INS

S9427-AN-OMP-010/WSN-7

TECHNICAL MANUAL
ORGANIZATIONAL LEVEL

RING LASER GYRO NAVIGATOR INERTIAL NAVIGATION SYSTEM, AN/WSN-7(V)1, -7(V)2, -7(V)3, PART NUMBERS CN-1695/WSN-7(V), CN-1696/WSN-7(V), and CN-1697/WSN-7(V); OPERATION AND MAINTENANCE, WITH PARTS LISTS

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Charlottesville, VA 22901-2827

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N65236-02-D-3823

UNITED STATES NAVY SEA SYSTEMS COMMAND

Note: Corporation, N. G. (2005). "Inertial Navigation System - Ring Laser Gyro - Technical Manual "

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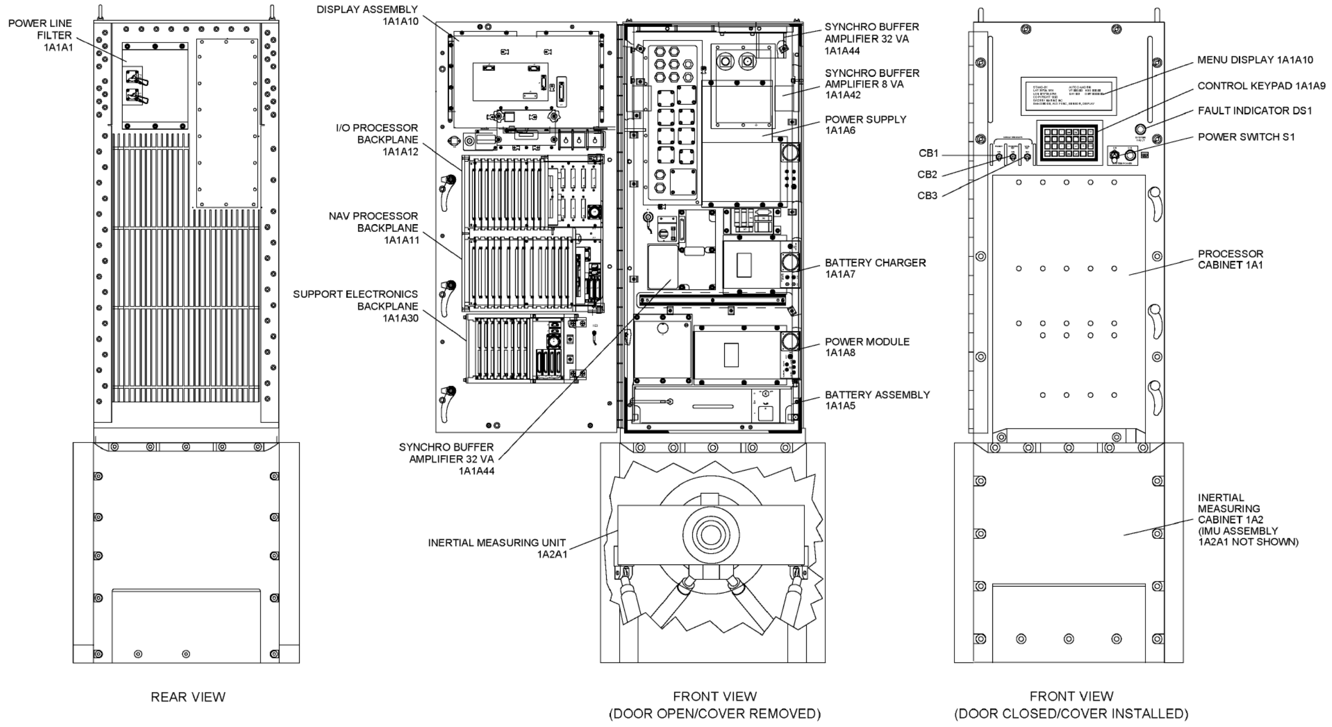
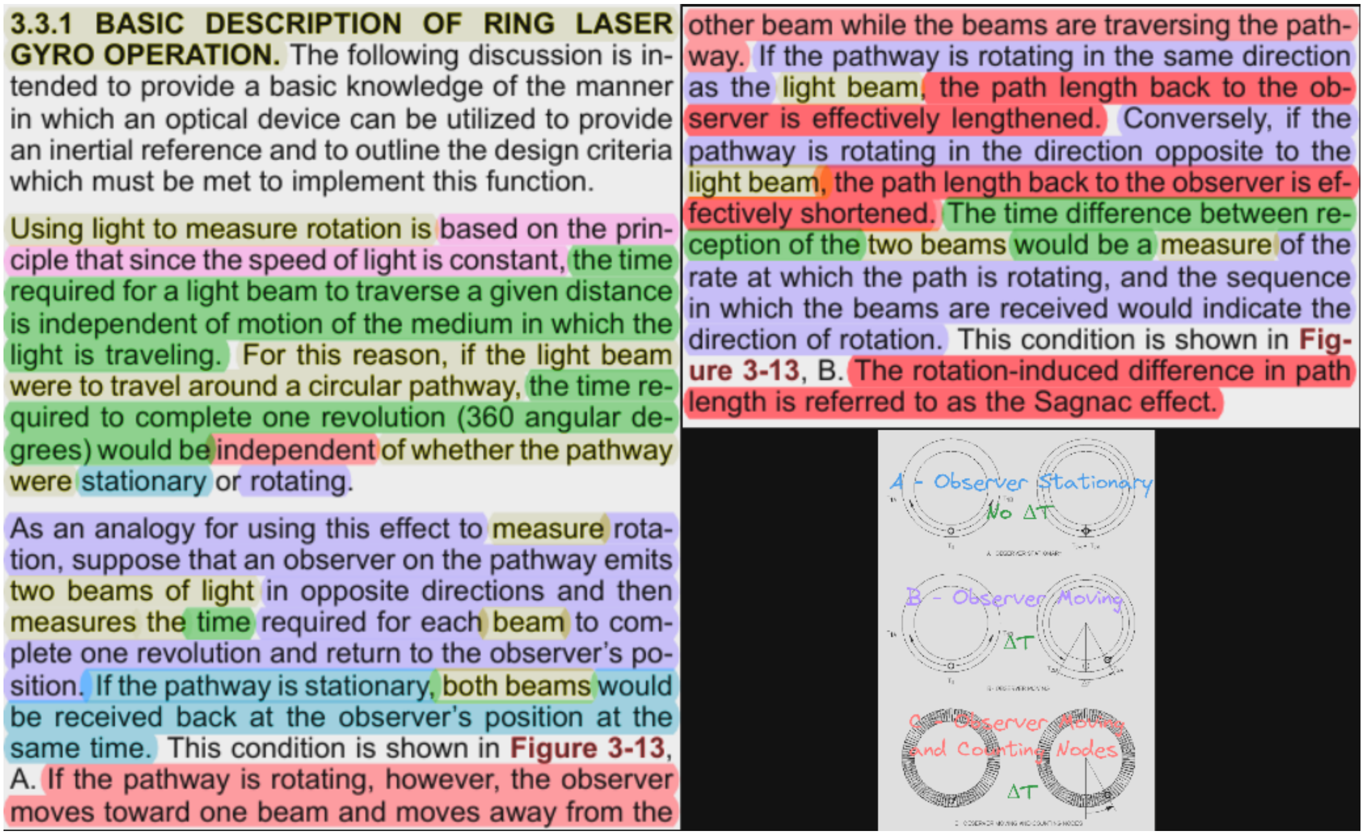


Note: Diagram of the system



3.3.1 BASIC DESCRIPTION OF RING LASER GYRO OPERATION. The following discussion is intended to provide a basic knowledge of the manner in which an optical device can be utilized to provide an inertial reference and to outline the design criteria which must be met to implement this function.

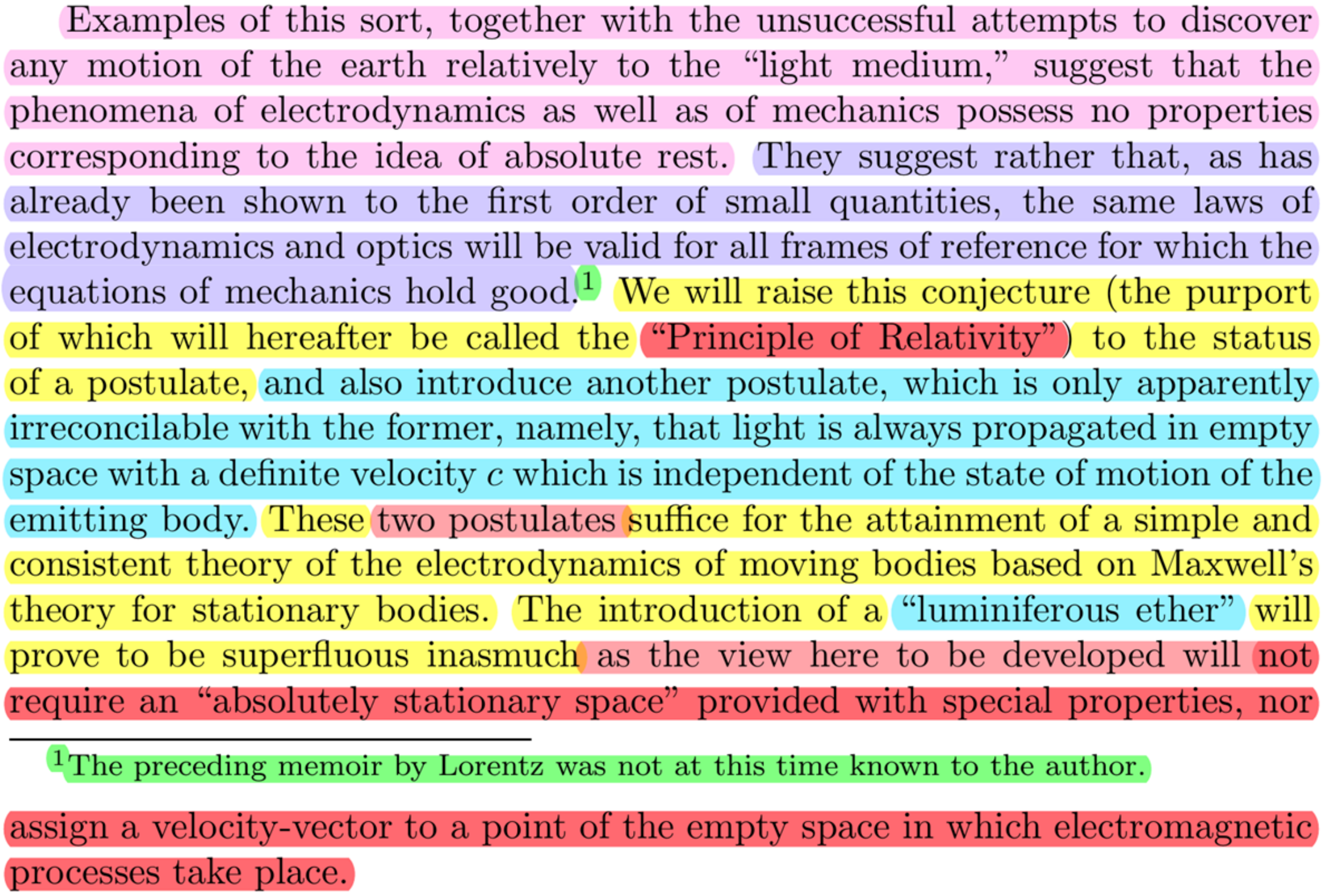
Using light to measure rotation is based on the principle that since the speed of light is constant, the time required for a light beam to traverse a given distance is independent of motion of the medium in which the light is traveling. For this reason, if the light beam were to travel around a circular pathway, the time required to complete one revolution (360 angular degrees) would be independent of whether the pathway were stationary or rotating.

As an analogy for using this effect to measure rotation, suppose that an observer on the pathway emits two beams of light in opposite directions and then measures the time required for each beam to complete one revolution and return to the observer's position. If the pathway is stationary, both beams would be received back at the observer's position at the same time. This condition is shown in **Figure 3-13**, A. If the pathway is rotating, however, the observer moves toward one beam and moves away from the other beam while the beams are traversing the pathway. If the pathway is rotating in the same direction as the light beam, the path length back to the observer is effectively lengthened. Conversely, if the pathway is rotating in the direction opposite to the light beam, the path length back to the observer is effectively shortened. The time difference between reception of the two beams would be a measure of the rate at which the path is rotating, and the sequence in which the beams are received would indicate the direction of rotation. This condition is shown in **Figure 3-13**, B. The rotation-induced difference in path length is referred to as the Sagnac effect.

Note: Time issue in the explain given in how the physicality of the fringe is produced

SR cannot explain the Sagnac effect:

Yellow = Light
Pink = Principles Invoking Relativity and/or Relativistic effects as an explanation
Red = Important things to note
Blue = Stationary ref. frame
Purple = Rotating ref. frame



Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the "light medium," suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.[1] We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies. The introduction of a "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolutely stationary space" provided with special properties, nor assign a velocity-vector to a point of the empty space in which electromagnetic processes take place.

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[1] The preceding memoir by Lorentz was not at this time known to the author.

Note: Before we continue, let's read the rule book for the competing non-aetheric framework. As we continue reading on, we'll compare the relativistic interpretation along with the classical.

important thing to note is that Einstein makes two specific claim regarding the "luminiferous ether"

1. The newly purposed theory will not require an "absolute stationary space" provided with special properties.
2. No assignment of a velocity-vector to a point of empty space in which electromagnetic process takes place.

Can't invoke absolute space or time to explain the RLG. If you extend any segment of the rotation to infinite, it's LINEAR.

measured aboard the object, traveling at uniform relative speed and $\gamma = (1 - v^2/c^2)^{-0.5}$. Using Binomial expansion:

$$t_{\text{[illegible]}} - t' = t' (v^2/2c^2) \text{ and}$$

$$\frac{t_0 - t'}{t_0} = \frac{v^2}{v^2 + 2c^2} \tag{3}$$

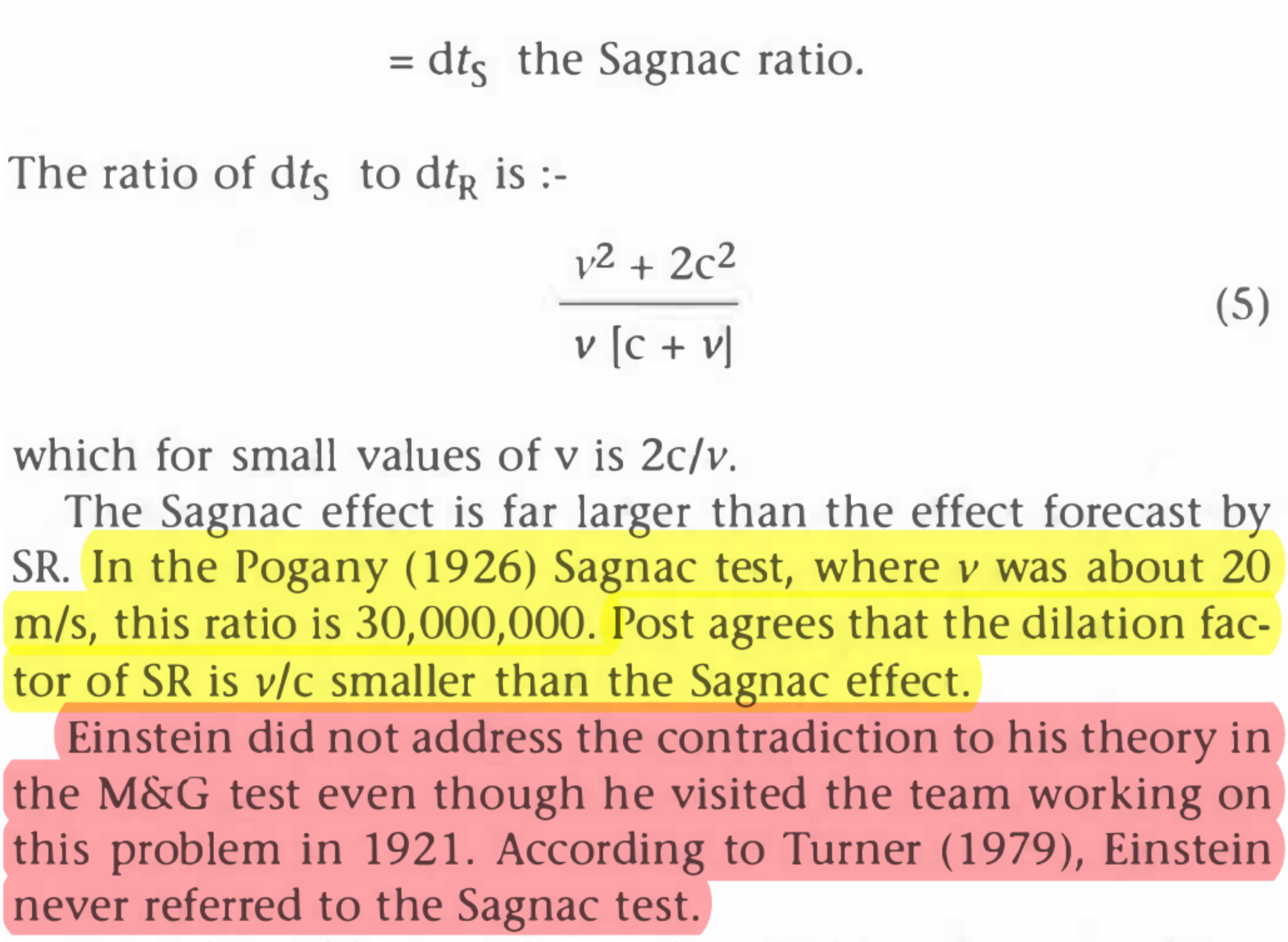
$= \mathrm{d}t_R$ the Relativity time ratio.

In the Sagnac case t_0 is the time for a light signal to traverse a stationary circular disc, and t' is the time to traverse the spinning disc against the direction of spin, according to the observer on the disc.

$$t_0 = (2\pi r/c) \text{ and } t' = 2\pi r/(c+v)$$

$$\frac{t_0 - t'}{t_0} = \frac{v}{c + v} \tag{4}$$

$= \mathrm{d}t_S$ the Sagnac ratio.



$= dt_S$ the Sagnac ratio.

The ratio of dt_S to dt_R is :-

$$\frac{v^2 + 2c^2}{v\,[c + v]} \tag{5}$$

which for small values of v is $2c/v$.

The Sagnac effect is far larger than the effect forecast by SR. In the Pogany (1926) Sagnac test, where v was about 20 m/s, this ratio is 30,000,000. Post agrees that the dilation factor of SR is v/c smaller than the Sagnac effect.

Einstein did not address the contradiction to his theory in the M&G test even though he visited the team working on this problem in 1921. According to Turner (1979), Einstein never referred to the Sagnac test.

Note: It's shown here that Pogany (1926) showing the SR derivation is unable to explain the first-order effect of rotational velocity. Even though it was explicitly stated by Einstein that his equations would hold true in that frame.

Notice here that the ratio is between a hypothetical stationary observer at the center of the rotating platform and the timer difference between him and photographic recorder, who is also on the rotating platform, but does not have the benefit of being considered stationary.

From the stationary position, the distance traveled for the rotating platform is preserved as to explain the frequency shift in c. The frequency shift is the speed changing to produce the fringe. But remember, in Relativity c = c in inertial frames.

Again, here to even attempt to explain this framework; ABSOLUTE SPACE and TIME must be invoked to preserve a distant traveled and imaginary vectors must be used to describe and area where electromagnetic propagation once occurred.

Without violating its own postulates and prefaces, Special Relativity has completely failed on the face of it.

Mechanistically, the only thing the ether model has failed is failed to support the heliocentric model with a first-order measurement of the alleged first-order effect of a 30 km/s velocity. Through a stationary Earth WRT a rotating sky, the aether framework remains unchallenged as a viable framework of interpretation.

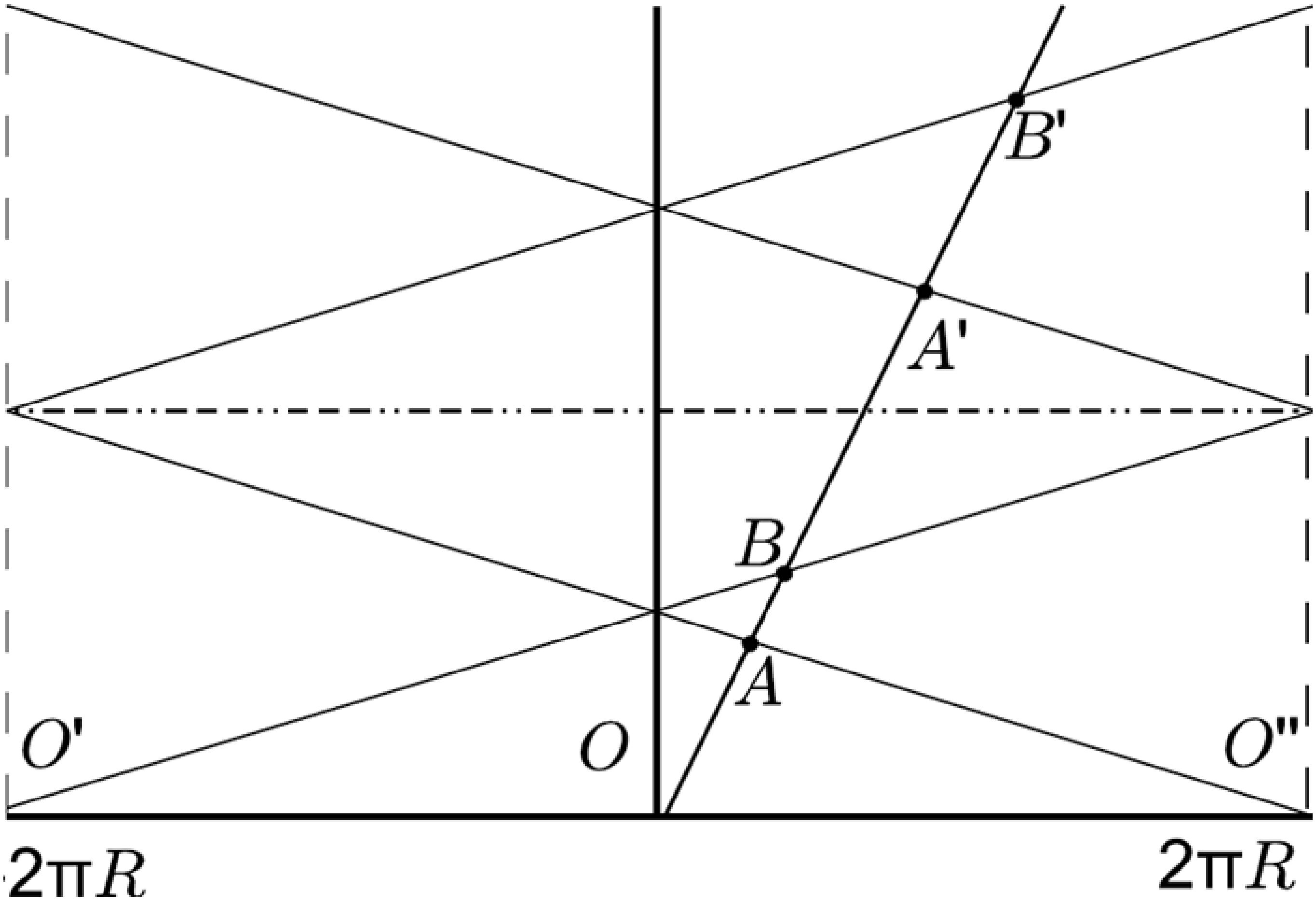
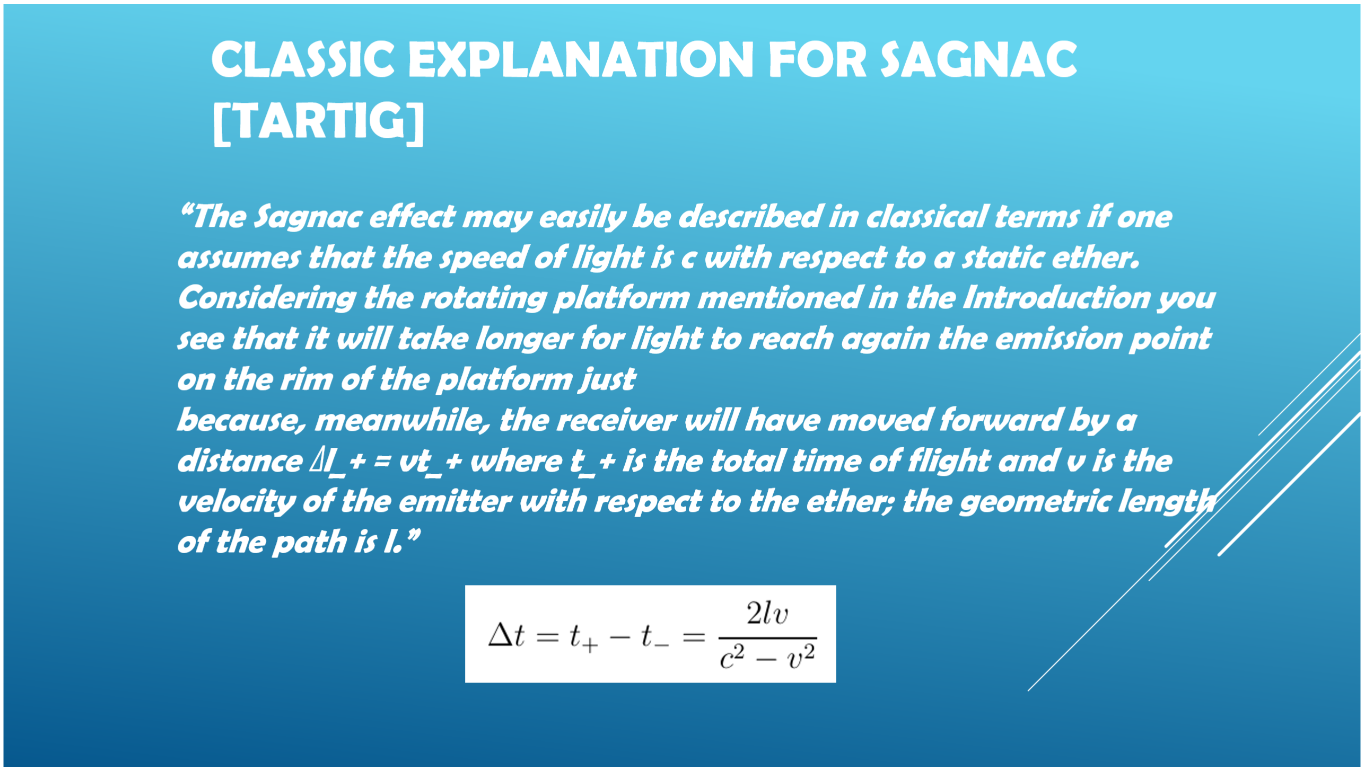


FIG. 2: Same as Fig. 1. The cylinder has been cut along a generatrix passing through the rotating observer at time 0, and opened. For convenience, in order to make the picture more compact, two replicas of the opened cylinder are shown side by side: one enrolled to the right, the other to the left. Points O' and O'' coincide with O. Four windings are shown. The vertical straight line is the world line of an inertial observer at rest with the axis of the disk. AB is the Sagnac effect expressed in terms of proper time of the rotating observer.

Note: To this day, Tartaglia, and Bhadra can't explain the Sagnac effect's physical fringe. They can't explain the second-order Doppler shift proportional to the velocity of the rotating platform without invoking absolute space.

1. Tartaglia, A. and M. L. Ruggiero (2015). "The Sagnac Effect and Pure Geometry." American Journal of Physics 83(5): 427-432.
2. Bhadra, A., et al. (2022). "A Quest for the Origin of the Sagnac Effect." European Physical Journal C 82: 649.



CLASSIC EXPLANATION FOR SAGNAC [TARTIG]

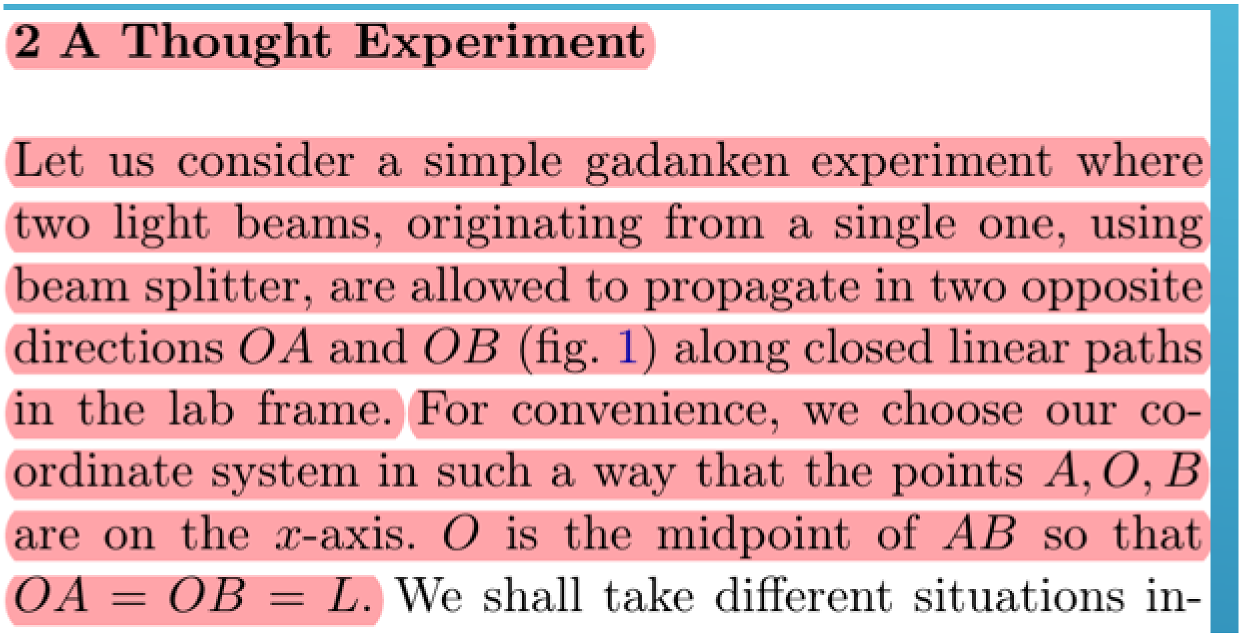
“The Sagnac effect may easily be described in classical terms if one assumes that the speed of light is c with respect to a static ether. Considering the rotating platform mentioned in the Introduction you see that it will take longer for light to reach again the emission point on the rim of the platform just
because, meanwhile, the receiver will have moved forward by a distance Δl_+ = vt_+ where t_+ is the total time of flight and v is the velocity of the emitter with respect to the ether; the geometric length of the path is l.”

$$\Delta t = t_+ - t_- = \frac{2lv}{c^2 - v^2}$$

Note: Even under second-order approximation, the first-order effect is fully accounted for.

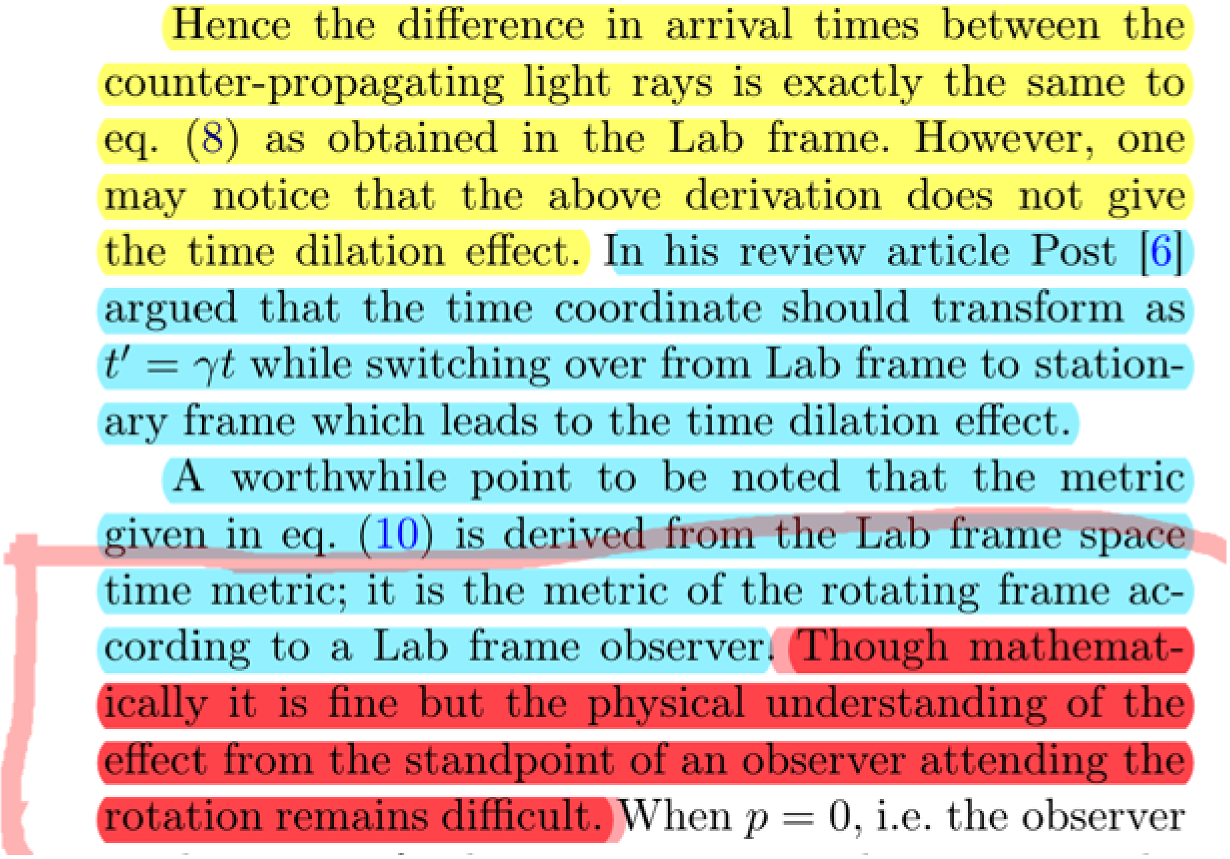
t+ = *going with ether wind*
t- = going with the ether wind

2lv/c^2-v^2



2 A Thought Experiment

Let us consider a simple gadanken experiment where two light beams, originating from a single one, using beam splitter, are allowed to propagate in two opposite directions OA and OB (fig. 1) along closed linear paths in the lab frame. For convenience, we choose our coordinate system in such a way that the points A, O, B are on the x-axis. O is the midpoint of AB so that $OA = OB = L$. We shall take different situations in-

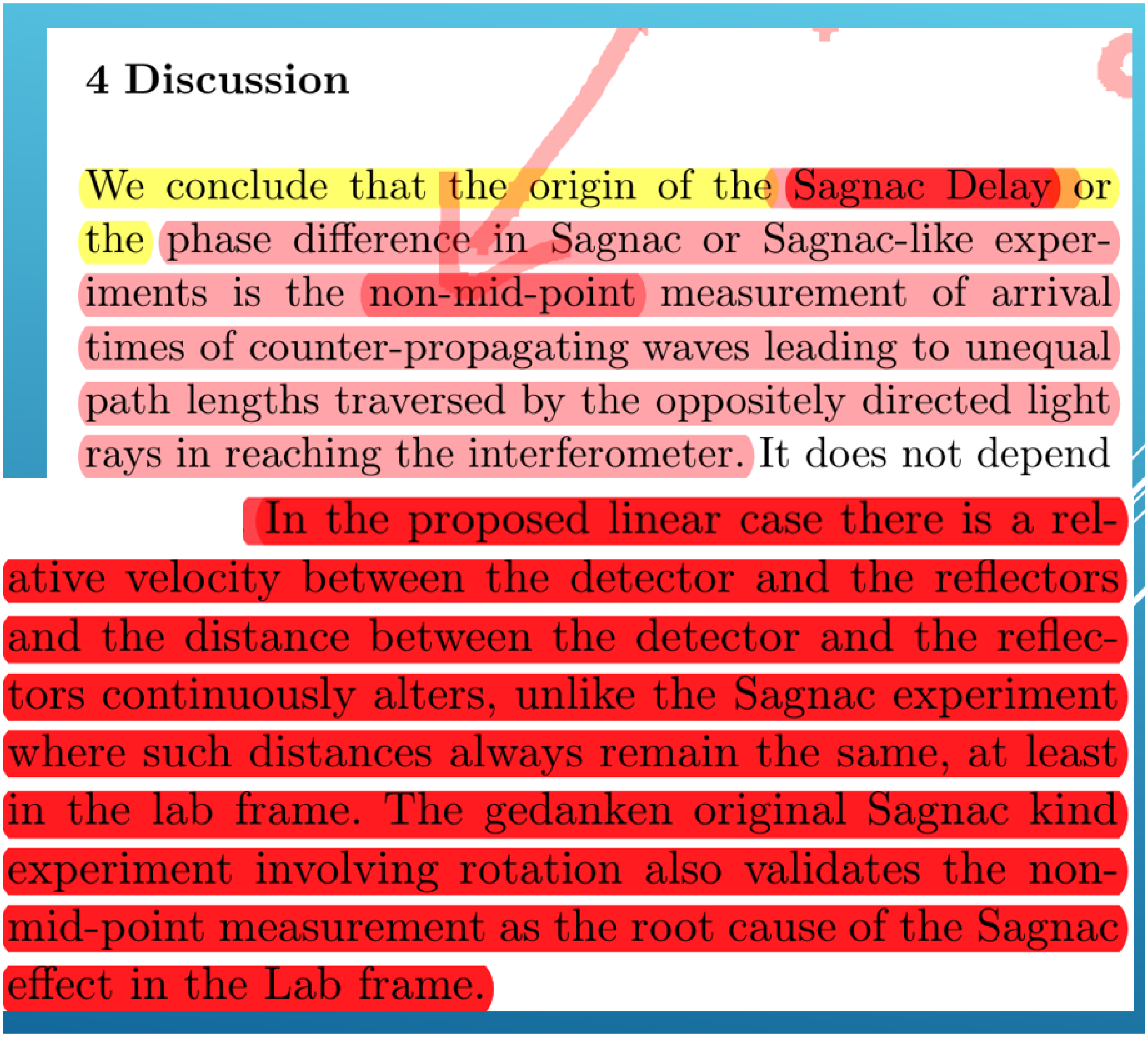


Hence the difference in arrival times between the counter-propagating light rays is exactly the same to eq. (8) as obtained in the Lab frame. However, one may notice that the above derivation does not give the time dilation effect. In his review article Post [6] argued that the time coordinate should transform as $t' = \gamma t$ while switching over from Lab frame to stationary frame which leads to the time dilation effect.

A worthwhile point to be noted that the metric given in eq. (10) is derived from the Lab frame space time metric; it is the metric of the rotating frame according to a Lab frame observer. Though mathematically it is fine but the physical understanding of the effect from the standpoint of an observer attending the rotation remains difficult. When $p = 0$, i.e. the observer

Note: Bhadra's explanation

Invokes the lab frame, denies absolute but can't explain the PHYSICAL DISPLACEMENT WITHOUT changing c.



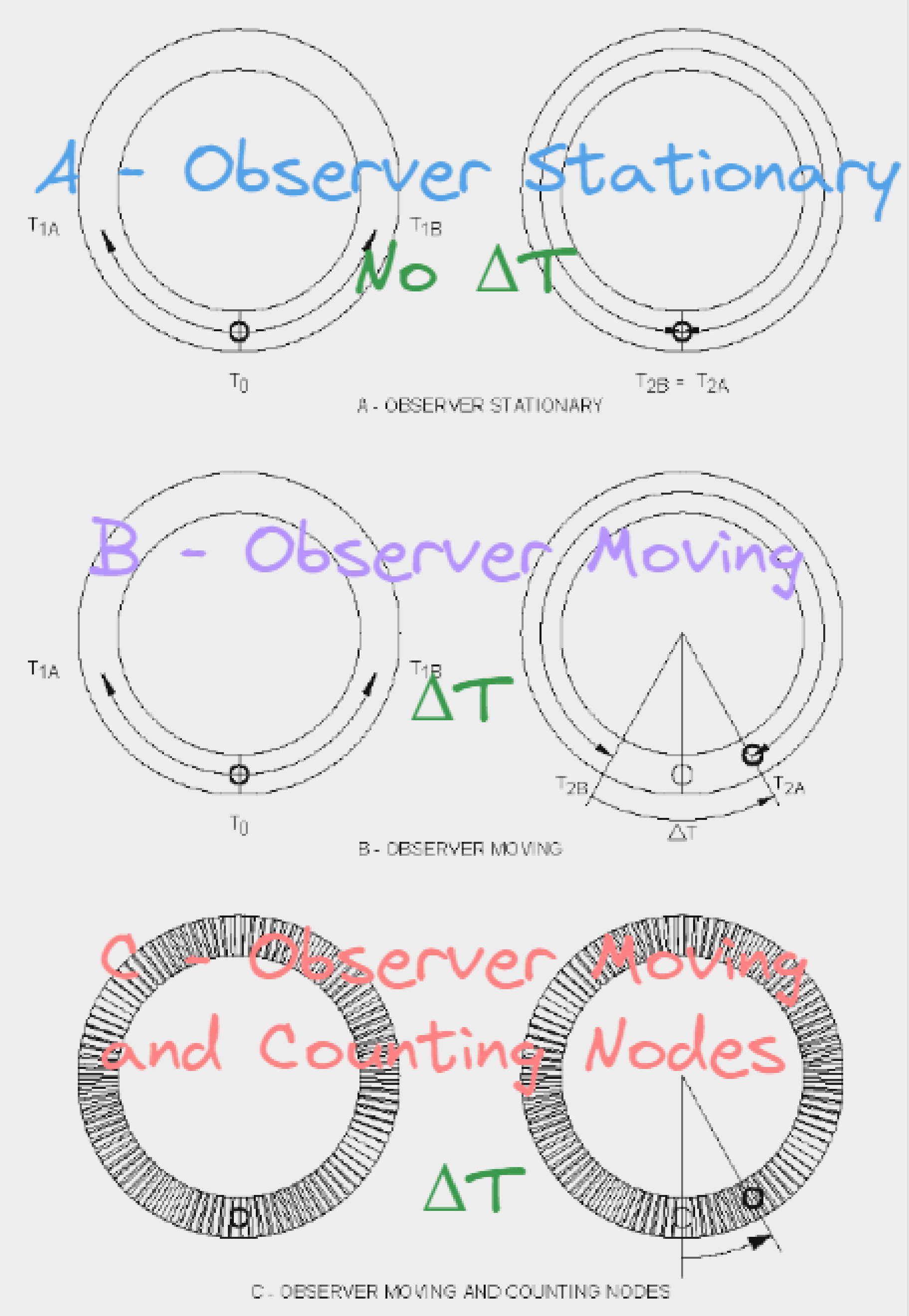
4 Discussion

We conclude that the origin of the Sagnac Delay or the phase difference in Sagnac or Sagnac-like experiments is the non-mid-point measurement of arrival times of counter-propagating waves leading to unequal path lengths traversed by the oppositely directed light rays in reaching the interferometer. It does not depend

In the proposed linear case there is a relative velocity between the detector and the reflectors and the distance between the detector and the reflectors continuously alters, unlike the Sagnac experiment where such distances always remain the same, at least in the lab frame. The gedanken original Sagnac kind experiment involving rotation also validates the non-mid-point measurement as the root cause of the Sagnac effect in the Lab frame.

Note: Unable to answer the Sagnac effect as a Relativistic as late as 2022.

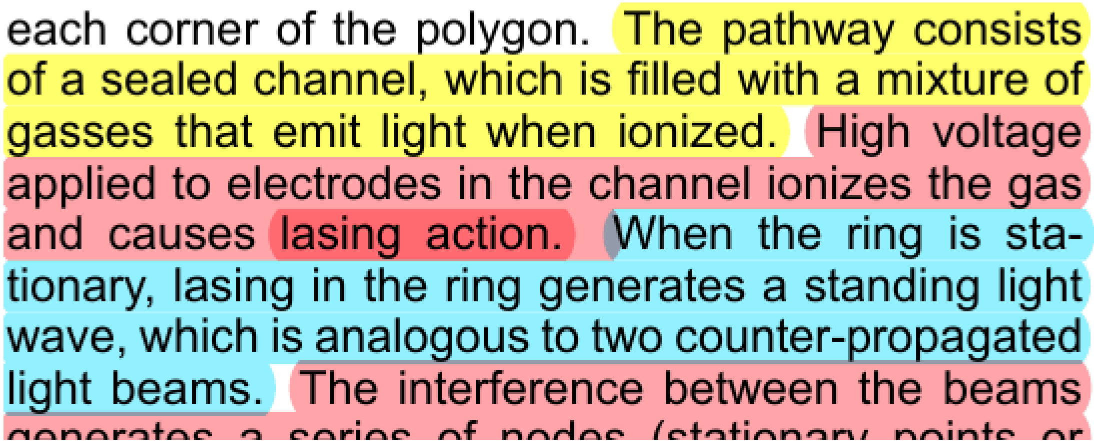
SR can't explain the fringe, GR can't explain it. The time predicted in the lab is the same as on the rotating gyro.



A - OBSERVER STATIONARY

B - OBSERVER MOVING

C - OBSERVER MOVING AND COUNTING NODES


each corner of the polygon. The pathway consists of a sealed channel, which is filled with a mixture of gasses that emit light when ionized. High voltage applied to electrodes in the channel ionizes the gas and causes lasing action. When the ring is stationary, lasing in the ring generates a standing light wave, which is analogous to two counter-propagated light beams. The interference between the beams generates a series of nodes (stationary points or

Note: Related to next slide;

The creation of laser beam creates a laminar flow inside the sealed channel that has to be accounted for i.e. Fresnel drag

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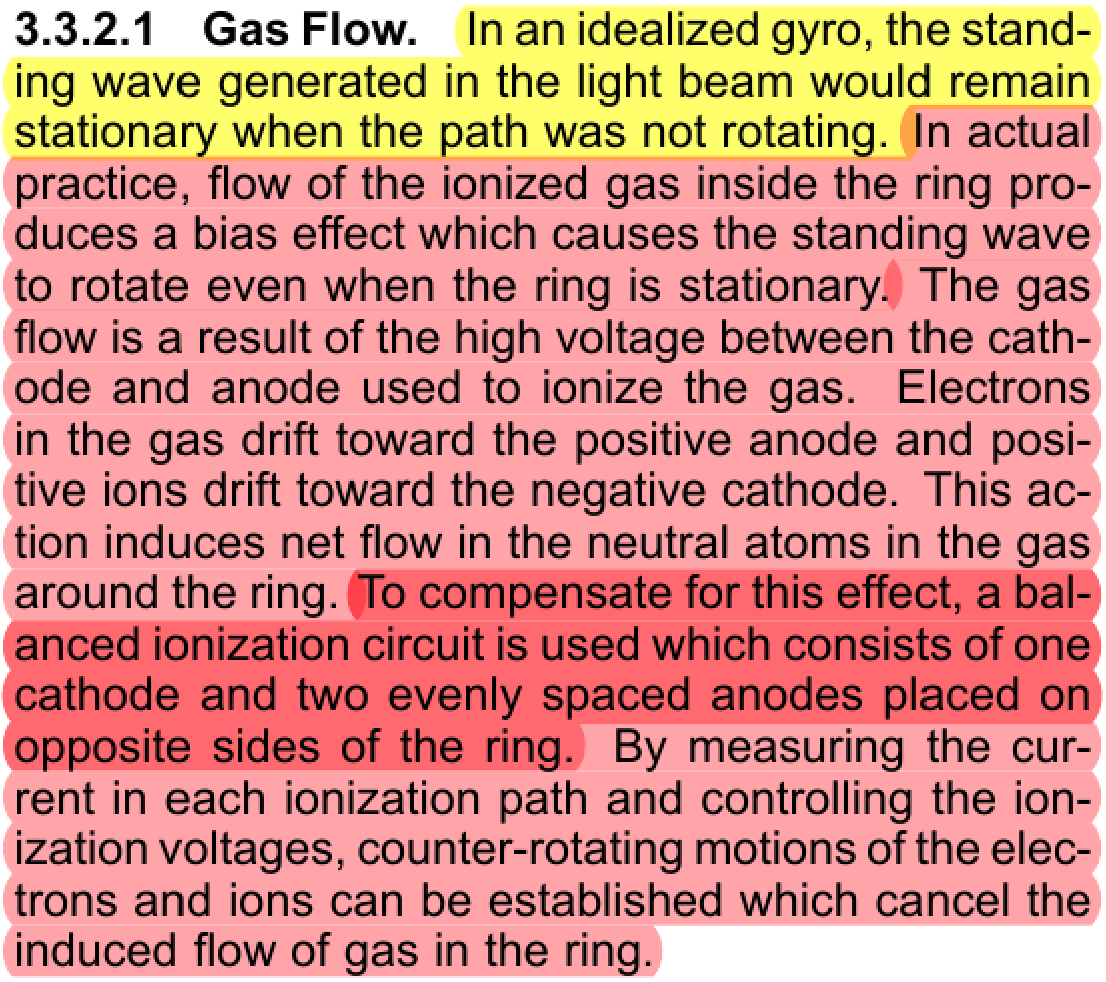


3.3.2.1 Gas Flow. In an idealized gyro, the standing wave generated in the light beam would remain stationary when the path was not rotating. In actual practice, flow of the ionized gas inside the ring produces a bias effect which causes the standing wave to rotate even when the ring is stationary. The gas flow is a result of the high voltage between the cathode and anode used to ionize the gas. Electrons in the gas drift toward the positive anode and positive ions drift toward the negative cathode. This action induces net flow in the neutral atoms in the gas around the ring. To compensate for this effect, a balanced ionization circuit is used which consists of one cathode and two evenly spaced anodes placed on opposite sides of the ring. By measuring the current in each ionization path and controlling the ionization voltages, counter-rotating motions of the electrons and ions can be established which cancel the induced flow of gas in the ring.

Note:

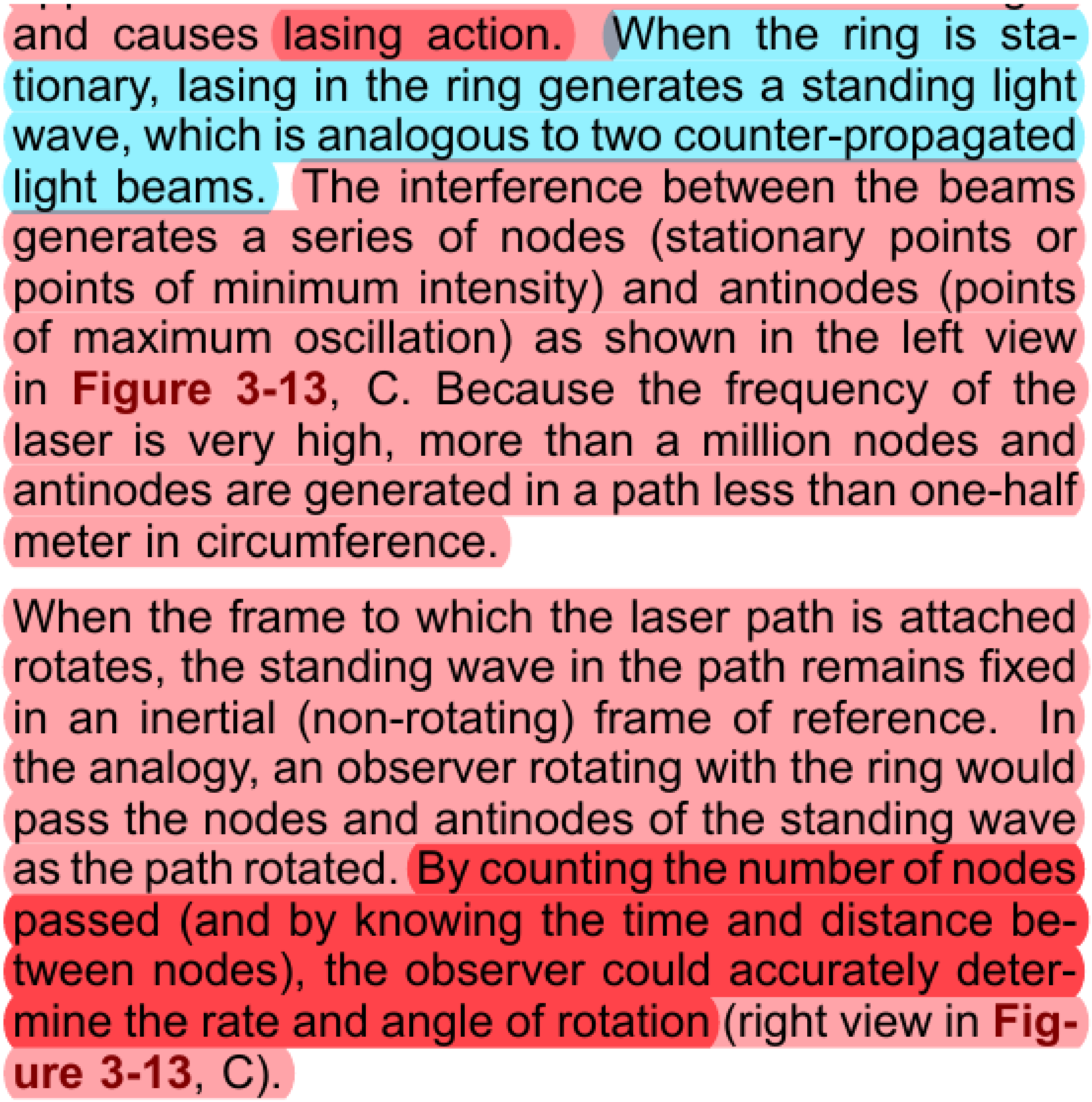
Introduces a medium of known refractive index to calibrate against. Zeroes out noise.

The provides a stabilized medium to calibrate against when new effects, i.e. motion are introduced.

Fresnel Drag needs to be compensated for. They're disguising in technical lingo.

Pressure mediation within the apparatus is creating a laminar flow that's actually causing c+-v in the first-order.

This is corrected for by inducting a current between evenly spaced anodes and cathodes within the sealed channels to counteract the Fresnel drag.



and causes lasing action. When the ring is stationary, lasing in the ring generates a standing light wave, which is analogous to two counter-propagated light beams. The interference between the beams generates a series of nodes (stationary points or points of minimum intensity) and antinodes (points of maximum oscillation) as shown in the left view in **Figure 3-13**, C. Because the frequency of the laser is very high, more than a million nodes and antinodes are generated in a path less than one-half meter in circumference.

When the frame to which the laser path is attached rotates, the standing wave in the path remains fixed in an inertial (non-rotating) frame of reference. In the analogy, an observer rotating with the ring would pass the nodes and antinodes of the standing wave as the path rotated. By counting the number of nodes passed (and by knowing the time and distance between nodes), the observer could accurately determine the rate and angle of rotation (right view in **Figure 3-13**, C).

Note:

If you know the time (*t*),

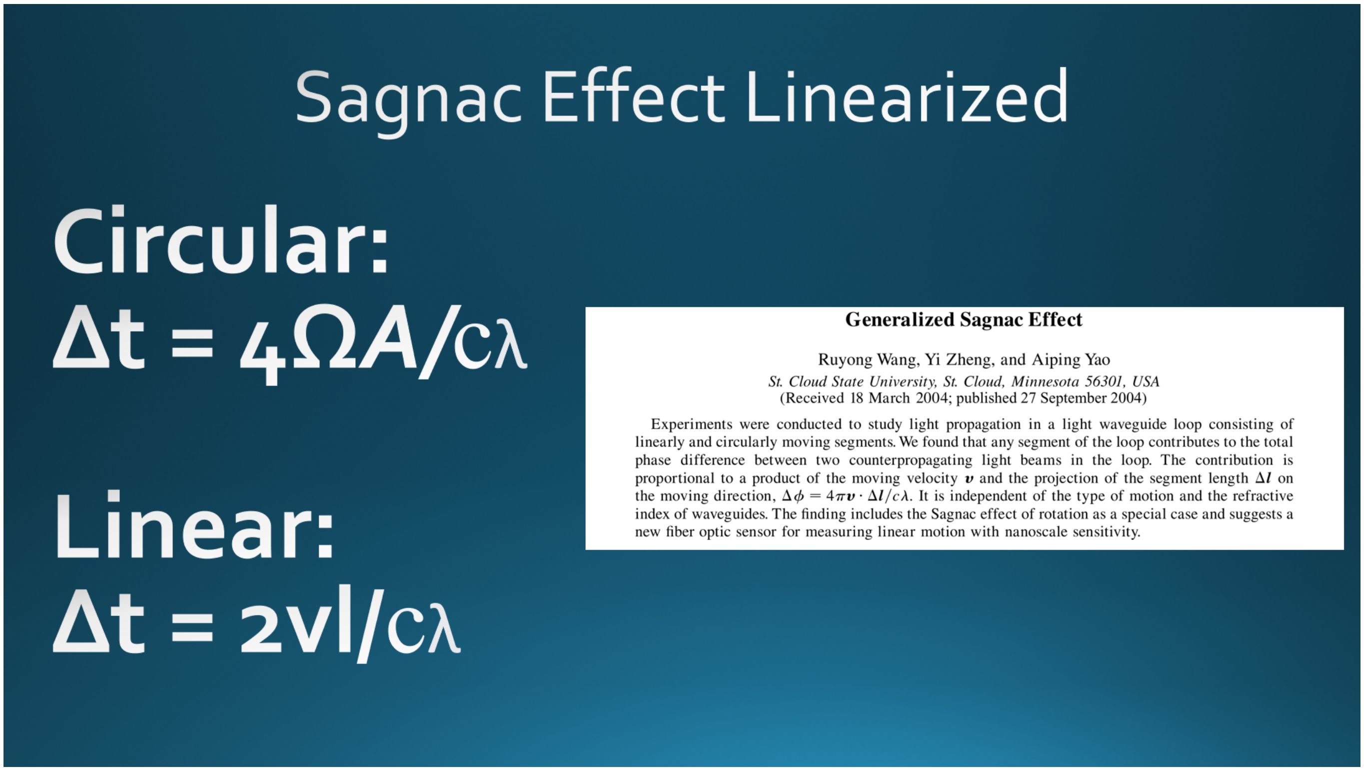
distance (*A* or *l*),

Wavelength (Lambda)

You can measure the fringe pattern to get a velocity.

Measuring fringe displacements over time gives you a velocity.

Special note - in the Relativistic paradigm, an FOG/RGL can only measure angular rotation (ω, Ω).



Sagnac Effect Linearized

Circular:

$\Delta t = 4\Omega A / c\lambda$

Linear:

$\Delta t = 2vl / c\lambda$

Generalized Sagnac Effect

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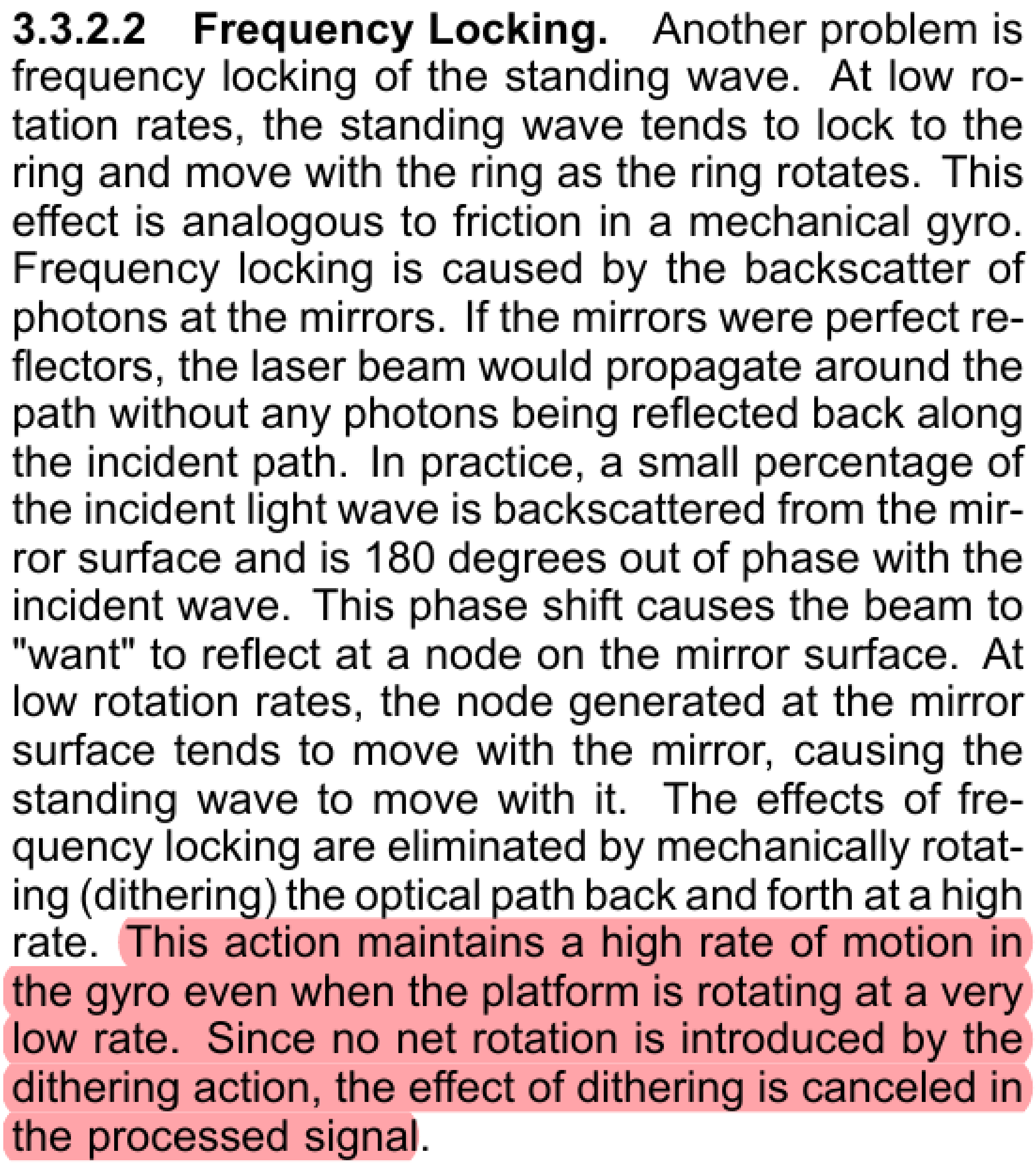
St. Cloud State University, St. Cloud, Minnesota 56301, USA

(Received 18 March 2004; published 27 September 2004)

Experiments were conducted to study light propagation in a light waveguide loop consisting of linearly and circularly moving segments. We found that any segment of the loop contributes to the total phase difference between two counterpropagating light beams in the loop. The contribution is proportional to a product of the moving velocity $\boldsymbol{v}$ and the projection of the segment length $\Delta\boldsymbol{l}$ on the moving direction, $\Delta\phi = 4\pi\boldsymbol{v}\cdot\Delta\boldsymbol{l}/c\lambda$. It is independent of the type of motion and the refractive index of waveguides. The finding includes the Sagnac effect of rotation as a special case and suggests a new fiber optic sensor for measuring linear motion with nanoscale sensitivity.

Note: The description given in the manual for how to derive speed is = the equations above

In 2004 Ruyong Wang, what was once thought to only measure angular rotation, the Sagnac effect was found to measure linear motion as well. (MMX equation just as valid of a velocity reading for the translational speed of the angular rotation of 15°/d.

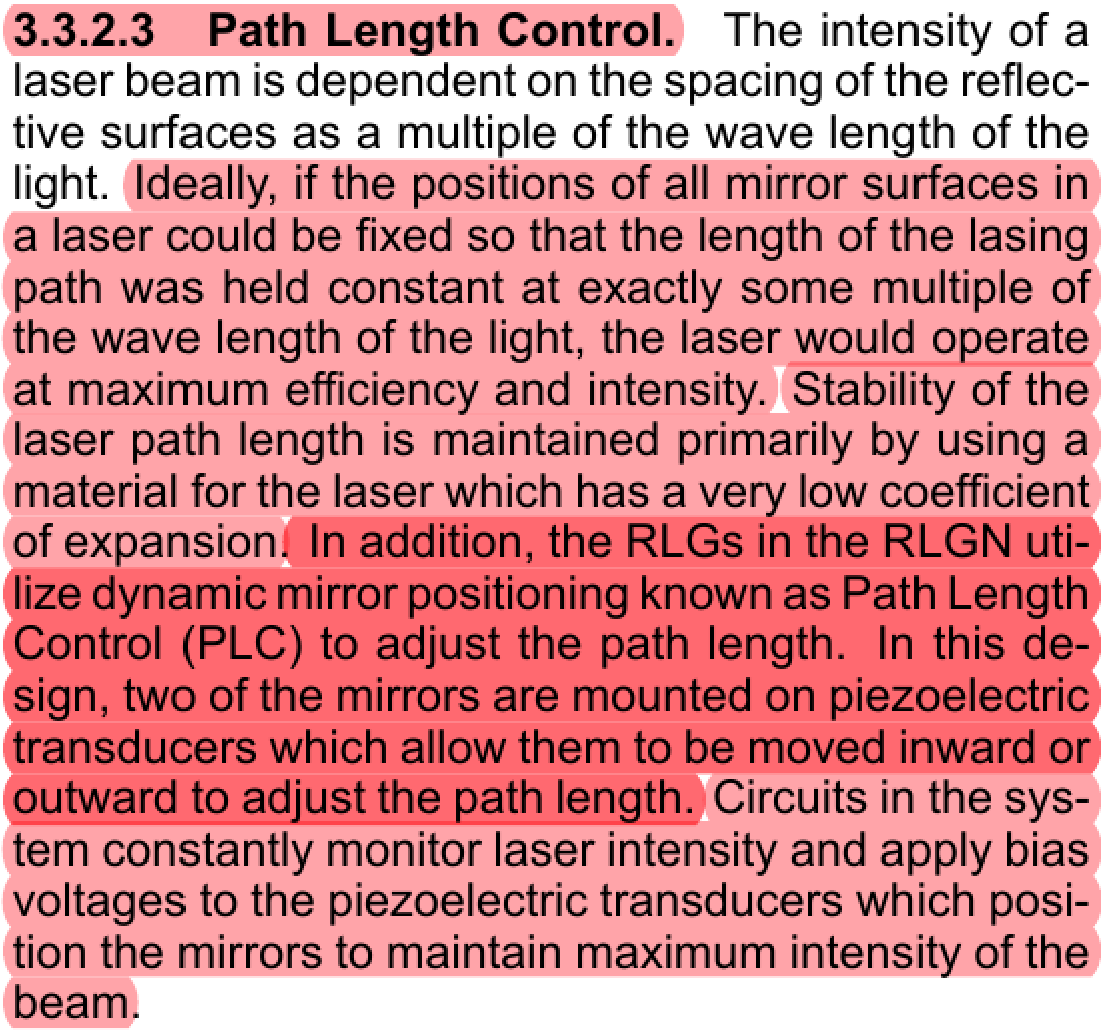


3.3.2.2 Frequency Locking. Another problem is frequency locking of the standing wave. At low rotation rates, the standing wave tends to lock to the ring and move with the ring as the ring rotates. This effect is analogous to friction in a mechanical gyro. Frequency locking is caused by the backscatter of photons at the mirrors. If the mirrors were perfect reflectors, the laser beam would propagate around the path without any photons being reflected back along the incident path. In practice, a small percentage of the incident light wave is backscattered from the mirror surface and is 180 degrees out of phase with the incident wave. This phase shift causes the beam to "want" to reflect at a node on the mirror surface. At low rotation rates, the node generated at the mirror surface tends to move with the mirror, causing the standing wave to move with it. The effects of frequency locking are eliminated by mechanically rotating (dithering) the optical path back and forth at a high rate. This action maintains a high rate of motion in the gyro even when the platform is rotating at a very low rate. Since no net rotation is introduced by the dithering action, the effect of dithering is canceled in the processed signal.

Note:

Frequency locking in the ring laser gyro occurs due to phase interference caused by the backscatter of photons at the mirrors. When a small percentage of the incident light wave is backscattered from the mirror surface and becomes 180 degrees out of phase with the incident wave, it can lead to the standing wave "wanting" to reflect at a specific node on the mirror surface, ultimately resulting in the effects of frequency locking.

In short: light passing through the mirror and back causes additional interference, causing the beams to be out of phase. To fix this, the device is rapidly vibrated in a process called "dithering"



3.3.2.3 Path Length Control. The intensity of a laser beam is dependent on the spacing of the reflective surfaces as a multiple of the wave length of the light. Ideally, if the positions of all mirror surfaces in a laser could be fixed so that the length of the lasing path was held constant at exactly some multiple of the wave length of the light, the laser would operate at maximum efficiency and intensity. Stability of the laser path length is maintained primarily by using a material for the laser which has a very low coefficient of expansion. In addition, the RLGs in the RLGN utilize dynamic mirror positioning known as Path Length Control (PLC) to adjust the path length. In this design, two of the mirrors are mounted on piezoelectric transducers which allow them to be moved inward or outward to adjust the path length. Circuits in the system constantly monitor laser intensity and apply bias voltages to the piezoelectric transducers which position the mirrors to maintain maximum intensity of the beam.

Note:

The laser beam has an optimal intensity that has to maintained in order to get accurate fringe measurements so that an accurate velocity can be deduced.

During use; the device will experience: vibration, thermal expansion and contraction, motion, etc.

To mitigate the effects of external factors such as vibration, thermal expansion, and motion, the device is constructed using materials with low coefficients of expansion.

Secondly, they correct for this would-be effect in real time with piezoelectric transducers (crystals in silicon).

A piezoelectric material will physically deform when a charge is applied to it. The physically move the mirrors, when the beam is not in its optimal phase, a current is applied to the piezoelectric transducers which physically moves the mirror when they deform.

You can also move the mirror back by discharging the transducer. Its deformation and charge stored has a ratio. Apply more/less charge to move the mirror accordingly.

General Relativity's physical mechanism for producing the fringe pattern (length contraction) out the window as an explanained here. They correct for it in real time and the functionality of the device requires there to be no actual distance change from its stationary configuration.

Any movement of the mirrors due to vibration, thermal expansion and contraction, motion, etc, can be corrected in real time

3.2.16 CONCEPTS OF STATISTICAL ESTIMATION, OVERVIEW OF KALMAN FILTER.

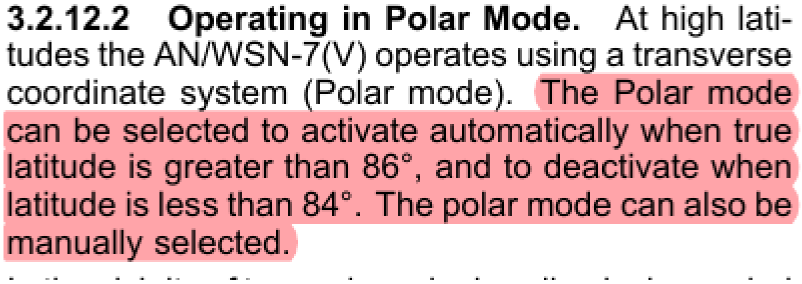
Note:

TL;DR:

The Kalman algorithm constructs a reference database using a specific set of parameters and coefficients to efficiently manage all aspects of the output readings. It achieves this by comparing the device against the information within the algorithm.

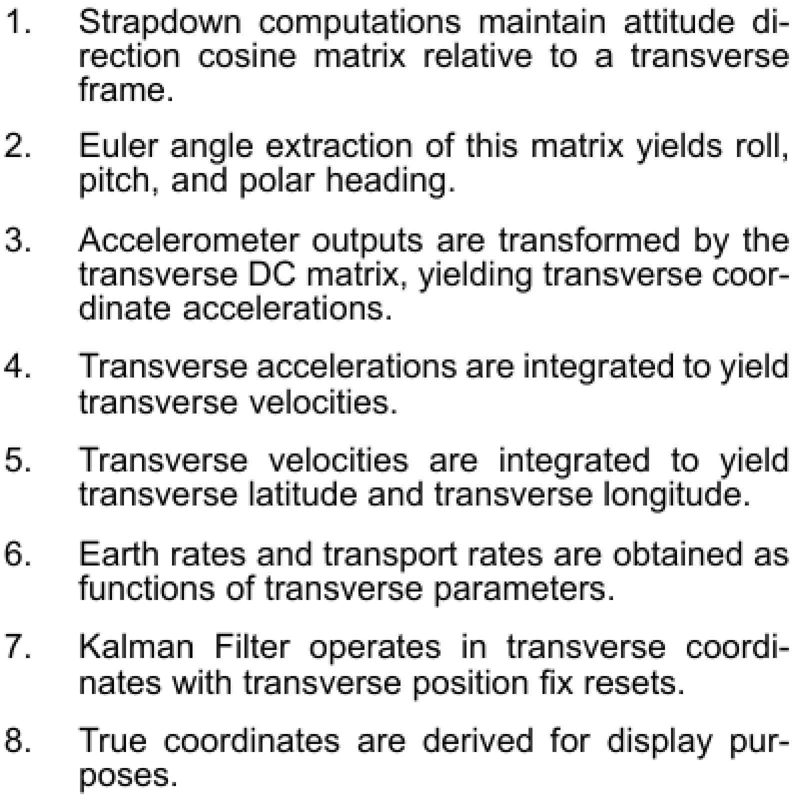
Extended:

- Inertial navigators develop errors due to initial misalignments or physical imperfections, leading to drift rates that change over time.
- The three-fix reset technique, used to correct outputs in some navigators, required three fixes within a 24-hour period and made assumptions about error-free fixes and constant gyro drift rates.
- R.E. Kalman's concept of optimum estimation revolutionized the performance optimization of modern inertial navigation systems by introducing the Kalman Filter, which compensates for measurement errors and system noise in reset computations.
- Statistical estimation involves using a variety of techniques to obtain the true value of a measurement and reduce the impact of random error. The example of using averaging illustrates key concepts of statistical estimation.
- Understanding the statistics of measurement errors and variations in the quantity being measured is crucial in the use of statistical estimation techniques.
- Sample variance and standard deviation are measures of variability and are used for estimating errors and confidence intervals in measurements.
- The Kalman Filter is a recursive form of averaging that uses a different weight factor, taking into account error statistics. It generates estimates through a prediction and measurement process, using a math model to extrapolate predictions and improve accuracy through external measurements.

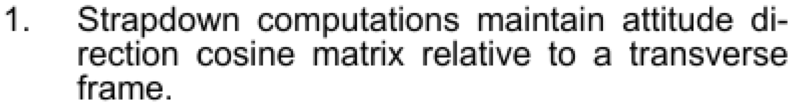


3.2.12.2 Operating in Polar Mode. At high latitudes the AN/WSN-7(V) operates using a transverse coordinate system (Polar mode). The Polar mode can be selected to activate automatically when true latitude is greater than 86°, and to deactivate when latitude is less than 84°. The polar mode can also be manually selected.

Note: Next slide



1. Strapdown computations maintain attitude direction cosine matrix relative to a transverse frame.
2. Euler angle extraction of this matrix yields roll, pitch, and polar heading.
3. Accelerometer outputs are transformed by the transverse DC matrix, yielding transverse coordinate accelerations.
4. Transverse accelerations are integrated to yield transverse velocities.
5. Transverse velocities are integrated to yield transverse latitude and transverse longitude.
6. Earth rates and transport rates are obtained as functions of transverse parameters.
7. Kalman Filter operates in transverse coordinates with transverse position fix resets.
8. True coordinates are derived for display purposes.

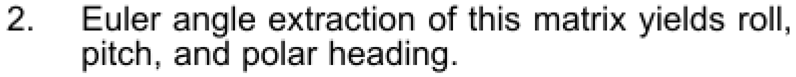


1. Strapdown computations maintain attitude direction cosine matrix relative to a transverse frame.

Note:

The direction cosine matrix is used to determine the angles between the axes of one coordinate system and those of another. In the context of the Inertial Navigation System, it would specifically involve representing the relationship between the axes of the polar coordinate system and the axes of the normal coordinate system. This allows for accurate transformations and computational operations between the two coordinate systems.

This the baseline for how the INS can be navigating WRT another coordinate system without you knowing true distances or locations.

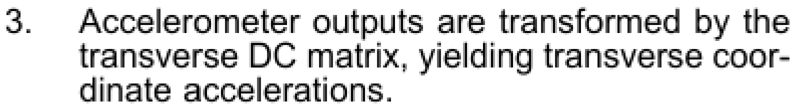


2. Euler angle extraction of this matrix yields roll, pitch, and polar heading.

Note:

The extraction of roll, pitch, and polar heading angles from the direction cosine matrix provides the system's orientation in three-dimensional space relative to both the polar and normal coordinate systems. This information is essential for accurately determining the system's spatial orientation and location in the specified coordinate frames.

This maintained your orientation and position in three dimensional space between both coordinate systems.

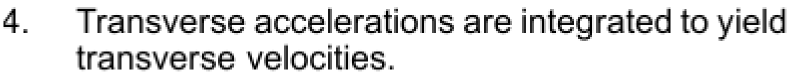


3. Accelerometer outputs are transformed by the transverse DC matrix, yielding transverse coordinate accelerations.

Note:

The accelerometer outputs, which represent the system's accelerations, are transformed using the transverse (polar Direction Cosine (DC) matrix. This transformation results in the representation of the accelerations in the transverse coordinate system. In essence, it allows for the characterization of the acceleration data in the context of the normal frame of reference.

This mirrors your acceleration and velocity onto the transverse coordinate system in real time.

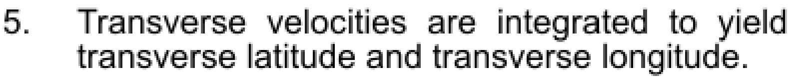


4. Transverse accelerations are integrated to yield transverse velocities.

Note:

The accelerations measured in the transverse coordinate system are mathematically integrated to provide the corresponding velocities in that same coordinate system. Essentially, it involves accumulating the transverse accelerations over time to derive the transverse velocities, effectively capturing how the system's velocity changes over time within the normal frame of reference.

More positioning and orientation corrections to make both coordinate work seamlessly when switching from Polar Mode to Traverse Mode



5. Transverse velocities are integrated to yield transverse latitude and transverse longitude.

Note:

Tracks your relative velocity between both coordinate and compares it against the lat/long of the two coordinate systems.

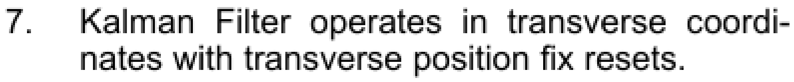
Keep in mind, it's the same velocity. It's just doing this to compensate for distance changes between the two coordinate systems.

6. Earth rates and transport rates are obtained as functions of transverse parameters.

Note:

Changes the amount of gyro drift that would normally be experienced south of the 86 parallel relative to the velocity of the craft. And of course, keeping it in alignment with the normal mode coordinate system

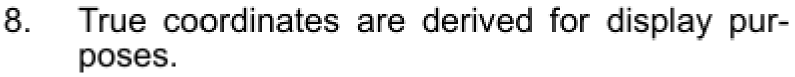
Q: What are the drift rate changes?
Q: Is the drift just another excuse for claiming to need two different coordinate systems?
T: The rotational or ether drift change in the North pole shouldn't change that extremely on either model



7. Kalman Filter operates in transverse coordinates with transverse position fix resets.

Note:

Backs up all polar mode data that was converted to transvers and applies the normal corrections (fix resets) as if were in normal mode the whole time.



8. True coordinates are derived for display purposes.

Note: The polar model cosine matrixies, velocity corrections, position corrections, lat/long corrections, all to display your as a transverse mode coordinate (lat/long).

They just adjusted the entire coordinate system in real time and kept you thinking you were where'd you expect to be on the geoidal earth coordinate system defined as the "True coordinate system"

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