Presented at the MG8 Meeting at Jerusalem in 1997. *Proceedings of the 8th Marcel Grossmann Meeting on General Relativity*, Ed. Tsvi Piran and R. Ruffini, World Scientific, Singapore, 1999, page 1226.

# The Two-Color Transcollimator, a Precision Position Detector for a Satellite Two-Sphere Equivalence-Principle Experiment

Benjamin Lange
1922 Page St., San Francisco, CA 94117-1804

**Abstract:** A minor modification to an autocollimator can transform it into a high precision instrument to detect the translation of a reflecting sphere. A two color version of this instrument can be used to measure the positions of two free-floating concentric spheres in an equivalence-principle experiment in a drag-free satellite.

One obvious design for a high precision equivalence-principle (EP) experiment would be a drag-free satellite [1] with two free-floating concentric spherical proof masses, a solid sphere inside of a transparent spherical shell. Until now this design has not been practical because no way was known to measure the positions of the two proof masses independently, the EP response grows less rapidly than the main disturbance, and because a violation of the equivalence principle and a radial bias error are not separately observable.

The measurement problem can be solved with a two-color transcollimator, and solutions to the other two problems will be discussed in companion papers in this volume [2, 3]. A transcollimator is a device for optically measuring the translation of a sphere. It is an autocollimator with the output beam focused to a point instead of being collimated. If the focal point of the output beam is chosen to coincide with the center of a reflecting sphere, a translation of the sphere perpendicular to the beam becomes equivalent to a rotation of an autocollimator mirror equal to the translation divided by the radius of the sphere. Figure 1 shows this principle and one possible design for a two-color transcollimator. If $W$ is the light-beam power in $\mu$watts, a design based on the Jones-Pfund reticule [4] would typically have a noise equivalent translation as low as $10^{-12}$ meters/Hz$^{1/2} \times (1\ \mu\text{watt}/W)^{1/2}$ for a 5-cm diameter sphere [5]. Since the noise equivalent angle is proportional to $W^{-1/2}$, the beam power could be greatly reduced if needed without seriously affecting the performance. For example, 0.0001 $\mu$watt would still give a noise equivalent translation of $10^{-10}$ meters/Hz$^{1/2}$.

If the light source of a transcollimator consists of two monochromatic colors in a wavelength ratio of two to one; and if the spherical shell is transparent with a quarter-wavelength coatings for the longer wavelength in the beam, separate high accuracy position measurements of the sphere and the shell can be made. This device has the additional advantage that all of the existing technology for autocollimator design can be immediately transferred to the design of the transcollimator so that very little additional development is necessary to realize the instrument.

The instrument noise is very low; but if the sphere is not accurately polished, this can lead to large systematic errors which are of the order of the polishing errors. Since the surfaces of high quality spheres can typically be polished to about $10^{-8}$ meters, there could be systematic errors $10^4$ times as large as the noise after one second of averaging. This could potentially create dynamic range problems for the electronics, but the problem can be solved by spinning the sphere. Spin separates the systematic errors in frequency from the very low frequency EP response; and in addition, it can be used to measure the polishing errors. This is done by commanding a large polhode motion using an active damper [6]. The surface of the sphere can be completely scanned by the polhodes, and the measurements fitted to a spherical-harmonic model.

The specific force error due to the light pressure from the beam power is not a serious problem since it can be reduced below $10^{-24}$ g's for a $10^{-8}$-Watt beam by roll averaging. In addition, the light pressure from opposing instruments can be balanced to a few percent.

Using a two-color transcollimator an equivalence-principle experiment can be designed which can detect an equivalence-principle violation between $10^{-20}$ and $10^{-24}$ $g$ [2, 3].


[1] Lange, B., Ph.D. Thesis, Stanford University, Stanford University Department of Aeronautical Engineering Report (SUDAER) No. 194, June 1964. AIAA Journal, **2**, 9, 1950 (1964).

[2] Lange, B., *Suppressing Radial Non-Observability in a Concentric Two-Sphere Equivalence-Principle Experiment by Gravity-Gradient Cancellation*, companion paper in this volume.

[3] Lange, B., *Separating Out the Radial-Offset Error in a Two-Sphere Equivalence-Principle Experiment in a Satellite*, companion paper in this volume.

[4] R. V. Jones and J. C. Richards, J. of Sci. Instr., **36**, 2, 90 (1959). R. V. Jones, J. of Sci. Instr., **38**, 2, 37 (1961).

[5] Lange, B., *Design and Analysis of a High-Accuracy Version of the Relativity-Gyro Experiment*, In preparation.

[6] B. Parkinson and B. Lange, J. Spacecr. Rockets, **7**, 6, 667; **7**, 6, 675 (1970). B. Lange, J. Spacecr. Rockets, **9**, 2, 96 (1972).

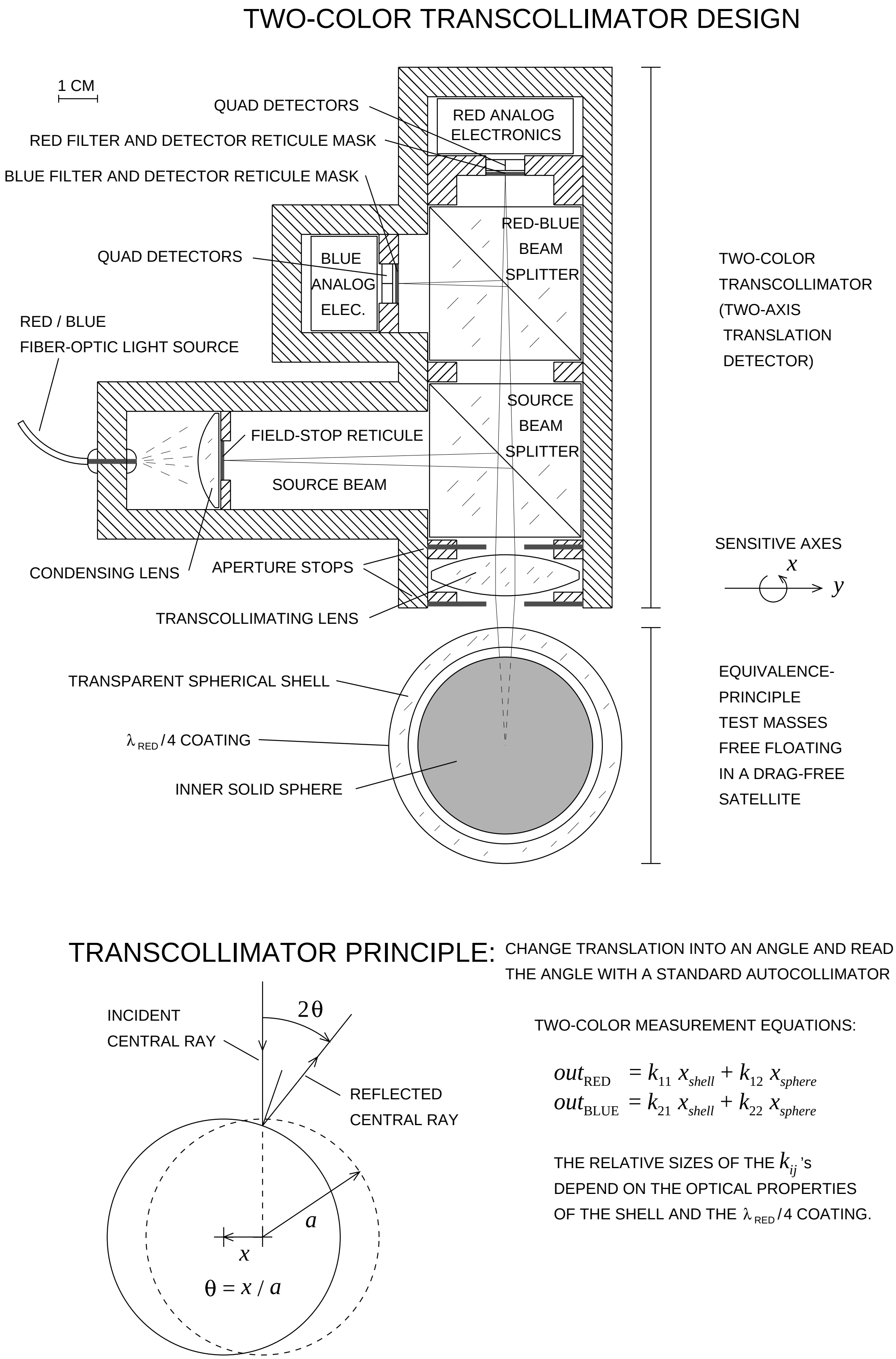


Figure 1. Two-Color Transcollimator Design and Principle of Operation