Preface

The present dissertation, as the title suggests deals with among other things some conceptual issues concerning relativistic Sagnac effect. Historically perhaps no other experiment posed so strong a conceptual challenge to special relativity, since its advent in 1905, as the Sagnac experiment did. This experiment was first conceived by O. Lodge, A. A. Michelson and few others and finally was successfully performed by G. Sagnac in 1913. This is essentially an interference experiment performed with counter-propagating light beams where the whole set up is mounted on a rotating turntable. The idea of the experiment as conceived was pre-relativistic and its main aim was to prove the existence of ether. The Sagnac result unlike that of Michelson-Morley experiment is a non-null effect. The experimental result was accurate up to the first order in v/c (it still remains so) and thus was easily explained through classical kinematics. When one considers the effect of relativity, one finds that the correction is only in the second order in v/c. In the disc type Sagnac experiments although this second order effect can be neglected, the considerations of relativity in explaining the effect from the theoretical standpoint is highly challenging in various ways. The existence of the rich ramifications of the problem can be appreciated from the fact that not one but at least twenty different derivations of the Sagnac phaseshift formula was reported to exist. In 1996, Franco Selleri pointed out that even though there are so many relativistic derivations of the Sagnac formula, there seems to exist no derivation from the perspective of the rotating frame. Our interest in Sagnac effect stemmed from this observation of Selleri. The special theory of relativity is challenged even today in the context of the Sagnac result. Some authors still claim that the use of the Lorentz transformation, and for that matter, standard relativity gives null result in the derivation of the Sagnac result. Again on the contrary some believe that classical physics gives null result for Sagnac effect with matter waves. Also one finds in the literature that even there is no unanimity among the authors about the correct relativistic formula of Sagnac effect and at least two different relativistic formulae exist for the Sagnac result. These are higher order corrections and present day precision may not resolve this dilemma experimentally, but from the theoretical point of view, this dilemma should not be left unresolved. I decided to take up some of these issues hoping to address various question related to relativistically rotating discs, Ehrenfest and other paradoxes of relativity, including some aspect of general relativistic (optical) Sagnac effect. The present thesis is a compilation of the findings of the present author with his collaborators following investigations in these basic issues.

In recent times the Sagnac effect is much discussed int the literature. In global positioning system whose purpose is accurate navigation on or near earth's surface and to provide accurate worldwide clock synchronization and timing system, the correction due to the Sagnac effect is essential for accuracy. It has also been proposed in recent times to make the Sagnac effect the basis of gravitational wave detection using a Laser Interferometer Space Antenna (LISA). In fact number of websites related to the Sagnac effect listed by search engines increased enormously in recent years from what we found when we started our work on it. This shows the intensity of interest of physics community in the Sagnac effect. Applications of the Sagnac effect in newer fields are emerging day by day. Newer experimental techniques are evolving taking the measurement of the Sagnac result more and more precise. The Sagnac experiment performed with matter wave has opened a new perspective of the Sagnac effect. In a very interesting experiment performed in 2003, Wang, Zheng, Aiping and Langley claim to have observed Sagnac effect in a fibre optic conveyer set up, which may be interpreted as an observation of two different speeds of light in opposite directions by an *inertial* observer! People used to believe that the Sagnac phaseshift is proportional to the area of the optical loop of the set up. Wang et. al. experiment refutes this claim showing that the effect can be observed in the zero area configuration too. The basic theory of this Wang et. al. effect can be found in our linear Sagnac thought experiment set up discussed in the main text. This thought experiment was however proposed earlier by the present authors.

The present dissertation is an investigation on the Sagnac effect from a purely theoretical point of view. The aim here is to discuss some foundational questions and paradoxes related to rotating frame in general and the Sagnac effect in particular. Indeed for the present author and his collaborators, the study of the theoretical aspects of the Sagnac effect converged into the study of the relativity theory in rotating frames. The *conventionality of simultaneity* (CS) thesis of special relativity has been found to be an essential tool in this study. The conceptual difficulties posed by the Sagnac effect are found to be related to improper handling of physics in rotating frames in special relativity. The correction to the Sagnac formula due to the curvature of spacetime is also discussed for the sake of completeness.

The main text of the present study comprises of Chap. 3 to Chap. 7 which report the observations and results obtained by me along with my collaborators during our studies in the last few years. Some of these observations have been published and some have been reported in the national and international meetings.

The whole volume is organized as follows: In Chap. 1, after a brief introduction, we give a topicwise summary of the main chapters (Chap. 3 through Chap. 7). The reader will find a bird's eye view of the topics discussed in the main text therein; this will act as a gateway for to the main contents. Mathematical language is by and large avoided therein. In Chap. 2, a review of the Sagnac effect is given. The readers familiar with the Sagnac effect may wish to skip this chapter. However, going through it will be beneficial because this will act as a ready reference since particularly those aspects of the Sagnac effect are covered which are relevant for the present study.

The next chapter (*i.e.* Chap. 3) discusses the resolution of the long standing problem of Ehrenfest paradox thereby offering a solution of the controversy over the form of the Sagnac effect formula. A recently posed paradox called Tippe-top paradox concerning rotating frames is analyzed and its resolution is offered in Chap. 4. Another recent paradox which apparently challenges the very foundation of SR has been discussed with a proposed resolution which finds its place in Chap. 5. In Chap. 6 we discuss the possibilities of having a transformation equation from an inertial frame to a rotating frame and uphold F. Selleri's claim that absolute synchrony is the natural synchrony in a rotating frame. In the process we point out a weak point in a work by Post which, to our knowledge has not received proper attention anywhere till date. In Chap. 7, the analysis of the Sagnac effect is extended in curved spacetimes and some interesting results have been obtained in the pre-horizon regime.

All the chapters are self contained assuming some prior knowledge of the reader in the CS thesis of relativity and of different relativistic transformations corresponding to different procedures of synchronization of clocks. However a brief introduction to the CS thesis is given in Chap 1 to start with. Also, whenever the CS thesis is used in a chapter, a brief introduction suitable for that purpose is given for the sake of completeness. A fairly comprehensive account of the CS thesis and relativistic transformations are given in appendices A and B, respectively with the hope that this will provide an introduction to those who are not much familiar with this aspect of SR. The reason behind adding this appendix is that textbooks on SR seldom discuss the CS thesis and consequent transformations and the present thesis heavily relies on this Reichenbach-Grünbaum thesis of CS.

The Chap. 4 in the dissertation discusses an issue which as such is not connected with Sagnac effect, however it involves rotations. The importance of the inclusion of this treatise and placing it before another Sagnac topic is that the resolution of the tippe top paradox makes use of a different coordinate transformation (Zahar transformation) in the Galilean (classical) world where the clocks are synchronized following Einstein's method. This kind of approach is used to resolve a paradox of SR is done for the first time. This novel method of posing a problem in a hypothetical classical world and resolving it through the Zahar transformation to understand a paradoxe appearing in SR is proposed by us and hitherto unavailable in the literature. This chapter which discusses the Tippe top paradox apart from its intrinsic importance, therefore provides a preparation for the reader to pass smoothly to Chap. 5, apart from its intrinsic importance. Indeed, this exercise will help the reader to understand the resolution of the Selleri paradox without any difficulty. Moreover our intellectual journey in this study is reflected in the order of appearance of the topics (apart from the fact that this is the chronological order of publication too). We wish to share this experience with our readers, as well.

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