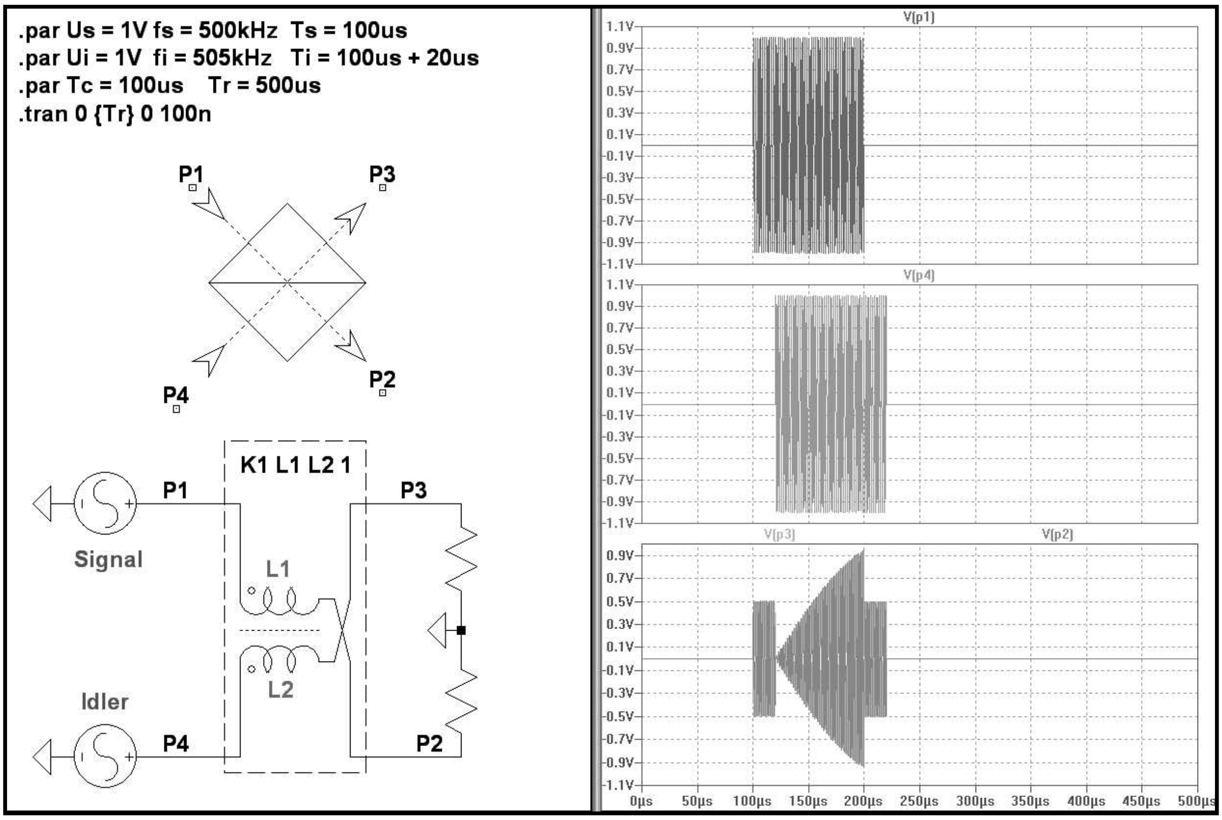


Fig. 8: Directional coupler simulation

At the top left are the parameters of the two oscillators and visualization instructions. ~500kHz are used, which correspond to 500 THz in the optics Below this is the sketch of the optical beam splitter including port labels. Below is the circuit diagram of the directional coupler with sources and terminator resistors.

At the top right, the voltage at P1 was plotted, which is present from Ts=100µs at 500kHz for Tc=100µs. Below this is the voltage at P4, which is present for the same length of time from Ti=120µs at 505kHz. Both outputs are plotted in the lower plot. A 120µs long antiphase wave train appears. The first 20µs come from P1 alone. This is followed by the 80µs long interference beat range due to the different frequencies (fs vs. fi). And then the remaining 20µs, which come solely from the "idler" at P4.

The simulated directional coupler behaves like the real directional coupler and therefore also like the optical beam splitter. It is possible to simulate the experiments.

4. Experiment: Hong-Ou-Mandel

The transit time of two photons is influenced by shifting the beam splitter so that they arrive at BS at the same time. Its outputs control the detectors D1 and D2.

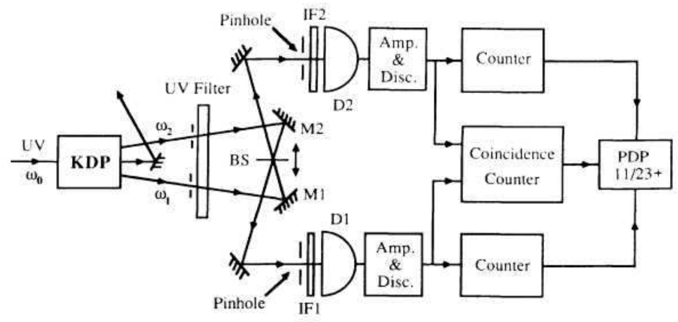


FIG. 1. Outline of the experimental setup.

Fig. 9: Setup sketch [HOM87]

There are four combinations of the two photon paths in the beam splitter.

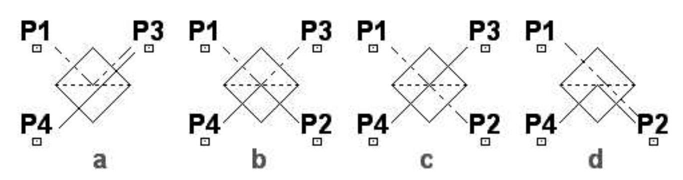


Fig. 10: Light paths in the beam splitter

In cases ***a*** and ***d***, one photon is transmitted and the other reflected. In cases ***b*** and ***c***, both photons are reflected or both are transmitted.

In the experiment, cases ***a*** and ***d***, in which two similar and simultaneous photons leave the beam splitter at the same port, are of particular interest. It appears that the photons agree on one output. In these cases, either detector D1 or detector D2 reacts. But not both at the same time.

In a quantum optics experiment, a maximum of two photons can therefore appear simultaneously at one output. However, this "simultaneity" must be defined.

In the wave experiment, the simultaneity corresponds to the maximum positive output voltage of the directional coupler (see Fig. 6). The switching threshold for this constructive interference is set to +0.7.

The directional coupler experiment from Fig. 8 only needs to be extended by a detector logic. The experimental parameters were taken from [HOM87] and rescaled.

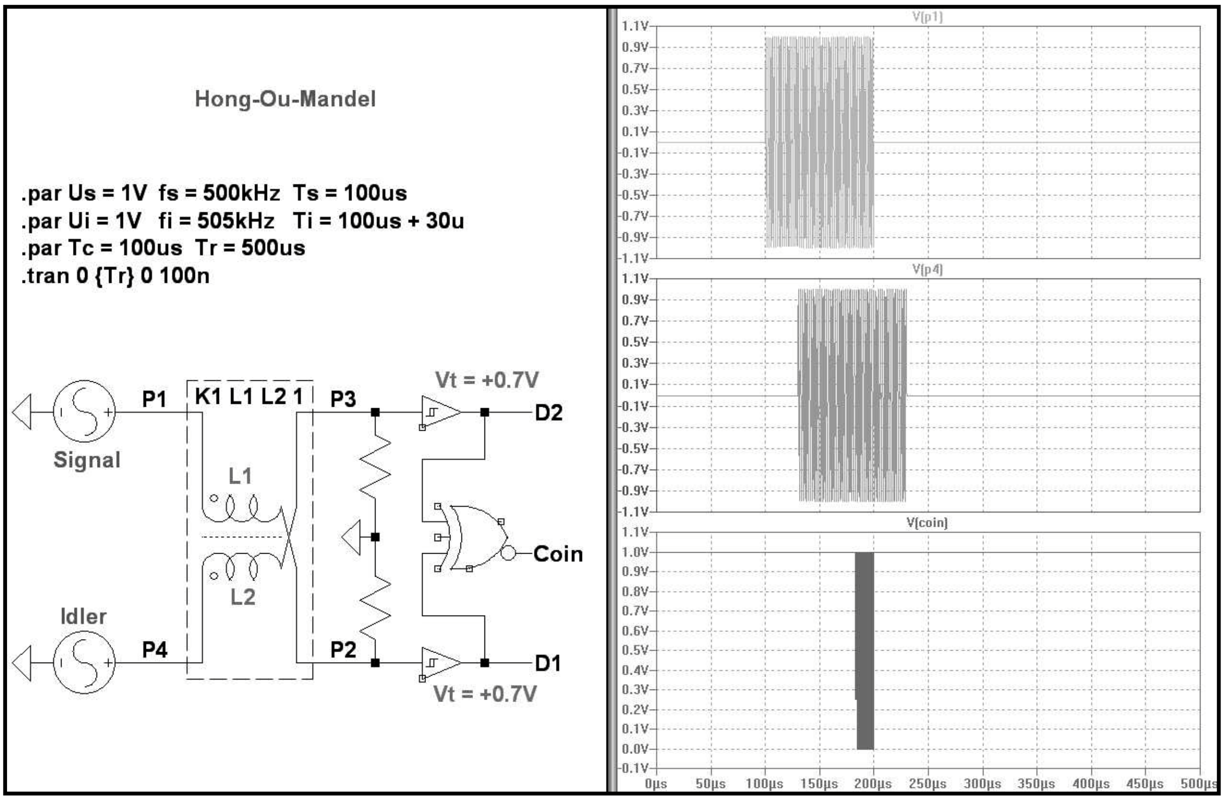
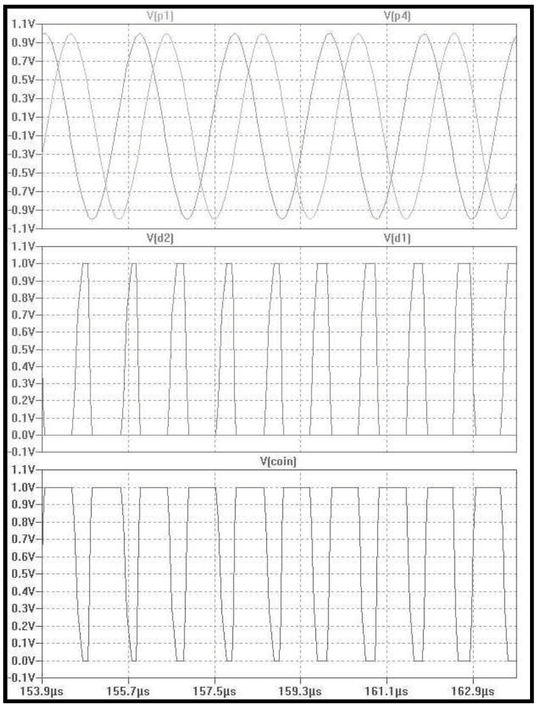


Fig. 11: Experiment Hong-Ou-Mandel with classic waves

The coincidence output shows a negative pulse sequence of maximum 100µs duration with maximum time correspondence between "Signal" and "Idler".



Two zoomed inputs P1 and P4 with different frequencies are shown at the top. The alternating outputs D1 and D2 are shown below. And at the bottom the coincidence output, which shows that D1 and D2 are never active at the same time.

The Hong-Ou-Mandel effect is obviously based on the opposite phase of the two beam splitter outputs, which is interpreted in QM as a "random" path selection.

Fig. 12: Zoom

With maximum coincidence of "signal" and "idler", there is the lowest number of detector coincidences in both the quantum optical experiment and the wave experiment. Both experiments achieve the same "dip":

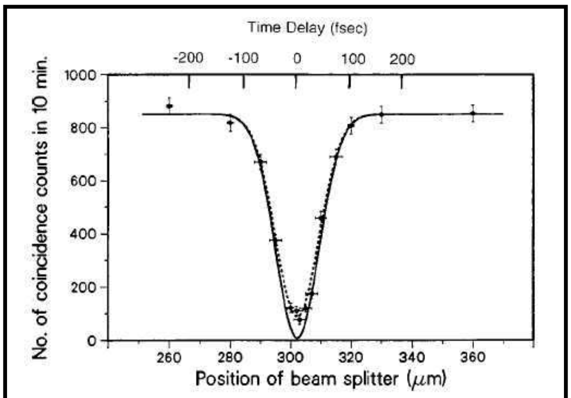


FIG. 9. Results of the two-photon interference experiment shown in Fig. 8. The measured coincidence rate is plotted as a function of beam-splitter displacement in μm or differential time delay in fsec. The continuous curve is theoretical.

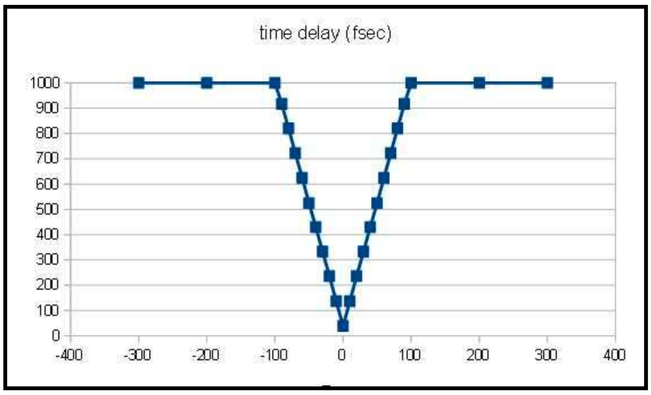


Fig. 13: Comparison of coincidence dips

Note: In the wave experiment dip, the times were scaled according to Table 1 and the measurement points were determined from the time average of the voltage of the coincidence output at variable Ti times.

Since the Hong-Ou-Mandel experiment also works with classical waves, its exclusive quantum mechanical interpretation is refuted.

5. Experiment: Franson

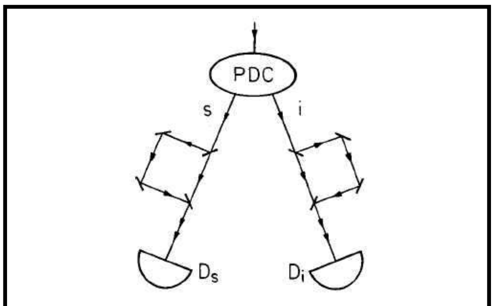
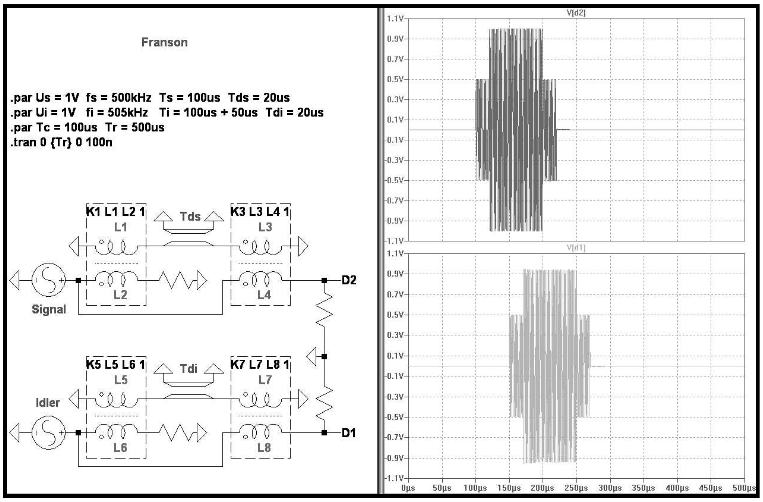


FIG. 2. Principle of the Franson (1989) two-photon interference experiment in which signal and idler photons never mix. PDC is the parametric downconverter. D_s and D_i are photodetectors.

This experiment [Fra89] is celebrated as "ingenious" by quantum mechanics [Man99].

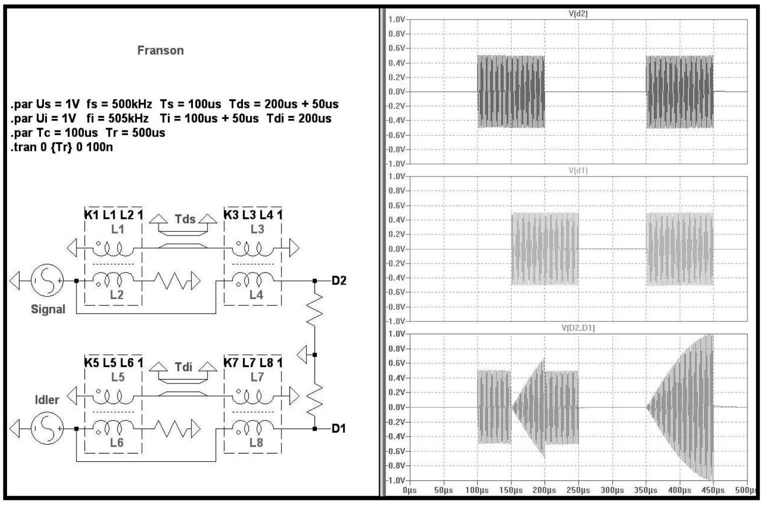
PDC sends two photons, slightly different in time and frequency, into two separate interferometers.

Fig. 14: Setup sketch [Man99]



If the two delays Tds and Tdi are kept within the coherence time Tc, the "normal" single photon interference occurs.

Fig. 15: Single photon interference



If both delay times are selected to be greater than Tc and Tds is optimized, interference beats are observed between the two detectors.

Fig. 16: 4th order interference [Man99]

QM interprets this phenomenon as proof of the entanglement of position and time of the "signal" and "idler" photons.

Since the Franson experiment with classical waves also succeeds, its exclusive quantum mechanical interpretation is refuted.

6. *Conclusion and discussion*

Quantum mechanics deals with the measurement of a few particles, while classical wave physics measures many particles. Individual particles are problematic to measure due to their uncertainty and unavoidable destroying. Direct measurements often do not work at high frequencies.

With wave measurements, the uncertainty is averaged out and the influence of the measurements on the waves can be kept to a minimum. Optical and radio frequency photons differ only in energy and frequency. A conversion to radio frequency waves is particularly advantageous, as the whole world of electronics is available in this frequency range.

The fog of the two experiments by Hong-Ou-Mandel and Franson was cleared by the successful conversion into radio waves. The experiments could be measured and understood. The successful reproduction of both experiments with classical waves refutes their exclusive quantum mechanical interpretation.

I would like to thank Prof. Dr. Bengt Nordén, who motivated me to write this paper.

[HOM87] C. Hong, Z. Ou, and L. Mandel, "Measurement of subpicosecond time intervals between two photons by interference", Physical Review Letters 59 (18), 2044 (1987)

[Fra89] J. Franson, "Bell inequality for position and time", Physical Review Letters 62 (19), 2205 (1989)

[Man99] L. Mandel, „Quantum effects in one-photon and two-photon interference“, Reviews of Modern Physics, Vol. 71(2), 274 (1999)

[Stu23] W. Sturm (2023)
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„Test of Bell/CHSH“, https://vixra.org/abs/2310.0055
„DIY Computer Calculates like Quanta“, https://vixra.org/abs/2310.0132