

A Synchronisation-Free Experiment to Test the One-Way Isotropy of Light Speed

Experimental Proposal -- Draft for Discussion

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Abstract

We propose an experiment to test whether the one-way speed of light is isotropic, without relying on clock synchronisation between separated stations. Two identical stations separated by a fixed distance exchange laser beams through complementary shutters driven by independent atomic clocks. The phase relationship between the two stations' light maxima directly encodes any asymmetry in one-way light speed. No synchronisation signal is required and the measurement is not circular. Relative clock drift between stations is monitored by observing whether the inter-station timestamp offset remains constant over the measurement interval. This offset is not interpreted as a one-way propagation time and does not constitute a synchronisation convention -- it serves solely as a stability diagnostic. The known frequency precision of atomic clocks, combined with regular monitoring of this offset, provides sufficient warranty of system integrity. The experiment is sensitive to any preferred-frame velocity component along the baseline. The true velocity of the apparatus through such a frame -- if one exists -- is unknown. Earth's orbital velocity of approximately 30 km/s is a lower bound only; contributions from the motion of the solar system and galaxy relative to other astronomical reference points could raise the true figure substantially. A null result would constrain preferred-frame theories. A non-null result would warrant careful independent replication.

1. Motivation

The one-way speed of light has not been measured without assuming what is being measured. Every experiment that claims to test light speed isotropy either uses a round-trip path -- which measures only the average speed in both directions -- or relies on synchronising two separated clocks using light signals, which implicitly assumes the isotropy it is trying to test. This circularity has been discussed extensively in the foundations literature [1, 2].

The experiment proposed here avoids this problem. The two stations run on independent clocks that are never synchronised by any signal. The measurement is purely local at each station. The observable -- whether the light maximum at one station corresponds to a light maximum at the other -- does not require any comparison of clock readings between stations.

2. Frequencies and Timing

The experiment involves two distinct and independent frequencies that must not be confused:

f_{sys} -- the system clock frequency, derived from the atomic clock at each station. This operates in the GHz range and provides the timing reference for all local operations. It determines the resolution of the phase adjustment: the minimum step by which the shutter cycle start time at E can be advanced or retarded is one system clock cycle, of order one nanosecond. f_{sys} is fixed and cannot be altered.

f_{s} -- the shutter operating frequency, fixed by the hardware design of the shutter units. f_{s} is much lower than f_{sys} , with a cycle period $T_{\text{s}} = 1/f_{\text{s}}$ chosen so that the open half-cycle $T_{\text{s}}/2$ is of the same order as the expected timing difference between the two directions of light travel. f_{s} is identical at both stations by design and is fixed. It cannot be altered during the experiment.

The only adjustment available to the operator is the phase offset of the shutter cycle at station E -- that is, the start time of the shutter cycle relative to the local system clock. This is adjusted in steps of one system clock cycle (one step $\sim 1/f_{\text{sys}}$). Neither f_{sys} nor f_{s} is altered at any point.

3. Apparatus

Two identical stations, designated W (west) and E (east), are positioned at a separation D along an east-west baseline at equal gravitational potential. The layout is shown in Figure 1. Each station consists of the following components:

1. An atomic clock providing a stable reference from which the local system clock at frequency f_{sys} is derived. The known frequency precision of atomic clocks [3], combined with the regular drift monitoring described in Section 7, provides sufficient warranty of system integrity without reference to any external standard or synchronisation convention.
2. A double shutter consisting of two windows positioned side by side in a vertical plane, both facing horizontally along the east-west baseline. The two windows are designated N (the north-side window) and S (the south-side window). The shutter is driven at the fixed hardware frequency f_{s} and is strictly complementary: at every instant exactly one window is open and the other is closed. Each window spends nominally half of every shutter cycle $T_{\text{s}} = 1/f_{\text{s}}$ open and half closed. The shutters at both stations are identical in construction and therefore share the same transition characteristics between open and closed states. Any systematic effect of the finite transition time cancels in the comparison between the two detectors. Neither f_{s} nor the duty cycle can be altered during the experiment.
3. At station W: a laser beam directed eastward, aligned with window S (south-side). At station E: the same beam arrives and passes through window S (south-side) to a light intensity detector positioned behind window S at E.
4. At station E: a laser beam directed westward, aligned with window N (north-side). At station W: the same beam arrives and passes through window N (north-side) to a light intensity detector positioned behind window N at W.

The complementary nature of the shutter means that when window N is open at W -- transmitting the incoming westward beam to the detector -- window S is simultaneously closed, and vice versa. At any given instant the shutter at each station passes light in only one direction.

5. A phase adjustment control at station E that allows an operator to advance or retard the start of the shutter cycle at E by integer numbers of system clock cycles (steps of order $1/f_{\text{sys}} \sim 1$ ns). Neither f_{sys} nor f_s is altered by this adjustment.

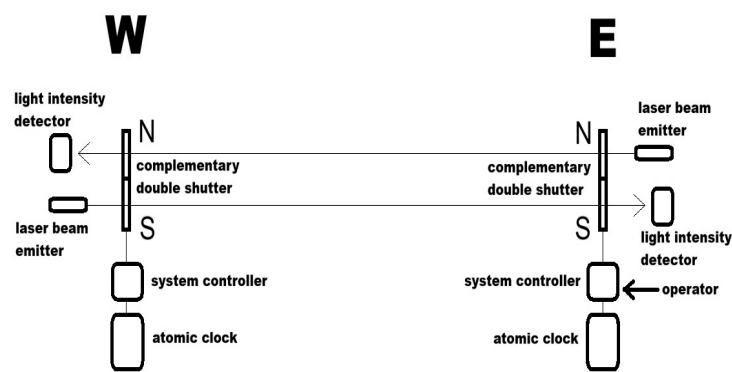


Figure 1. Plan view of the two-station apparatus. Station W (left) and station E (right) are separated by baseline distance D along the east-west axis. Each station has a complementary double shutter with north-side window N and south-side window S. The westward laser beam from E passes through window N at both stations; the eastward laser beam from W passes through window S at both stations. Detectors are positioned behind the receiving window at each station.

4. Procedure

The experiment proceeds as follows:

1. Both stations begin their shutter cycles independently, each driven at the fixed hardware frequency f_s referenced to the local system clock at f_{sys} .
2. The operator at station E adjusts the phase of the E shutter cycle -- advancing or retarding its start time by integer numbers of system clock cycles -- until the detector at station W records a maximum of received light intensity from the E laser. This condition corresponds to the E laser pulses arriving at W exactly as window N at W is opening, so that the full open half-cycle $T_s/2$ is available to pass light to the detector.

3. With the phase adjustment fixed at this setting, the operator records the light intensity at the detector behind window S at station E, which is receiving the W laser beam.
4. The experiment is run continuously over a full rotation of the Earth and across seasons to sample all orientations of the baseline relative to any preferred-frame velocity vector.

5. The Shutter Mechanism and the Observable

The operation of the shutter is central to the experiment. Each window spends nominally half of every shutter cycle $T_s = 1/f_s$ open and half closed. Real shutters have a finite transition time between open and closed states. However, since both stations use identical shutters driven at the same fixed frequency f_s , the transition characteristics are the same at both stations and any systematic effect cancels in the comparison between detectors.

The intensity recorded by a detector over many cycles depends on what fraction of each arriving pulse finds the window open. This fraction is determined by the phase relationship between the arrival time of the pulse and the shutter cycle at the receiving station.

5.1 Isotropic case

Suppose the one-way speed of light is the same in both directions: $c_{WE} = c_{EW} = c$. The travel time from W to E and from E to W are both equal to D/c .

The operator adjusts the phase offset at E until the E laser pulses arrive at W exactly as window N at W is opening, maximising the W detector. Since $c_{WE} = c_{EW} = c$, the W laser pulses take the same time D/c to reach E. The phase adjustment that optimised the W detector has -- by symmetry -- also arranged for the W laser pulses to arrive at E exactly as window S at E is opening. The detector at E also records maximum intensity.

Maximum at W corresponds to maximum at E. This is the null result.

5.2 Anisotropic case

Suppose the apparatus moves through a preferred frame at velocity v along the east-west baseline. The one-way travel times are:

$$t(E \rightarrow W) = D / (c - v) \text{ [westward, against the flow]}$$

$$t(W \rightarrow E) = D / (c + v) \text{ [eastward, with the flow]}$$

The operator adjusts the phase offset at E until the E laser pulses arrive at W exactly as window N at W is opening, maximising the W detector. This sets the phase offset at E to match the travel time $t(E \rightarrow W) = D/(c-v)$.

The W laser pulses travel time $t(W \rightarrow E) = D/(c+v)$ differs from $t(E \rightarrow W) = D/(c-v)$. The W laser pulses therefore arrive at E not synchronised with the reciprocal E laser pulses. The timing difference is:

$$\Delta t = t(E \rightarrow W) - t(W \rightarrow E) = 2 * D * v / (c^2 - v^2)$$

part of each arriving $W \rightarrow E$ pulse or its entirety will find window S at E in a closed state and be blocked. The fraction of each pulse that finds the window open is:

$$\text{Fraction open} = (T_s/2 - \Delta_t) / (T_s/2) = 1 - 2*\Delta_t/T_s$$

provided $\Delta_t < T_s/2$. If $\Delta_t \geq T_s/2$ the pulses are entirely blocked and the E detector records zero intensity.

The key observable is: when the W detector is at maximum, is the E detector also at maximum? Any reduction in E intensity relative to maximum is evidence of one-way light speed anisotropy.

6. The Rotational Signature and Phase Degeneracy

A potential concern is that a periodic shutter system could show apparent maxima at E not only when $\Delta_t = 0$ but also when Δ_t equals an integer multiple of T_s -- the pulses arrive one or more complete cycles late but still find the window opening. However any such degeneracy itself implies anisotropy. If $\Delta_t = n*T_s$ for some non-zero integer n , then a non-zero velocity v exists. This is not the isotropic case.

As the Earth rotates, the component of v along the east-west baseline varies continuously and smoothly with a 24-hour period. Δ_t therefore varies continuously. The integer relationship $\Delta_t = n*T_s$ can hold at most at isolated orientations -- it cannot be maintained throughout a full rotation. At all other orientations the intensity at E departs from maximum, producing a distinct rotational signature.

A true null result -- isotropic light speed -- produces constant maximum intensity at E at all orientations throughout Earth's rotation. No anisotropic case can maintain maximum intensity at E throughout a full rotation. Running the experiment continuously over a full rotation of the Earth therefore provides a discriminating rotational signature that resolves any phase degeneracy.

7. Clock Drift Monitoring

At regular intervals during the experiment, a timestamp signal is sent from one station to the other. The receiving station records the offset between the arrival time of the timestamp and its own local clock reading. This offset is not interpreted as a one-way propagation time and no physical meaning is assigned to its absolute value. It is used solely as a stability diagnostic.

If the two clocks are running at the same frequency with no relative drift, this offset will remain constant over successive measurements. Any change in the offset indicates relative drift between the clocks and allows the operator to verify that drift remains below the experimental sensitivity over the measurement interval.

This procedure does not constitute clock synchronisation. The absolute value of the offset is never used. No simultaneity convention is adopted. The offset monitor is purely a consistency check. The known frequency precision of atomic clocks [3] -- with fractional frequency uncertainty of order 2×10^{-18} -- means that drift over a measurement interval of hours is far below the experimental sensitivity for any plausible preferred-frame velocity.

8. Why Synchronisation is Not Required

The experiment does not require the two station clocks to be synchronised with each other. The procedure requires only that both stations run their system clocks at the same frequency f_{sys} and their shutters at the same fixed hardware frequency f_{s} . The known precision of atomic clocks, combined with the drift monitoring of Section 7, provides sufficient warranty of system integrity without any synchronisation convention.

The phase adjustment at E is purely local -- it changes only the relationship between the E shutter cycle and the E system clock. No information about absolute time is transmitted between stations. The observable -- whether the W maximum coincides with an E maximum -- is determined by reading two local detectors independently. No clock reading is compared between stations. The result is not contaminated by any synchronisation convention.

9. Sensitivity and Signal Magnitude

The expected signal magnitude depends on the true velocity v of the apparatus through the preferred frame, which is not known a priori. Earth's orbital velocity around the Sun of approximately 30 km/s is a lower bound only. The motion of the solar system and the galaxy relative to other astronomical reference points could raise the true figure substantially.

For illustration, the signal $\Delta_t = 2Dv/(c^2 - v^2)$ for representative values of v with $D = 1$ km is:

$$v = 30 \text{ km/s: } \Delta_t = 2.00 \times 10^{-10} \text{ s (200 picoseconds)}$$

$$v = 220 \text{ km/s: } \Delta_t = 1.49 \times 10^{-9} \text{ s (1.49 nanoseconds)}$$

$$v = 600 \text{ km/s: } \Delta_t = 4.02 \times 10^{-9} \text{ s (4.02 nanoseconds)}$$

The shutter half-cycle $T_{\text{s}}/2$ must be of the same order as the expected Δ_t to give good sensitivity. The system clock at $f_{\text{sys}} = 1$ GHz provides phase adjustment steps of 1 nanosecond. Electro-optical and acousto-optical modulators can switch in sub-nanosecond timescales and are appropriate for implementing the shutter function.

10. Practical Considerations

Several practical issues must be addressed in any implementation:

1. Shutter technology. Electro-optical modulators or acousto-optical modulators are the appropriate technology, providing sub-nanosecond switching at the required shutter frequency f_{s} . Both stations must use identical shutter units to ensure that any systematic effect of the finite transition time cancels in the comparison.
2. Clock stability. The system clocks at both stations must maintain the same frequency f_{sys} to a precision better than the expected phase signal. Drift is monitored as described in Section 7.
3. Gravitational potential. Both stations must be at equal gravitational potential to avoid gravitational redshift introducing a spurious frequency difference between the system clocks. This requires careful attention to station altitude.

4. Baseline orientation and repetition. The east-west baseline samples only the component of any preferred-frame velocity in that direction. Running the experiment over a full rotation of the Earth and across seasons, and repeating with a north-south baseline, provides sensitivity to the full velocity vector and resolves any phase degeneracy as described in Section 6.

5. Propagation medium and atmospheric effects. The two windows N and S are positioned side by side, separated by only a few centimetres. Any atmospheric turbulence or refractive index variation along the kilometre-scale baseline therefore affects both beam paths essentially identically, constituting a common mode effect that cancels in the comparison between the two detectors. The experiment would ideally be conducted in vacuum -- for example along an evacuated tube -- eliminating this residual concern entirely.

6. Phase adjustment resolution. The minimum phase adjustment step is one system clock cycle ($1/f_{\text{sys}}$). A system clock at 1 GHz provides 1 nanosecond resolution. Higher system clock frequencies improve phase resolution proportionally.

11. Interpretation of Results

11.1 Null result

The intensity at E remains at maximum for all orientations and all seasons, with no periodic variation locked to Earth's rotation. This places an upper bound on any preferred-frame velocity component along the tested baselines. It is consistent with isotropic one-way light speed. It does not prove that no preferred frame exists -- only that any velocity component along the tested baselines is below the experimental sensitivity.

11.2 Non-null result

The intensity at E shows a periodic variation locked to Earth's rotation period, with maximum reduction when the baseline is best aligned with any preferred-frame velocity vector. The amplitude of the variation gives Δ_t , from which the velocity component is:

$$v = c * \text{sqrt}(\Delta_t / (2*D/c + \Delta_t))$$

A non-null result would require careful independent replication at multiple baselines and times before any strong conclusion could be drawn. Systematic effects -- clock drift, atmospheric variation, equipment asymmetry -- would need to be excluded rigorously.

12. Conclusion

We have proposed an experiment that tests the one-way isotropy of light speed without relying on clock synchronisation between separated stations. The experiment avoids the circularity that affects most proposed one-way measurements. The observable is the coincidence or mismatch of light intensity maxima at two local detectors, directly encoding any difference in one-way travel times through the action of complementary shutters on the arriving laser pulses.

Running the experiment continuously over a full rotation of the Earth provides a distinct rotational signature. Any phase degeneracy arising from integer-cycle offsets itself implies anisotropy and

resolves as the Earth rotates. Clock drift is monitored without synchronisation by observing the constancy of an inter-station timestamp offset used solely as a stability diagnostic. The close proximity of the two shutter windows provides natural common mode rejection of atmospheric noise. Conducting the experiment in vacuum eliminates this concern entirely.

A null result constrains preferred-frame theories. A non-null result -- manifest as a smooth periodic variation in detector intensity locked to Earth's rotation -- warrants careful replication and systematic investigation.

This proposal is presented as a conceptual design. The author does not have access to the hardware required for implementation. The proposal is offered in the hope that experimentalists with appropriate facilities may find it worth examining.

References

- [1] Reichenbach, H. The Philosophy of Space and Time. Dover, New York, 1958.
- [2] Salmon, W. The Philosophical Significance of the One-Way Speed of Light. *Nous*, 11, 253--292, 1977.
- [3] Nicholson, T.L. et al. Systematic evaluation of an atomic clock at 2×10^{-18} total uncertainty. *Nature Communications*, 6, 6896, 2015.