One-Way Speed of Light Measurements Without Clock Synchronisation

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The 1991 DeWitte double one-way 1st order in υ/c experiment successfully measured the anisotropy of the speed of light using clocks at each end of the RF coaxial cables. However Spavieri *et al.*, Physics Letters A (2012), have reported that (i) clock effects caused by clock transport should be included, and (ii) that this additional effect cancels the one-way light speed timing effect, implying that one-way light speed experiments "do not actually lead to the measurement of the one-way speed of light or determination of the absolute velocity of the preferred frame". Here we explain that the Spavieri *et al.* derivation makes an assumption that is not always valid: that the propagation is subject to the usual Fresnel drag effect, which is not the case for RF coaxial cables. As well DeWitte did take account of the clock transport effect. The Spavieri *et al.* paper has prompted a clarification of these issues.

1 Introduction

The enormously significant 1991 DeWitte [1] double one-way 1st order in υ/c experiment successfully measured the anisotropy of the speed of light using clocks at each end of the RF coaxial cables. The technique uses rotation of the light path to permit extraction of the light speed anisotropy, despite the clocks not being synchronised. Data from this 1st order in υ/c experiment agrees with the speed and direction of the anisotropy results from 2nd order in υ/c Michelson gas-mode interferometer experiments by Michelson and Morley and by Miller, see data in [2], and with NASA spacecraft earth-flyby Doppler shift data [3], and also with more recent 1st order in υ/c experiments using a new single clock technique [2], Sect. 5. However Spavieri *et al.* [4] reported that (i) clock effects caused by clock transport should be included, and (ii) that this additional effect cancels the one-way light speed timing effect, implying that one-way light speed experiments "do not actually lead to the measurement of the one-way speed of light or determination of the absolute velocity of the preferred frame". Here we explain that the Spavieri *et al.* derivation makes an assumption that is not always valid: that the propagation is subject to the usual Fresnel drag effect, which is not the case for RF coaxial cables. The Spavieri *et al.* paper has prompted a clarification of these issues. In particular DeWitte took account of both the clock transport effect, and also that the RF coaxial cables did not exhibit a Fresnel drag, though these aspects were not discussed in [1].

2 First Order in v/c Speed of EMR Experiments

Fig. 1 shows the arrangement for measuring the one-way speed of light, either in vacuum, a dielectric, or RF coaxial cable. It is usually argued that one-way speed of light measurements are not possible because the clocks C_1 and C_2 cannot be synchronised. However this is false, although an important previously neglected effect that needs to be included is the clock offset effect caused by transport when the apparatus is rotated [4], but most significantly the Fresnel drag effect is not present in RF coaxial cables. In Fig. 1 the actual travel time $t_{AB} = t_B - t_A$ from A to B, as distinct from the clock indicated travel time $T_{AB} = T_B - T_A$, is determined by

$$V(\upsilon\cos(\theta))t_{AB} = L + \upsilon\cos(\theta)t_{AB} \tag{1}$$

where the 2nd term comes from the end B moving an additional distance $\upsilon\cos(\theta)t_{AB}$ during time interval t_{AB}. With Fresnel drag $V(\upsilon) = \frac{c}{n} + \upsilon\left(1 - \frac{1}{n^2}\right)$, when V and υ are parallel, and where n is the dielectric refractive index. Then

$$t_{AB} = \frac{L}{V(\upsilon\cos(\theta)) - \upsilon\cos(\theta)} = \frac{nL}{c} + \frac{\upsilon\cos(\theta)L}{c^2} + .. \tag{2}$$

However if there is no Fresnel drag effect, $V = c/n$, as is the case in RF coaxial cables, then we obtain

$$t_{AB} = \frac{L}{V(\upsilon\cos(\theta)) - \upsilon\cos(\theta)} = \frac{nL}{c} + \frac{\upsilon\cos(\theta)Ln^2}{c^2} + .. \tag{3}$$

It would appear that the two terms in (2) or (3) can be separated by rotating the apparatus, giving the magnitude and direction of $\mathbf{v}$. However it is $T_{AB} = T_B - T_A$ that is measured, and not t_{AB}, because of an unknown fixed clock offset τ, as the clocks are not *a priori* synchronised, and as well an angle dependent clock transport offset $\Delta\tau$, at least until we can establish clock synchronisation, as explained below. Then the clock readings are $T_A = t_A$ and $T_B = t_B + \tau$, and $T'_B = t'_B + \tau + \Delta\tau$, where $\Delta\tau$ is a clock offset that arises from the slowing of clock C_2 as it is transported during the rotation through angle $\Delta\theta$, see Fig. 1.

3 Clock Transport Effect

The clock transport offset $\Delta\tau$ follows from the clock motion effect

$$\Delta\tau = dt\sqrt{1 - \frac{(\mathbf{v}+\mathbf{u})^2}{c^2}} - dt\sqrt{1 - \frac{\mathbf{v}^2}{c^2}} = -dt\frac{\mathbf{v}\cdot\mathbf{u}}{c^2} + ..., \tag{4}$$

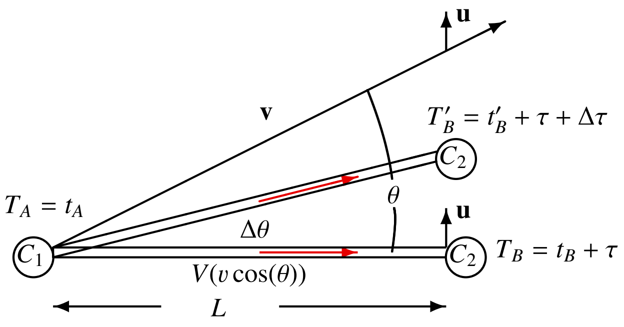

Fig. 1: Schematic layout for measuring the one-way speed of light in either free-space, optical fibres or RF coaxial cables, without requiring the synchronisation of the clocks C_1 and C_2. Here τ is the, initially unknown, offset time between the clocks. Times t_A and t_B are true times, without clock offset and clock transport effects, while $T_A = t_A$, $T_B = t_A + \tau$ and $T'_B = t'_B + \tau + \Delta\tau$ are clock readings. $V(v\cos(\theta))$ is the speed of EM radiation wrt the apparatus before rotation, and $V(v\cos(\theta - \Delta\theta))$ after rotation, **v** is the velocity of the apparatus through space in direction θ relative to the apparatus before rotation, **u** is the velocity of transport for clock C_2, and $\Delta\tau < 0$ is the net slowing of clock C_2 from clock transport, when apparatus is rotated through angle $\Delta\theta > 0$. Note that $\mathbf{v} \cdot \mathbf{u} > 0$.

when clock C_2 is transported at velocity **u** over time interval dt, compared to C_1. Now $\mathbf{v} \cdot \mathbf{u} = vu\sin(\theta)$ and $dt = L\Delta\theta/u$. Then the change in T_{AB} from this small rotation is, using (3) for the case of no Fresnel drag,

$$\Delta T_{AB} = \frac{v\sin(\theta)Ln^2\Delta\theta}{c^2} - \frac{v\sin(\theta)L\Delta\theta}{c^2} + ... \tag{5}$$

as the clock transport effect appears to make the clock-determined travel time smaller (2nd term). Integrating we get

$$T_B - T_A = \frac{nL}{c} + \frac{v\cos(\theta)L(n^2-1)}{c^2} + \tau, \tag{6}$$

where τ is now the constant offset time. The $v\cos(\theta)$ term may be separated by means of the angle dependence. Then the value of τ may be determined, and the clocks synchronised. However if the propagation medium is vacuum, liquid, or dielectrics such as glass and optical fibres, the Fresnel drag effect is present, and we then use (2), and not (3). Then in (6) we need make the replacement $n \to 1$, and then the 1st order in v/c term vanishes, as reported by Spavieri *et al.*. However, in principle, separated clocks may be synchronised by using RF coaxial cables.

4 DeWitte 1st Order in v/c Detector

The DeWitte $L = 1.5$ km 5 MHz RF coaxial cable experiment, Brussels 1991, was a double 1st order in v/c detector, using the scheme in Fig. 1, but employing a 2nd RF coaxial cable for the opposite direction, giving clock difference $T_D - T_C$, to cancel temperature effects, and also used 3 Caesium atomic clocks at each end. The orientation was NS and

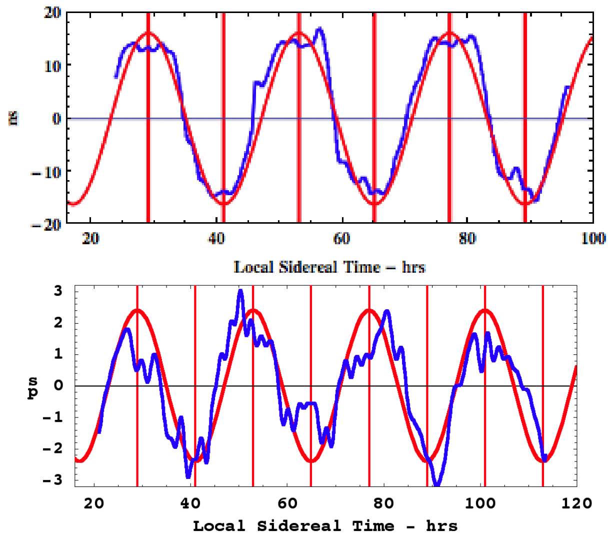

Fig. 2: Top: Data from the 1991 DeWitte NS RF coaxial cable experiment, $L = 1.5$ km, using the arrangement shown in Fig. 1, with a 2nd RF coaxial cable carrying a signal in the reverse direction. The vertical red lines are at RA=5^h and 17^h. DeWitte gathered data for 178 days, and showed that the crossing time tracked sidereal time, and not local solar time, see Fig. 3. DeWitte reported that $v \approx 500$ km/s. If a Fresnel drag effect is included no effect would have been seen. Bottom: Dual coaxial cable detector data from May 2009 using the technique in Fig. 4 with $L = 20$ m. NASA Spacecraft Doppler shift data predicts Dec= $-77°$, $v = 480$ km/s, giving a sidereal dynamic range of 5.06 ps, very close to that observed. The vertical red lines are at RA=5^h and 17^h. In both data sets we see the earth sidereal rotation effect together with significant wave/turbulence effects.

rotation was achieved by that of the earth [1]. Then

$$T_{AB} - T_{CD} = \frac{2v\cos(\theta)L(n^2-1)}{c^2} + 2\tau \tag{7}$$

For a horizontal detector the dynamic range of $\cos(\theta)$ is $2\sin(\lambda)\cos(\delta)$, caused by the earth rotation, where λ is the latitude of the detector location and δ is the declination of **v**. The value of τ may be determined and the clocks synchronised. Some of DeWitte's data and results are in Figs. 2 and 3. DeWitte noted that his detector produced no effect at RF frequency of 1GHz, suggesting that the absence of Fresnel drag in RF coaxial cables may be a low frequency effect. This means that we should write the Fresnel drag expression as $V(v) = \frac{c}{n} + v\left(1 - \frac{1}{m(f)^2}\right)$, where $m(f)$ is RF frequency f dependent, with $m(f) \to n$ at high f.

5 Dual RF Coaxial Cable Detector

The single clock Dual RF Coaxial Cable Detector exploits the absence of the Fresnel drag effect in RF coaxial cables [2]. Then from (3) the round trip travel time for one circuit is, see Fig. 4,

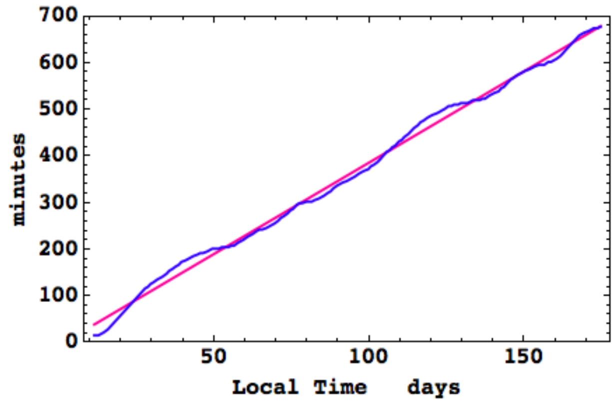

Fig. 3: DeWitte collected data over 178 days and demonstrated that the zero crossing time, see Fig. 2, tracked sidereal time and not local solar time. The plot shows the negative of the drift in the crossing time vs local solar time, and has a slope, determined by the best-fit straight line, of -3.918 minutes per day, compared to the actual average value of -3.932 minutes per day. Again we see fluctuations from day to day.

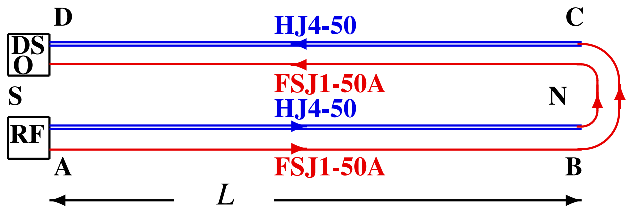

Fig. 4: Because Fresnel drag is absent in RF coaxial cables this dual cable setup, using one clock (10 MHz RF source) and Digital Storage Oscilloscope (DSO) to measure and store timing difference between the two circuits, as in (9)), is capable of detecting the absolute motion of the detector wrt to space, revealing the sidereal rotation effect as well as wave/turbulence effects. Results from such an experiment are shown in Fig. 2. Andrews phase-stablised coaxial cables are used. More recent results are reported in [2].

$$t_{AB} + t_{CD} = \frac{(n_1 + n_2)L}{c} + \frac{v\cos(\theta)L(n_1^2 - n_2^2)}{c^2} + .. \quad (8)$$

where n_1 and n_2 are the effective refractive indices for the two different RF coaxial cables. There is no clock transport effect as the detector is rotated. Dual circuits reduce temperature effects. The travel time difference of the two circuits at the DSO is then

$$\Delta t = \frac{2v\cos(\theta)L(n_1^2 - n_2^2)}{c^2} + .. \quad (9)$$

A sample of data is shown in Fig. 2, using RF=10 MHz, and is in excellent agreement with the DeWitte data, the NASA flyby Doppler shift data, and the Michelson-Morley and Miller results.

6 Conclusions

The absence of the Fresnel drag in RF coaxial cables enables 1st order in v/c measurements of the anisotropy of the speed of light. DeWitte pioneered this using the multiple clock technique, and took account of the clock transport effect, while the new dual RF coaxial cable detector uses only one clock. This provides a very simple and robust technique to detect motion wrt the dynamical space. Experiments by Michelson and Morley 1887, Miller 1925/26, DeWitte 1991, Cahill 2006, 2009, 2012, and NASA earth-flyby Doppler shift data now all agree, giving the solar system a speed of ~ 486 km/s in the direction RA=4.3^h, Dec= -75.0°. These experiments have detected the fractal textured dynamical structure of space - the privileged local frame [2]. This report is from the Gravitational Wave Detector Project at Flinders University.

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