Errata to: Analysis of Atmospheric Laser Doppler Velocimeters

W. M. Farmer

ARO, Inc., Arnold Air Force Station, Tennessee 37389.

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There are two errors in the paper by Farmer and Brayton.[1]

The numerical factors in Eqs. (16), (20), (27), (28), and (33) are incorrect and should be multiplied by a factor of 2.

Conclusion 2 (on page 2323) should read: ". . . (inversely proportional to λ^2R^4) . . . ."

References

1. W. M. Farmer and D. B. Brayton, Appl. Opt. **10**, 2319 (1971).

Twyman-Green Interferometer to Test Large Aperture Optical Systems

David G. Kocher

MIT Lincoln Laboratory, Lexington, Massachusetts 02173.

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This letter describes a simple unequal path laser interferometer that can be used for wavefront testing of large aperture focusing optical systems and components. Interferometers for this purpose usually are designed to work at the focus of the system being tested so that large apertures are not required in the interferometer. The familiar Twyman-Green interferometer frequently is used together with an auxiliary lens to focus the parallel beam at the focus of the system being tested. This method has the disadvantage of requiring an extra component (the focusing lens) that must be of higher quality than the system being tested.

An interferometer that does not require the focusing lens and uses a minimum number of components is shown in Fig. 1. This arrangement essentially is identical to the first illustration given in the Twyman-Green patent.[1] (In the patent illustration the beam splitter and compensating plate are separated, and the pathlengths for the reference mirror R and lens L are equal.) Often this configuration is referred to as the Williams interferometer, possibly because it was attributed to W. E. Williams in an article by Burch in 1940.[2] A significant feature is the use of the optically thick beam splitter substrate in the diverging beam. Although it is true that such a plate introduces aberration, if the aberrations in each arm are made equal intentionally, such as by the use of a compensating plate, to the first approximation there is no net effect in the fringe pattern.

Apparently it was Williams who first realized the advantage of the interferometer in Fig. 1 for testing large aperture systems, since only a small beam splitter was required. In addition, it can be seen that with a laser source the pathlengths in the two arms need not be equal, so it is possible to make the reference mirror R in Fig. 1 with a short radius (and hence small in diameter). An interferometer built with these principles in mind is described here.

In Fig. 1 the compensating plate has been sandwiched with the beam splitter to ensure exact parallelism between the two. Light from a laser is focused approximately at the beam splitting surface in the center of plate P and diverges to illuminate both the reference spherical mirror R and the lens L or mirror M being tested. Interpretation of the fringes projected on the screen S is similar to the usual Twyman-Green fringes.

The interferometer introduces only very small aberrations of its own because of the symmetry of the beam splitter plate. The two halves of the beam splitter are precisely the same thickness.

In Fig. 1, it is seen that rays A and A' traverse identical pathlengths in P, and likewise rays B and B' traverse identical pathlengths. Although the beam splitter introduces a variable glass thickness into the beams (depending on the angle of the rays), the symmetrical construction assures that the pathlength is the same for any corresponding reference and test rays.

The symmetry of the beam splitter also permits testing large relative aperture systems, limited only by the small effects described below. It can be seen from Fig. 2 that as the test lens relative aperture becomes very large, after passing through the beam splitting substrate the rays do not appear to be emerging from a common focus. As a result, the marginal rays to the edges of the reference mirror or test lens appear to diverge from a virtual source located slightly off-axis relative to the focus for the central rays, which is located on-axis. This effect introduces an effective aberration whenever the focal lengths in the two arms are unequal. The aberration is negligible if the total thickness of the beam splitter is kept small. The maximum permissible beam splitter thickness has been calculated for specific maximum test beam cone angles and is given in Table I. The example here assumes the reference arm focal length to be 150 mm, the test arm focal length to be greater than 100 mm, the beam-splitter substrate refractive index to be 1.5, and the maximum tolerable aberration to be $\lambda/20$ (in visible light).

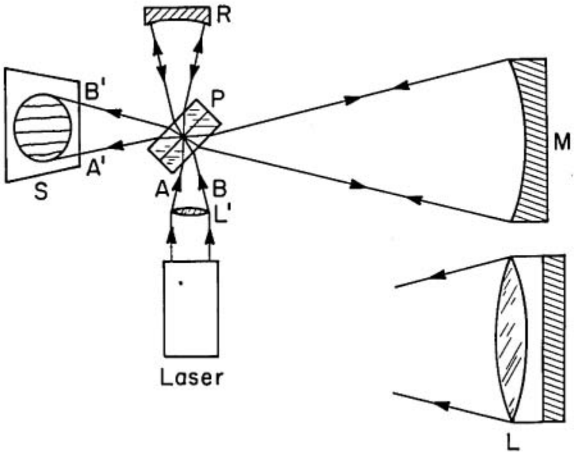


Fig. 1. Optical diagram of the wavefront measuring interferometer for testing mirror M, or lens L in autocollimation, against reference sphere R. Fringe pattern is projected on screen S.

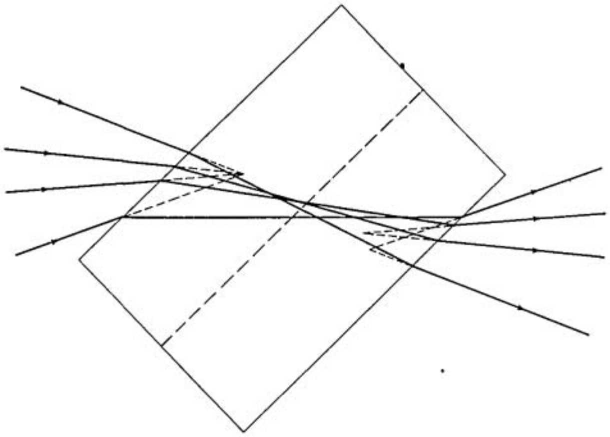


Fig. 2. Aberration introduced by the thick beam splitter substrate.

Table I. Limits on Interferometer Parameters

Test beam *f*/No.	Test beam cone half-angle (rad)	Maximum total beam splitter thickness (mm)	Maximum plate thickness asymmetry (μm)	Maximum fringes in field
15	—	—	—	16
8	0.066	20	4	32
5	0.10	10	2	48
2.5	0.20	3.1	1	—
1.4	0.36	0.75	0.33	—

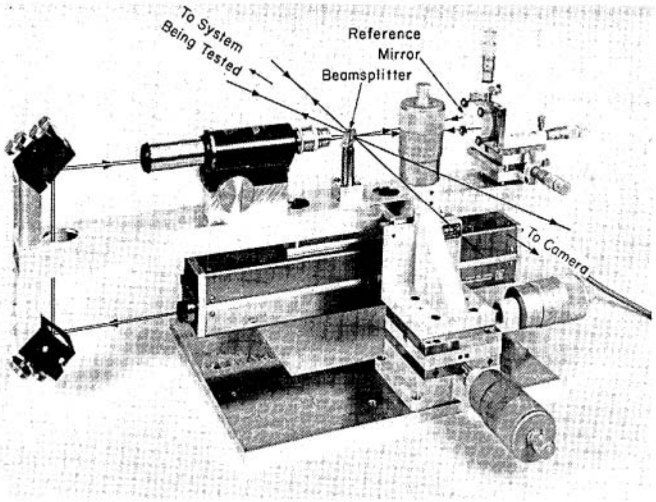
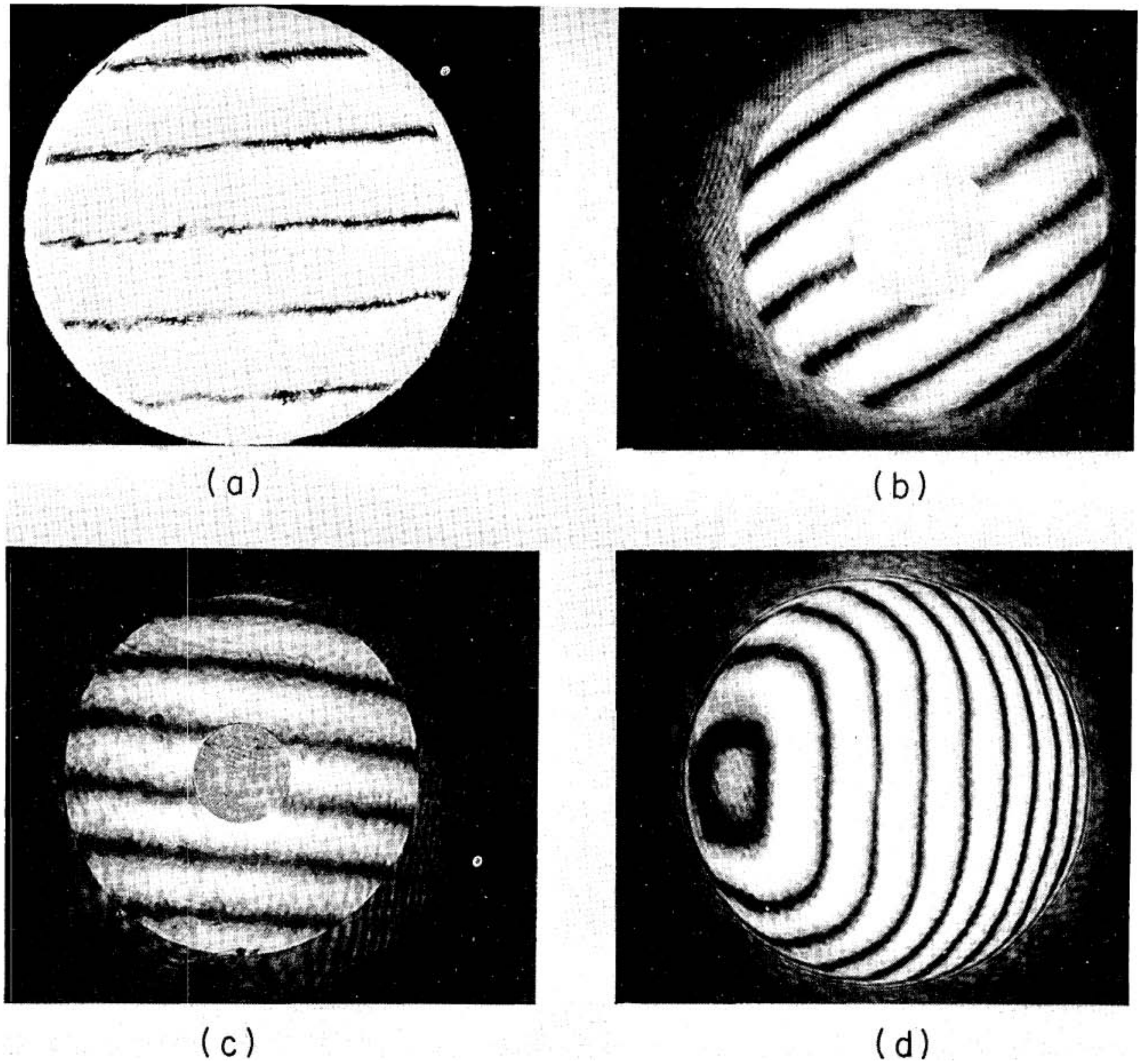


Fig. 3. Photograph of the interferometer mounted on three-stage micropositioner.

Fig. 4. Test fringes obtained using a 6-mm thick beam splitter and a 150-mm spherical reference mirror (a) 37-mm diam, 150-mm radius spherical mirror; (b) 178-mm aperture, 2.54-m focal length Questar telescope in autocollimation; (c) 33-cm diam, 1.86-m radius sphere, not aluminized; (d) 30.5-cm diam, 2.75-m focal length parabola at center of curvature.



The permissible difference in thickness of the two component parts of the beam splitter also has been computed. Any asymmetry of these two plates results in the same aberrations as a single plate beam splitter (such as a pellicle) of thickness equal to the amount of asymmetry. The permissible difference in thickness is a function of the relative aperture of the test beam. Limits for this difference are given in the fourth column of Table I for a maximum tolerable aberration of $\lambda/20$.

The limits in Table I have been set according to pathlength differences determined by ray tracing techniques. It clearly is practical to construct sufficiently symmetrical two component beam splitters that are thin enough to test accurately large relative aperture systems.

A beam splitter is fabricated by cutting a plane parallel glass plate into two smaller plates that become the halves of the finished beam splitter. One side of one plate is given the beam splitting coating and then pressed into optical contact with the second plate. (Procedures for producing an optical contact bond are given by Smartt and Ramsay.[3]) The amount of residual wedge in the original plate determines the resulting thickness differences of the two halves.

For an interferometer constructed in our laboratory, the lens L' in Fig. 1 is actually a microscope fitted with a suitable eyepiece and objective to produce the desired cone-angle of illumination. The laser, microscope, beam splitter, and reference mirror are mounted on a common supporting beam as shown in Fig. 3. The reference mirror is mounted on a three-axis micropositioner so the returning beam focus can be made to coincide with the focus of the illumination. This is necessary to avoid aberrations that occur if the reference mirror is used off-axis. In practice, this coincidence is accomplished by adjusting the reference mirror position while observing the returning reference beam focus as it is magnified and projected by the microscope on a screen placed close to the laser source.

Adjustment of the test lens focus as well as tilting of the wavefront about two orthogonal axes is provided by mounting the supporting beam on a larger three-axis micropositioner. For use, the interferometer focus is placed at the test arm focus. Fringes then are obtained by making lateral translations of the interferometer, perpendicular to the test arm axis. When testing mirrors, aberration can appear for large lateral translations, because the test mirror is being used off-axis. However, if the number of fringes in the test aperture is kept smaller than the number given in column 5 of Table I, this aberration will be less than $\lambda/20$ for the same conditions stated earlier.

To achieve maximum fringe contrast, it is necessary to fit the laser with a polarizer and polarization rotator. Also, the fringe visibility is a function of path difference in unequal path interferometers when illuminated by a conventional He–Ne cw type laser in which multiple axial modes nearly always are present.[4] This fact must be remembered when setting up the test system.

Figure 4(a) is a photograph of the fringes obtained by testing two 37-mm diam., 150-mm radius spherical mirrors against each other, using a beam splitter 6 mm (total) thick. Similar results have been obtained when spherical mirrors of unequal radii are tested against each other. Figure 4(b) shows the interferogram obtained from a 178-mm aperture diameter Questar telescope in autocollimation, using a 150-mm radius reference mirror. Figure 4(c) is an unaluminized 33-cm diam $f/5.6$ experimental thinned-edge sphere. Figure 4(d) shows the fringes obtained when the interferometer focus is placed at the center of curvature of the central zone of a parabola.

In conclusion, we have found this interferometer to be a very useful and versatile testing instrument. Among its advantages are simplicity, ease of fabrication and operation, and relatively low cost.

The writer wishes to thank Dennis Kelsall for helpful discussions and valuable criticisms and Donald Boucher for constructing this and several prototype interferometers.

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References

1. British Patent Specification 103,832 (1916).
2. C. R. Burch, Monthly Notices Royal Astron. Soc. **100,** 488 (1940).
3. R. N. Smartt and J. V. Ramsay, J. Sci. Instrum. **41,** 514 (1964).
4. E. F. Erickson and R. M. Brown, J. Opt. Soc. Am. **57,** 367 (1967).

Comments on: Fabry Lens

Michael F. A'Hearn

University of Maryland, Astronomy Program, College Park, Maryland 20742.

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The article on the Fabry lens by Michlovic[1] that appeared in the February issue was very good as far as it went. Unfortunately, one might leave the article with the impression that the Fabry lens solves all problems associated with seeing in the terrestrial atmosphere. As Michlovic points out, the Fabry lens is needed to compensate for the seeing that causes a star image to wander randomly in the focal plane of a telescope. For this reason a Fabry lens is essential to astronomical photometry. The atmosphere, however, also produces scintillation that is the random fluctuation in intensity received from the star and that varies from place to place on the telescope objective producing the shadow patterns seen in out of focus stellar images. These shadow patterns are, of course, imaged onto the photocathode by the Fabry lens and move around on the photocathode limiting the ability of the lens to eliminate the coupling of atmospheric effects with photocathode nonuniformities. To reduce further the effect of the atmosphere, one can, after imaging the telescope objective, scramble it before letting it hit the photocathode as pointed out, for example, by Connes and Connes.[2] Alternatively (or in addition), if one is interested primarily in the ratio of two intensities (e.g., at two different wavelengths) one can use a modulation technique wherein the two signals of interest are alternately switched onto the photocathode, with identical imaging by the Fabry lens, at a frequency higher than typical scintillation frequencies. This latter method will work, of course, only if their is coherence of the shadow bands between the two beams, a condition that is usually found to hold if the two wavelengths being compared are within one or two thousand angstroms of each other. Although the use of a Fabry lens alone does lead to a significant reduction in noise, the addition of either of the latter techniques leads to a significantly greater reduction, and they must therefore be considered in many instances where high accuracy is required.

References

1. J. Michlovic, Appl. Opt. **11,** 490 (1972).
2. J. Connes and P. Connes, J. Opt. Soc. Am. **56,** 896 (1966).