

The 300-Year Quest for Binoculars

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ABSTRACT

The modern form of the refracting telescope advanced rapidly following its invention in 1608, but almost 300 years elapsed before practical prismatic binoculars became available. The evolution of binoculars and the associated manufacturing issues are discussed.

Keywords: Binoculars, Telescopes, History of Optics, Antique Optics, Optical Design, Optical Instrumentation

1. INTRODUCTION

On September 25, 1608 Hans Lipperhay was provided a letter of introduction in order to present his invention to the States-General in The Hague of the Netherlands for the purpose of obtaining a patent [1]. The invention was described as “a certain device by means of which all things at a very great distance can be seen as if they were nearby, by looking through glasses...” This first documented demonstration of a telescope was followed a week later with a request “to ascertain ... whether he could improve it so that one could look through it with both eyes.” He was then asked to construct several such instruments. On December 15, 1608 members of the examining committee reported “that they have seen the instrument for seeing far with two eyes, invented by the spectacle-maker Lipperhay, and have found the same to be good...” So begins the history of binoculars.

Even though the development of telescopes and binoculars began almost simultaneously, the telescope reached its modern design configuration in about a century while it took almost three hundred years for the modern form of prism binoculars to become practical. The impediments to practical binoculars were not only in optical design, but in mechanical design, manufacturing, and materials. This paper will document the development of the binoculars using examples from the collection of antique optics at the College of Optical Sciences at the University of Arizona.

While clearly related instruments, there are several requirements for binoculars that are not shared with telescopes. Some of the requirements for a pair of binoculars include:

- two telescopes for magnifying distant objects
- matched magnifications of the two telescopes
- erect images
- individually focusable, but preferably jointly focusable
- parallel optical axes of the two telescopes
- adjustable interpupillary separation

2. REFRACTING TELESCOPES

Following the demonstration of the Galilean or Dutch form of the telescope (a positive focal length objective lens with a negative focal length eye lens) in 1608, the telescope evolved rapidly. Some of the important dates in the development of the refracting telescope are [1-7]:

- 1611: proposal by Johannes Kepler of the astronomical telescope consisting of two positive lenses.
- 1617: first recorded construction of a Keplerian telescope by Christoph Scheiner
- Circa 1625: the introduction of a single erecting lens in the Keplerian telescope to produce an erect image by Christoph Scheiner.

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- 1645: Anton Maria Schyrle de Rheita used a two element erecting couplet to produce a practical terrestrial telescope with an erect image and acceptable magnification and field of view.
- 1662: two lens eyepiece incorporating both an eye lens and a field lens was invented by Christian Huygens.

This combination of a Schyrle erecting system and a Huygens eyepiece represents the basic optical system layout of the terrestrial or relayed-Keplerian telescope that survives to this day. Figure 1 schematically illustrates the evolution of the refracting telescope. In most situations, all of the optical elements except the objective lens are mounted with fixed spacing in the last draw or eye draw of the telescope. Additional improvements that were incorporated into the design are a field stop placed between the two elements of the Huygens eyepiece, and a glare stop at the intermediate pupil location between the two erecting lenses. The intermediate pupil is the image of the objective lens or aperture formed by the first erecting lens.

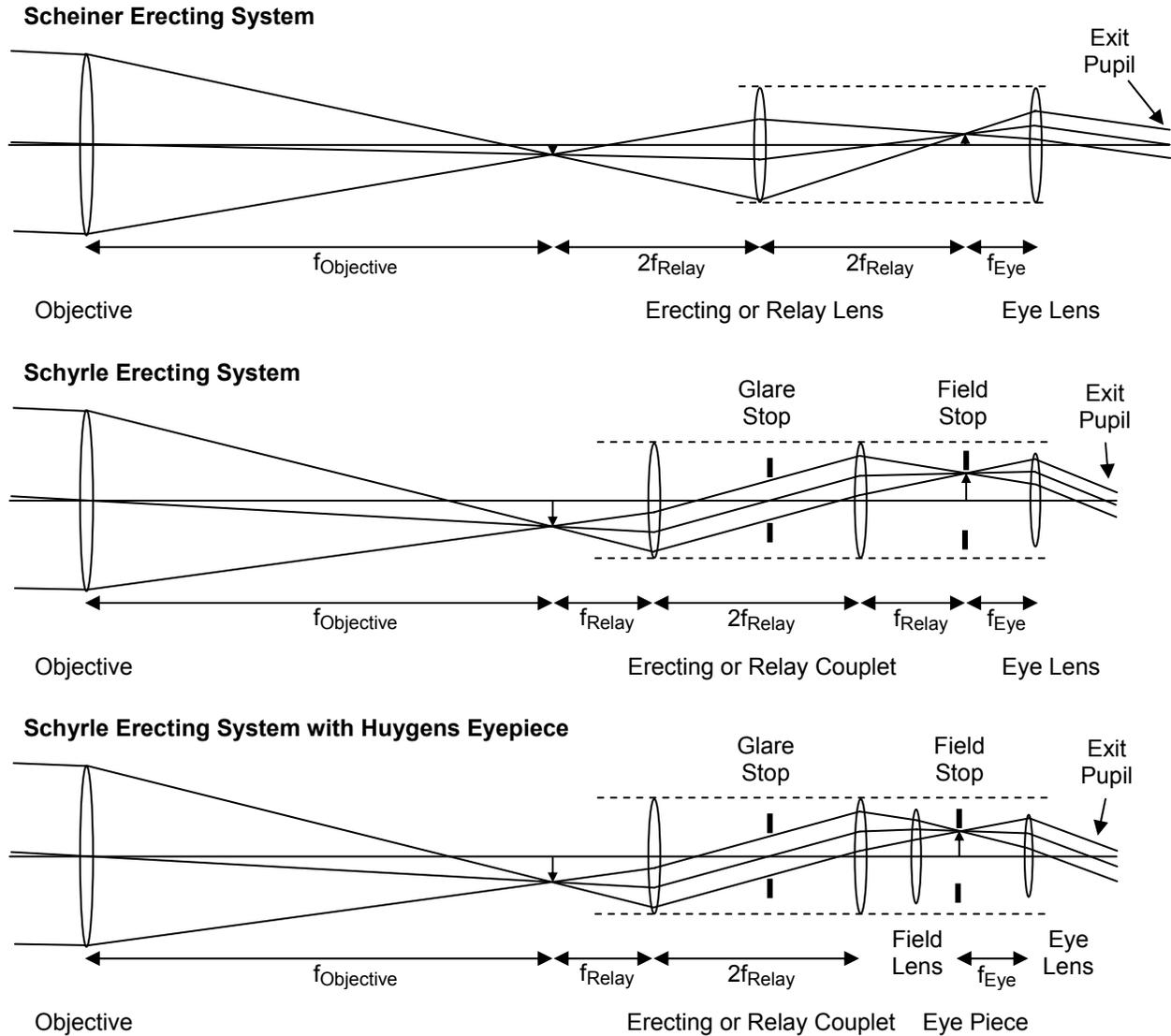


Figure 1. The evolution of the design of the terrestrial or relayed-Keplerian telescope. The separation between the elements in the erecting couplet was often twice the lens focal length, but this is not required. The Schyrle erecting system is often referred to as a three-lens eyepiece, and the Schyrle-Huygens erecting system as a four-lens eyepiece. In some telescopes, an additional field lens was inserted at or near the first intermediate image resulting in a five-lens eyepiece.

Telescopes incorporating the Schyrle erecting system (three-lens eyepiece) were in production and readily available by about 1700. Most of the telescopes of this era were constructed with paper or cardboard tubes, usually covered in vellum, and the lens mounts were often wood or horn. An example from the early 1700s is shown in Figure 2. Later, wooden barrels were utilized, and by the mid-1700s brass draw tubes became common. Figure 3 shows a pre-achromatic single-draw telescope (circa 1750) with a Schyrle erecting system and a field stop.

There is some evidence that the four-lens eyepiece was in use in the late 1600s, however it fell out of favor until the mid-1700s [6]. At that time, telescopes using Schyrle-Huygens erecting systems with both four and five-lens eyepieces were in production. While there were improvements to follow, most notably the achromatic objective in the mid-1700s, the modern design form of the terrestrial refracting telescope was firmly in place by this time. It should be noted that the vast majority of telescopes produced were not intended for astronomical use, but for nautical and military purposes.



Figure 2. Italian 3-draw telescope by Leonardo Semitecolo (Venice) from the early 1700s. The telescope consists of cardboard tubes covered in decorated vellum. It is 850 mm in length and the main barrel is 55 mm in diameter. The objective lens diameter is 35 mm, and as was usual in pre-achromatic telescopes, a small aperture of 20 mm diameter is placed behind the lens to control longitudinal chromatic aberration. A Schyrle erecting system is used. The fittings on the tubes are horn with wood lens mounts.

3. GALILEAN BINOCULARS

Early attempts to create binoculars using a pair of Galilean or Dutch telescopes date back to Lipperhey in 1608. Various other attempts were reported through the 18th century, but the difficulties of alignment, focusing, and magnification match made reproducible manufacturing almost impossible. It was not until the early 1800s that Galilean binoculars were produced.

By the early 1700s, small Galilean telescopes, usually called spyglasses, prospect glasses, or opera telescopes, had become common. Initially, these handheld telescopes had a single draw and a small field of view. They usually had a magnifying power of 2-3X. By the end of the century, larger optics and achromatic objectives had allowed for increased field of view. Multiple draw spyglasses also were produced. A variety of spyglasses are shown in Figure 4.



Figure 3. Single-draw pre-achromatic telescope with a wooden barrel and a Schyrle erecting system (unsigned, circa 1750, English). The telescope has an overall length of 570 mm. The objective diameter is 23 mm with a 13 mm diameter aperture. Each section of the draw contains one of the three lenses of the Schyrle erecting system.



Figure 4. Galilean spyglasses: (A) Tooled silver and tortoise shell (Dollond, London); (B) Five-draw with silver plating (Dollond, London); (C) Cardboard draw with tooled leather, barrel covered with shagreen (Ramsden, London); (D) Ivory and silver-plated brass (Chevellier, Paris); (E) Shagreen covered wooden barrel with cardboard draw (Ayscough, London). All date from mid to late 1700s.

A major advance occurred in 1823 when J. F. Voigtländer patented the combination of two achromatic opera telescopes or spyglasses into a pair of opera glasses by using a frame with two bridges [8]. J. P. Lemiére of Paris improved upon this design by adding a third bridge between the two eye tubes. The focusing of the two telescopes was then coupled. One very early design was focused by turning the barrel or body of one of the telescopes to drive the motion of the eye tubes (Figure 5). A later approach used a central focusing knob with a threaded screw. This basic design of opera glasses remains in use today. It is quite likely that there were earlier attempts to mount two spyglasses together with a single frame. In early implementations, the bridging frame runs straight between the two telescopes. Later, the bridging frame was curved to allow “nose room” and provide user comfort. Examples of both types are shown in Figure 6.

In addition to their optical function, opera glasses became fashion accessories and as a result could be quite ornate. They were often covered in painted or patterned enamel or mother of pearl (sometimes covering the draw tubes). Several examples are shown in Figure 7. Optical performance also improved during the later 1800s as opera glasses were available with triplet objectives and triplet eye lenses for a total of 12 lenses in the pair. Larger diameter lenses were also used. This combination resulted in reduced chromatic aberration and wider field of view; however the magnification remained limited to about 3X. Another design variation was the development of folding or collapsible opera glasses as shown in Figure 8. A clever opera glass configuration is the triple eyepiece or triple magnification opera glasses (Figure 9).



Figure 5. Lorgnette-style opera glasses with the early focusing mechanism. The left barrel is rotated to focus both telescopes, and the two eyepieces are attached to a third bridge. (French, early 1800s). The eyepiece inscription reads “Par Brevet de Perfectionnement,” indicating that this design is “by patent of improvement.”



Figure 6. Opera glasses showing the two varieties of bridging frames. Both use a central knob that drives a third bridge for focusing (unsigned, French, mid-1800s; La Favorite, Paris, late 1800s).



Figure 7. Decorative opera glasses. Enamel, mother of pearl, and tooled aluminum (French, mid to late 1800s).

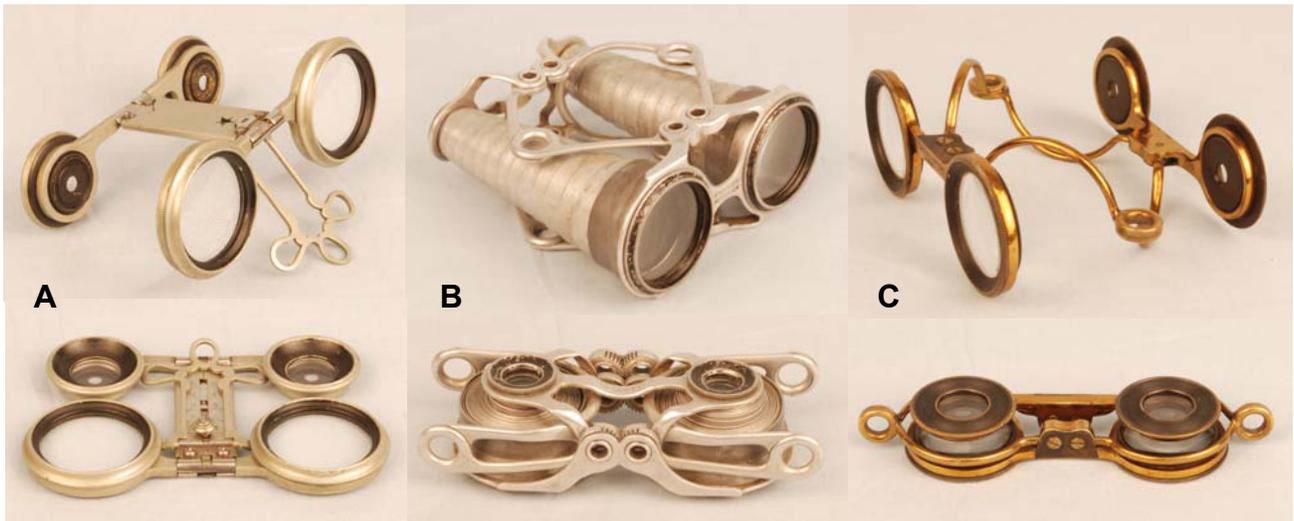


Figure 8. Folding and collapsible opera glasses: (A) Folds into a thin, flat package (R&J Beck, London); (B) and (C) Collapse in a shorter configuration for transport or storage (Aitcheson, London); (B) Two aluminum ribbon coils form the barrels; (C) The barrels are eliminated leaving an open frame supporting the objective and eye lenses. All date from the early 1900s.



Figure 9. Triple eyepiece opera glasses (French, late 1800s). A knob on the side rotates turrets in both eyepieces to bring one of three different eye lens into place to achieve three different magnifications: Theatre ~2.5X; Field ~3X; Marine ~4X.

Larger Galilean binoculars with somewhat higher magnifying power (sometimes called field glasses) were also developed by the mid-1800s (Figure 10). The maximum magnifying power was about 5-6X, and the field of view decreased with increased magnification. These field glasses were widely used for military and other applications through WWI. Because of their larger size, weight could be a significant issue, and therefore field glasses took advantage of aluminum when it became available in the late 1800s. Both opera glasses and field glasses have the advantage of being relatively simple optical systems, but suffer from the low magnification and limited field of view inherent to Galilean telescopes.

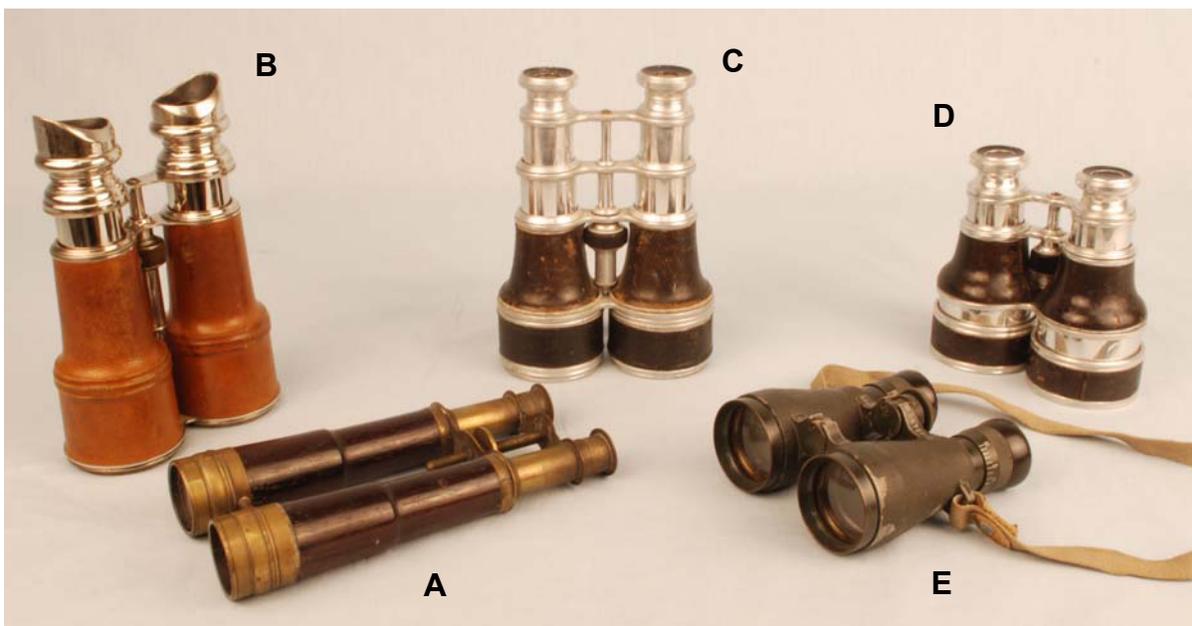


Figure 10. Field Glasses (mid-1800s through early 1900s): (A) Early example with a long wooden barrels and brass fittings; (B) Stylish low-power field glasses with leather covering; (C) Unusual aluminum field glasses with two draws; (D) Aluminum field glasses; (E) German military field glasses (fernglas) dating from WWI.

4. TWIN TELESCOPES

The alternate solution for obtaining an erect image in a pair of binoculars was to use two Keplerian telescopes with Schyrle erecting lenses (terrestrial telescopes). This twin telescope configuration tended to be relatively long due to the number of optical elements, but nonetheless there were a number of early attempts to construct binoculars of this form. A surviving example was built in 1675 by Chérubin d'Orleans [9]. At over a meter in length, it must have been very unwieldy to use. Binoculars of this form suffered from the same problems as the early attempts at Galilean binoculars: alignment, magnification match and focusing. Because of the longer length, higher magnification and more complicated optical systems, the issues are more severe with twin telescope binoculars than Galilean binoculars.

A particularly unusual and perhaps unique approach to binoculars was to use two reflecting Gregorian telescopes. A pair of tripod-mounted Gregorian binoculars is shown in Figure 11. These were made circa 1760 by James Short in London [10]. James Short was the leading maker of reflecting telescopes in this era, and he is considered the first to produce parabolic mirrors in quantity. A Gregorian telescope provides an erect image through the use of two concave or positive mirrors and an eyepiece. It is the mirror equivalent of a relayed Keplerian telescope, or more precisely, a Scheiner relay system.



Figure 11. Gregorian reflecting binoculars (James Short, London, circa 1760). From the collection of Rolf Willach (Taegerwilten, Switzerland); photograph used with permission.

By the mid-1800s, mechanical and optical technology had advanced enough to allow twin telescope binoculars to be produced. An early example from G. & S. Merz dates from the 1850s [11]. By the last quarter of the 19th century, twin telescopes had evolved to very sophisticated optical systems. In some models, the lens system and the mechanical mounting were miniaturized so that twin telescope binoculars could be produced with a length of less than 160 mm. The smallest twin telescope binoculars had objective lenses with aperture diameters of 10-12 mm, and they collapsed for storage to under 120 mm. A variety of twin telescope binoculars are shown in Figure 12.



Figure 12. Various twin telescopes. All date from the late 1800s. Three of the twin telescopes shown are aluminum and one is brass. The large telescope has a length of 750 mm with its sunshades extended. The magnifying powers range from about 5X to 20X.

The twin telescopes of the late 1800s were a *tour de force* of optical and mechanical fabrication. The optical elements and mounts from a small twin telescope are shown in Figure 13. However, the life of this technology was abruptly ended by the advent of prism binoculars in the 1890s. Twin telescopes would be considered difficult to fabricate even today.

In the mid-1800s, the problem of adjusting binoculars for interpupillary spacing was solved by allowing the bridge between the two telescopes to bend at a hinge. An alternate and unusual approach to adjusting the interpupillary spacing is to use a rack and pinion. A twin telescope with this arrangement is in Figure 14.

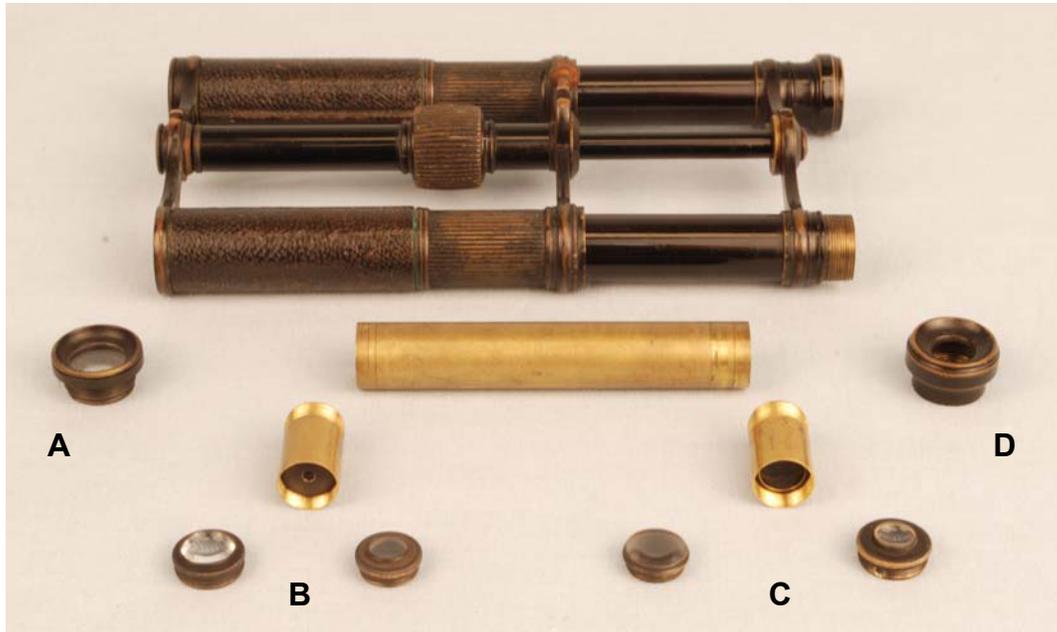


Figure 13. Exploded view of the components and mounts of a pair of small twin telescope binoculars. From left to right the components are: (A) achromatic objective lens; (B) erecting couplet and mounting cell (note the small glare stop in the mounting cell); (C) eyepiece field and eye lenses and mounting cell (the field stop is in the mounting cell); and (D) eye cup. The long brass tube receives both of the smaller mounting cells to provide fixed element spacings. This tube slides into the eye draw of the twin telescope.



Figure 14. Twin telescope binoculars featuring rack-and-pinion adjustment of the interpupillary distance (Negretti & Zambra, London, late 1800s). The pair of knobs attached to the rod that is perpendicular to the telescopes adjusts the focus; the single knob adjusts the interpupillary distance.

5. PRISM BINOCULARS

The technical advance that led to the modern design of binoculars was the invention of image erecting prisms in 1854 by Ignatio Porro [12-13]. The Porro prism system uses two right-angle prisms (Porro prisms) with a total of four internal reflections. With this prism system, the eyepieces are laterally displaced from the objective lenses. The Porro prism system allowed the image in a Keplerian telescope to be erect without the need for erecting lenses. This greatly shortened the overall length of the system and allowed for larger diameter objective lenses. The result is the modern embodiment of prism binoculars consisting of an objective lens, image erecting prisms and a two-element eyepiece with a field lens and an eye lens.

Attempts to fabricate prism binoculars after the invention of the Porro prism system failed primarily due to poor glass quality. The folded optical path through even a small Porro prism system can be 60 mm or more. Even a small amount of inhomogeneity or stria in the glass can destroy the image quality of the binoculars.

The association of Carl Zeiss with the glass maker Otto Schott resulted in the production of the high quality prisms that were essential for successful Porro prism binoculars. Ernst Abbe provided the optical design of these binoculars. These high-performance modern binoculars were first sold in 1894. An early pair of Zeiss 6X15 Porro prism binoculars with serial number 306 and dating from 1895 is shown in Figure 15. Note that in these binoculars, focusing was performed by individually adjusting both eyepieces. The prism mount consists of a recess machined into the cast aluminum body of the binoculars. Each Porro prism is held in place by the prism cover or end plate and a thin piece of cork on the prism apex. This same arrangement was used on both ends of the body of the binoculars so that there is a large separation between the two Porro prisms. In modern binoculars, the two Porro prisms are mounted in contact or in close proximity near the eyepiece. The dimensions of the hypotenuse of this early Zeiss Porro prism are 15x32 mm. Based upon Abbe refractometer measurements, the prism is a crown glass with an index of refraction of 1.513 and an Abbe number of about 63.



Figure 15. Zeiss 6X15 binoculars with serial number 306 (1895). The script inscription reads “Carl Zeiss, Jena D.R.P.” and “Feldstecher Vergr = 6”. The familiar Zeiss lens logo was first used in 1904. Removing the prism cover and the objective lens shows the prism mount and a Porro prism for a pair of 8X20 binoculars of the same era (No. 4976; 1897). The insert schematically shows the arrangement of the prisms in the housing. Of course, both prisms are actually rotated by 45 deg out of the plane. In this 8X pair, the prism separation is approximately 30 mm; the separation is approximately 20 mm in the 6X binoculars as the prism body is shorter.

In 1897, erecting prism systems incorporating roof surfaces were introduced into binoculars [14]. They were first used in a penta-prism configuration by the firm of Hensoldt in Wetzlar, Germany, and a more compact arrangement made use of a Leman (or Sprenger-Leman) prism. A later example of Leman-prism binoculars is shown in Figure 16. The Abbe-Konig prism appears in the very early 1900s, and with this prism, image erection is obtained without a displacement of the optical axis. The Abbe-Konig prism is the precursor of the Pechan-roof prism (also know as a Schmidt-Pechan prism) used in modern roof-prism binoculars. By 1907, Zeiss was also producing binoculars incorporating roof surfaces. Another variation of roof prisms is the Möller prism that produces six internal reflections (Figure 17). Along with the Leman prism, this prism allows for the design of a flat pair of prism binoculars where the required out-of-plane reflections are obtained from the roof surface. In both cases the eyepieces are laterally displaced from the objectives. Neither of these prisms is in common use today.



Figure 16. Leman prism binoculars (Theatis 3½X; J.D. Möller, Wedel, Germany, late 1920s). Four reflections are obtained with this compact image-erection prism.



Figure 17. Möller prism binoculars (Tourox 8X; J.D. Möller, Wedel, Germany, mid-1920s). This image-erection prism system consists of two bonded prisms that are held in place by a spring clip. A total of six reflections are obtained.

6. CONCLUSIONS

This paper has highlighted some of the important advances in the development of binoculars. While none of the information presented in this paper is actually new, the evolution of binoculars was treated from the perspective of an

engineering design study. It is easy to think of binoculars as just two telescopes, but the requirements for binoculars are much more complicated than for telescopes. As a result, terrestrial refracting telescopes were able to reach their modern design form in a little over a century, while it took binoculars nearly three centuries. In order to obtain a practical solution for high-performance binoculars several significant developments were required. These included the invention of prism systems, significant advances in mechanical design, and improved optical glasses.

The antique optics collection of the College of Optical Sciences at the University of Arizona can be viewed on-line at www.optics.arizona.edu/antiques. Significant effort has been made to be as accurate as possible in the description and dating of the instruments presented in this paper, however many of these items are difficult to accurately characterize and/or date.

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A useful collection of on-line resources associated with the history of binoculars and telescopes is maintained by Peter Abrahams. It can be viewed at www.europa.com/~telscope.