

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. Because the shutters are complementary, the two detector readings always move in opposite directions as the phase offset at one station is swept — they never reach maximum simultaneously. The correct observable is the phase offset at which the two detectors read equal intensity: the crossing point. In the isotropic case this crossing point is stable as Earth rotates. In the anisotropic case it drifts cyclically with the sidereal period. No synchronisation signal is required and the measurement is not circular.

The experiment provides two independent observables recorded in parallel. The first is the optical crossing point described above. The second is the timestamp time series δ_{WE} and δ_{EW} recorded independently at each station. In the isotropic case both series show no variation. In the anisotropic case both series show a cyclic variation locked to the sidereal day. Both observables respond to the same underlying quantity — the asymmetry between $W \rightarrow E$ and $E \rightarrow W$ propagation times — and both share a common-mode rejection of local environmental disturbances by virtue of the 50-metre station separation.

Frequency identity between the two stations rests on the constancy of the atomic transition — a physical fact, not an engineering convention. The only signals exchanged between stations are timestamp pulses transmitted at regular intervals to build up the time series described in Section 5.2. No synchronisation signal of any kind is used. The phase relationship between the two shutter drives is never imposed externally; it is found empirically by the crossing-point procedure. The experiment is sensitive to any preferred-frame velocity component along the baseline. A null result constrains preferred-frame theories. A non-null result warrants 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 atomic clocks that are never synchronised by any signal. The observable is the drift of an equal-intensity crossing point between the two detector readings — a

purely differential measurement that requires no comparison of clock readings between stations and is robust against any synchronisation convention.

2. Frequencies and Timing

The experiment involves two distinct and independent frequencies:

- f_s — the shutter operating frequency, fixed by the hardware design of the shutter units. The cycle period $T_s = 1/f_s$ is chosen so that the open half-cycle $T_s/2$ is of the same order as the expected timing difference between the two directions of light travel.
- f_{DDS} — the clock frequency of a Direct Digital Synthesiser (DDS) that generates the shutter drive signal at station E. The DDS produces a signal at exactly f_s but with arbitrary phase, settable in software to a resolution of $f_s / 2^N$ where N is the DDS bit depth (typically 32–48 bits). This gives sub-femtosecond phase resolution — effectively continuous — at any shutter frequency.

The phase adjustment at station E is implemented by commanding the DDS to advance or retard its output phase by a chosen increment. This is a purely digital operation: the computer sends a slow command to the DDS, which shifts the phase of its 15 GHz (or other frequency) output instantaneously and precisely. No analog phase shifter is required at any shutter frequency. The DDS replaces the system clock step concept from earlier versions of this proposal: the minimum phase step is now a software parameter, not a hardware constraint.

This is the same technology used in modern radar, software-defined radio, and atomic clock distribution systems. DDS chips operating up to 10–15 GHz are commercially available. For higher shutter frequencies, a DDS at a lower frequency can drive a phase-locked frequency multiplier chain, preserving the phase resolution while reaching 15 GHz or beyond.

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. Each station is self-contained and operates independently. The only signals exchanged between stations are timestamp pulses used to monitor relative clock drift, as described in Section 5.2. No synchronisation signal of any kind is used. Each station consists of:

1. An atomic clock based on a well-defined atomic transition — for example, a caesium hyperfine standard or a strontium optical lattice clock. The atomic transition frequency is a constant of nature: two clocks of the same type, in identical local environments, will run at the same frequency without any connection between them. This is the only form of frequency agreement used in this experiment. No synchronisation signal of any kind is used to relate the two station clocks. The only signals exchanged between stations are timestamp pulses transmitted at regular intervals for the purpose described in Section 5.2.
2. A local frequency synthesis chain: a phase-locked loop (PLL) or Direct Digital Synthesiser (DDS) that derives the shutter drive frequency f_s from the local atomic clock reference. The synthesis ratio is identical at both stations. Since both atomic clocks run at the same frequency by virtue of the same atomic transition, the two synthesised shutter drive signals also run at the same frequency — independently, without communication.
3. A complementary double shutter with two windows N (north-side) and S (south-side). The shutter is driven by the local synthesis chain at frequency f_s and is strictly complementary: at every instant exactly one window is open and the other is closed.

4. At station W: a laser beam directed eastward, aligned with window S. At station E: a laser beam directed westward, aligned with window N.
5. At station E only: a DDS phase register in the synthesis chain, software-controllable to sub-femtosecond resolution. The operator increments or decrements this phase register one step at a time to sweep the relative phase between the two shutter drive signals. This is a purely local operation at station E — it shifts the phase of the local shutter drive without altering its frequency and without transmitting any signal to station W.

The phase relationship between the two stations is never imposed externally — it is found empirically by the crossing-point procedure described in Section 4.

For two identical optical atomic clocks operating in the same controlled room at the same altitude, the expected frequency agreement can be estimated quantitatively. The best optical lattice clocks achieve a fractional frequency uncertainty of approximately 2×10^{-18} [3]. Over a 24-hour measurement interval, the worst-case accumulated timing difference between the two clocks is:

$$\delta t_{\text{clock}} = 2 \times 10^{-18} \times 86,400 \text{ s} \approx 0.17 \text{ ps}$$

The expected signal from a preferred-frame velocity of 400 km/s on a 50-metre baseline is:

$$\Delta t_{\text{signal}} = 2Dv/c^2 = 2 \times 50 \times 400,000 / (9 \times 10^{16}) \approx 0.44 \text{ ns}$$

The signal is approximately 2,600 times larger than the worst-case clock drift over a full measurement day. In practice, for two identical clocks in the same controlled environment at the same altitude, the actual frequency difference will be far smaller than this upper bound — gravitational redshift, the dominant environmental perturbation, is negligible over 50 metres at the same altitude. Clock drift is therefore not a meaningful source of uncertainty for this experiment.

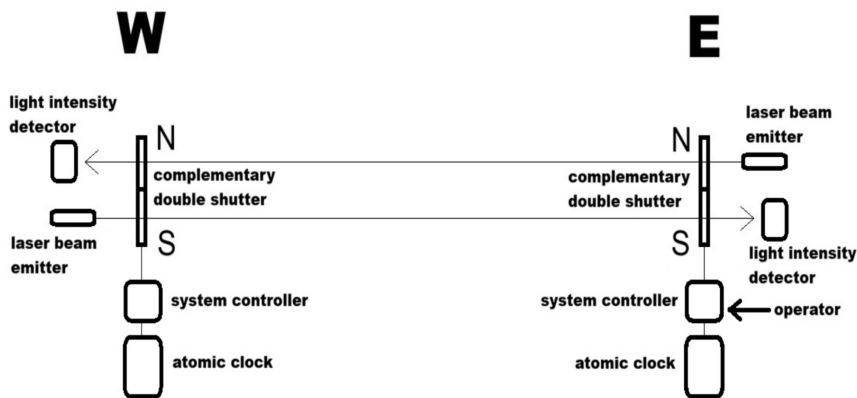


Figure 1. Plan view of the two-station apparatus. Station W (left) and station E (right) are separated by baseline distance D along the east-west axis. Each station has a complementary double shutter with north-side window N and south-side window S. The westward laser beam from E passes through window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

6. Both stations begin their shutter cycles independently, each driven at the fixed hardware frequency f_s .
7. The operator at station E adjusts the phase offset — via DDS phase commands — sweeping through the full cycle while monitoring both detectors simultaneously.
8. The operator finds the crossing point: the phase offset at which both detectors read equal intensity. This offset is recorded.
9. The measurement is repeated at regular intervals — ideally every 30 seconds to 1 minute — over a full rotation of the Earth (24 hours) and across multiple seasons. This sampling rate provides sufficient resolution to unambiguously distinguish a sidereal-period signal from a solar-period signal: the two periods differ by only 3 minutes 56 seconds per day, and dense sampling allows the slow phase drift between them to be tracked reliably over many days.
10. The time series of crossing-point offsets is analysed for periodic drift. A null result shows no drift. A non-null result shows a smooth periodic variation with a period close to the sidereal day (23 h 56 min).

In parallel with the optical crossing-point measurement, a second independent observable is recorded throughout the experiment:

11. At regular intervals, station W transmits a timestamp signal to station E. Station E records the arrival time of this signal according to its own local clock, logging the value δ_{WE} . At regular intervals, station E independently transmits a timestamp signal to station W, which records the arrival time δ_{EW} . These signals are transmitted over a dedicated channel — optical fibre or coaxial cable — solely for this purpose. No interpretation of the absolute one-way travel time is made. The values δ_{WE} and δ_{EW} are recorded as raw numbers.
12. Because both stations transmit at regular intervals, each builds up a time series of δ values. The observable is not a cross-station subtraction — which would require a simultaneity convention — but the cyclic variation within each time series independently. If δ_{WE} shows a cyclic variation locked to the sidereal day, and δ_{EW} shows the same period in opposite phase, this pattern cannot be attributed to clock drift or any known environmental effect. Clock drift would cause both series to vary in the same direction; a cyclic environmental effect locked to the solar day would be distinguishable by its period.

5. The Observables

The experiment provides two independent observables, recorded in parallel from the same apparatus. Their agreement or disagreement is itself informative — a signal appearing in one channel but not the other indicates a systematic error rather than a genuine physical effect.

5.1 Optical Crossing-Point Observable

Due to the complementary nature of the shutters, the two beams are interleaved in time: when the W-to-E beam passes through the S windows, the E-to-W beam is blocked, and vice versa. As the operator advances the phase offset at station E, the two detector readings move in opposite directions — when one increases, the other decreases. This is a direct consequence of the complementary shutter design and is present in both the isotropic and anisotropic cases.

The two detector readings therefore always cross at some phase offset — a point where both detectors read equal intensity. This crossing point is the first observable.

- Null result (isotropic): the crossing point remains stable as Earth rotates over 24 hours and across seasons.
- Non-null result (anisotropic): the crossing point oscillates cyclically with a period close to the sidereal day (23 h 56 min). The amplitude encodes the preferred-

frame velocity component along the baseline.

This observable does not require any absolute measurement of light speed or travel time, and requires no synchronisation convention. No convention can make a real drift disappear, making it convention-independent by construction.

5.2 Timestamp Asymmetry Observable

At regular intervals, station W transmits a timestamp signal to station E, and station E independently transmits a timestamp signal to station W. Each timestamp carries the value of the sending station's local clock at the moment of transmission.

Upon receiving a timestamp, each station computes the difference between the arrival time according to its own local clock and the value carried in the timestamp. Station E records this difference as δ_{WE} ; station W records it as δ_{EW} . Each is a purely local measurement — no cross-station comparison is required to compute either value.

Because transmissions occur at regular intervals, each station builds up a time series of δ values. The absolute initial value of each δ is not interpreted — it encodes an arbitrary combination of clock offset and propagation time. What matters is whether the time series remains constant or drifts over time.

The character of any drift distinguishes between possible causes:

- Both δ_{WE} and δ_{EW} constant: clocks are stable and propagation is symmetric. Null result.
- Both δ_{WE} and δ_{EW} drifting in the same direction at the same rate: one clock is drifting relative to the other.
- δ_{WE} and δ_{EW} drifting in opposite directions cyclically: the propagation time is asymmetric between the two directions. If this variation is locked to the sidereal day it cannot be attributed to any known terrestrial or solar environmental effect.

The observable of interest is the cyclic variation within each time series independently — not the absolute value of any single measurement, and not a cross-station subtraction.

5.3 Cross-Validation and Common-Mode Rejection

Both observables share a common-mode rejection property — but through entirely independent physical mechanisms.

For the timestamp time series: any environmental perturbation that affects both clocks simultaneously — temperature, magnetic field, vibration, power supply noise — shifts both δ_{WE} and δ_{EW} by the same amount in the same direction. The variation cancels when comparing the character of the two series. What remains is any asymmetry between the $W \rightarrow E$ and $E \rightarrow W$ directions.

For the optical crossing point: any environmental perturbation that shifts both shutter frequencies simultaneously shifts them equally, leaving the phase relationship between the two stations unchanged. The crossing point does not move.

In both cases, the only effect that breaks the symmetry between the two stations is an asymmetry in the $W \rightarrow E$ and $E \rightarrow W$ propagation times — which is precisely the quantity under investigation. Over a 50-metre baseline, no plausible environmental disturbance preferentially affects one direction of propagation over the other.

Agreement between the two channels corroborates the result across different physical mechanisms, reducing the likelihood that the signal originates from a single hardware failure or instrument-specific drift. It does not constitute independent replication — both channels share the same propagation path.

The character of any observed variation in either channel is itself informative. The following cases can be distinguished:

- No variation in either channel: null result, consistent with isotropic c.
- Secular drift in both δ_{WE} and δ_{EW} in the same direction: most likely attributable to a small residual frequency difference between the two atomic clocks.
- Variation in one channel only: likely an instrument-specific artefact in that channel.
- Cyclic variation in both channels locked to the solar day: consistent with a thermal or environmental effect driven by the day-night cycle.
- Cyclic variation in both channels locked to the sidereal day (23 h 56 min): not attributable to any known terrestrial or solar environmental effect. This would be of great interest and would warrant rigorous systematic investigation and independent replication.

6. Sensitivity and Practical Scale

The expected timing difference between the two directions is:

$$\Delta t = 2Dv / c^2$$

where D is the baseline length, v is the preferred-frame velocity component along the baseline, and c is the speed of light. For Earth's orbital velocity $v \approx 30$ km/s:

$$\Delta t = 2D \times (30,000) / (3 \times 10^8)^2 = 2D / (3 \times 10^{12}) \quad [D \text{ in metres, } \Delta t \text{ in seconds}]$$

The shutter half-cycle $T_{s/2}$ must be of the same order as Δt for maximum sensitivity. Setting $T_{s/2} = \Delta t$:

$$f_s = c^2 / (4Dv) = 9 \times 10^{16} / (4 \times D \times 30,000) = 7.5 \times 10^{11} / D \quad [D \text{ in metres}]$$

The introduction of Direct Digital Synthesis (DDS) for phase control removes the previous constraint that the system clock must be faster than the shutter. Since DDS phase resolution is a software parameter — effectively sub-femtosecond at any shutter frequency — the minimum detectable phase step is no longer limited by hardware. The experiment is therefore viable at any shutter frequency and baseline combination where $T_{s/2} \approx \Delta t$.

The following table shows the required shutter frequency for the preferred baseline length with DDS phase control:

Baseline D	Required f_s	$T_{s/2}$	Shutter Technology	Phase Control
500 m	1.5 GHz	0.33 ns	Microwave EOM	DDS + PLL multiplier
50 m	15 GHz	33 ps	LiNbO ₃ EOM (telecom grade)	DDS + ×100 PLL chain
5 m	150 GHz	3.3 ps	Advanced photonic EOM	DDS + photonic multiplier

6.1 Preferred Implementation

The preferred implementation uses a 50-metre baseline with a 15 GHz shutter frequency. This combination offers the best balance of practicality and sensitivity:

- A 50-metre baseline fits within a single building or laboratory corridor, eliminating atmospheric turbulence, making alignment straightforward, and avoiding any need for civil infrastructure.
- 15 GHz lithium niobate electro-optic modulators are commercially available telecom components, used routinely in coherent optical communications.
- DDS phase control via a PLL frequency multiplier chain provides sub-femtosecond phase resolution — orders of magnitude finer than the 33 ps shutter half-cycle. The phase step size is a software parameter with no hardware floor.
- $T_s/2 = 33$ ps matches Δt for $D = 50$ m and $v = 30$ km/s, giving maximum sensitivity to Earth's orbital velocity.

6.2 Signal magnitude and velocity scale

The experiment is sensitive to the total velocity of the apparatus through any preferred frame, not just Earth's orbital velocity. Two physically motivated velocity scales are:

Velocity source	v (km/s)	v/c	Δt at $D=50$ m, $f_s=15$ GHz	$\Delta t / (T_s/2)$
Earth orbital	30	0.000 1	0.033 ps	0.001
Solar system galactic	220	0.000 73	0.24 ps	0.007

At Earth's orbital velocity alone the effect is small — about 0.1% of $T_s/2$ at 50 m. The solar system's velocity through the galaxy of approximately 220 km/s gives a 0.7% effect. The experiment is most powerful as a time-series measurement: even a sub-percent effect becomes unambiguous when its amplitude modulates with a 24-hour sidereal period as Earth rotates.

7. Clock Drift Monitoring and Timestamp Interpretation

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 serves as a diagnostic for both clock stability and potential light speed anisotropy — but the two contributions must be carefully distinguished, as described below. The absolute value of the offset is never interpreted as a one-way propagation time and does not constitute a synchronisation convention.

The known frequency precision of atomic clocks [3] — with fractional frequency uncertainty of order 2×10^{-18} — means that any genuine clock drift over a measurement interval of hours is far below the experimental sensitivity. However, the timestamp offset may also contain a contribution from light speed anisotropy, which must not be confused with clock drift.

A remark is necessary regarding the timestamp itself in the anisotropic case. If the one-way speed of light is anisotropic, the timestamp signal also travels at an anisotropic speed, and the recorded offset will contain a component due to propagation asymmetry in addition to any clock drift. This anisotropy component is not constant: as Earth rotates, the projection of any preferred-frame velocity onto the baseline changes continuously, causing the propagation-asymmetry contribution to the offset to vary with an approximately 24-hour sidereal period.

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 shutters at the same frequency f_s . The observable — the drift of the equal-intensity crossing point over time — is determined by reading two local detectors independently at each measurement epoch. No clock reading is compared between stations.

A potential objection is that the phase adjustment at E constitutes a synchronisation convention in hardware. The response is that the time-varying signature under Earth's rotation is convention-independent: no choice of synchronisation convention can make a periodic drift in the crossing point disappear. The rotational modulation of the crossing-point offset is the physically meaningful observable, and it is robust against any reasonable choice of phase convention.

9. Interpretation of Results

9.1 Null result

The equal-intensity crossing point — the phase offset at which both detectors read the same intensity — remains stable as Earth rotates over 24 hours and across seasons. This places an upper bound on any preferred-frame velocity component along the tested baselines. It is consistent with isotropic one-way light speed.

9.2 Non-null result

The crossing point varies cyclically with a period close to the sidereal day (23 h 56 min). The amplitude of the oscillation encodes the magnitude of the preferred-frame velocity component along the baseline. The variation is smooth and periodic — not a random fluctuation — and its phase is locked to sidereal time rather than solar time. A non-null result would require careful independent replication at multiple baselines and orientations before any strong conclusion could be drawn.

10. 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 key advance over previous proposals is the recognition that the correct observable is the drift of an equal-intensity crossing point, not the absolute intensity at either detector. As the operator sweeps the phase offset at station E, the two detector readings move in opposite directions and cross at a specific offset. In the isotropic case this crossing point is stable. In the anisotropic case it drifts with the sidereal period as Earth's rotation changes the projection of any preferred-frame velocity onto the baseline.

The experiment is viable at laboratory scale. At 15 GHz shutter frequency — commercially available in the telecom industry — a 50-metre baseline is sufficient, with DDS phase control providing sub-femtosecond phase resolution under software control.

A null result constrains preferred-frame theories. A non-null result — a smooth periodic drift in the crossing-point offset locked to the sidereal day — would constitute evidence for a preferred frame and would warrant 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

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- [3] Nicholson, T.L. et al. Systematic evaluation of an atomic clock at 2×10^{-18} total uncertainty. *Nature Communications*, 6, 6896, 2015.