Riflescopes:
Basic Principles & Technologies

Branson T Fausey

March 2025

Table of Contents

Audience & Scope

The purpose of this document is to describe the technologies and principles around the design, manufacture, and use of telescopic rifle optics, known as riflescopes. While there are other uses for telescopes and the technologies within, the primary audience for this document will be users of firearms – specifically rifles – for the purpose of either hunting or target sport shooting. The audience should have at least a surface-level understanding of how firearms operate, including basic principles such as aim, recoil and bullet drop. For clarity, some of these principles will still be discussed further.

Introduction

A riflescope is one of many possible devices which may be used for the aiming of a firearm, most commonly a rifle. Rifles are firearms that are meant to be used at a long range with high levels of precision. Riflescopes, therefore, are also designed for long range precision shooting, and are a necessary component for any shooter wanting to make accurate target impacts at long range. Just as a telescope magnifies an image of the moon or stars, so too does a riflescope magnify the image of whatever it is aimed at downrange. Scopes use shaped glass lenses to perform this image magnification – or zoom – to varying levels, and carry additional features to accompany the effective use of a rifle. This document will provide an overview of how a riflescope magnifies an image, its basic features, and some of the more advanced principles of riflescope technology.

How a Riflescope Works

This section describes how the physical construction of a riflescope is designed to magnify an image at a particular scale and provide a precise point of aim.

A riflescope uses a series of shaped glass lenses to pass light from the front of the scope to the rear. This light that the scope collects is perceived as an image that is zoomed in, magnified in size. The objective lens is the typically larger lens at the front of the scope, responsible for collecting the light, which in the case of a riflescope, is the visible light being reflected by the target. That light is passed into the main body of the scope, where it goes through more lenses in the erector assembly. The erector assembly – or erector tube – has a few jobs. Primarily, it is responsible for making sure the light that makes its way through the scope to your eye is upright rather than upside down, and can be adjusted to control the magnification – the perceived size of the target. Next, the light makes its way to the rear of the scope, where the ocular lens / eyepiece directs it into your eye, specifically focused to a single point called the focal point. This is the point where the rays of visible light converge to present the optimal picture.

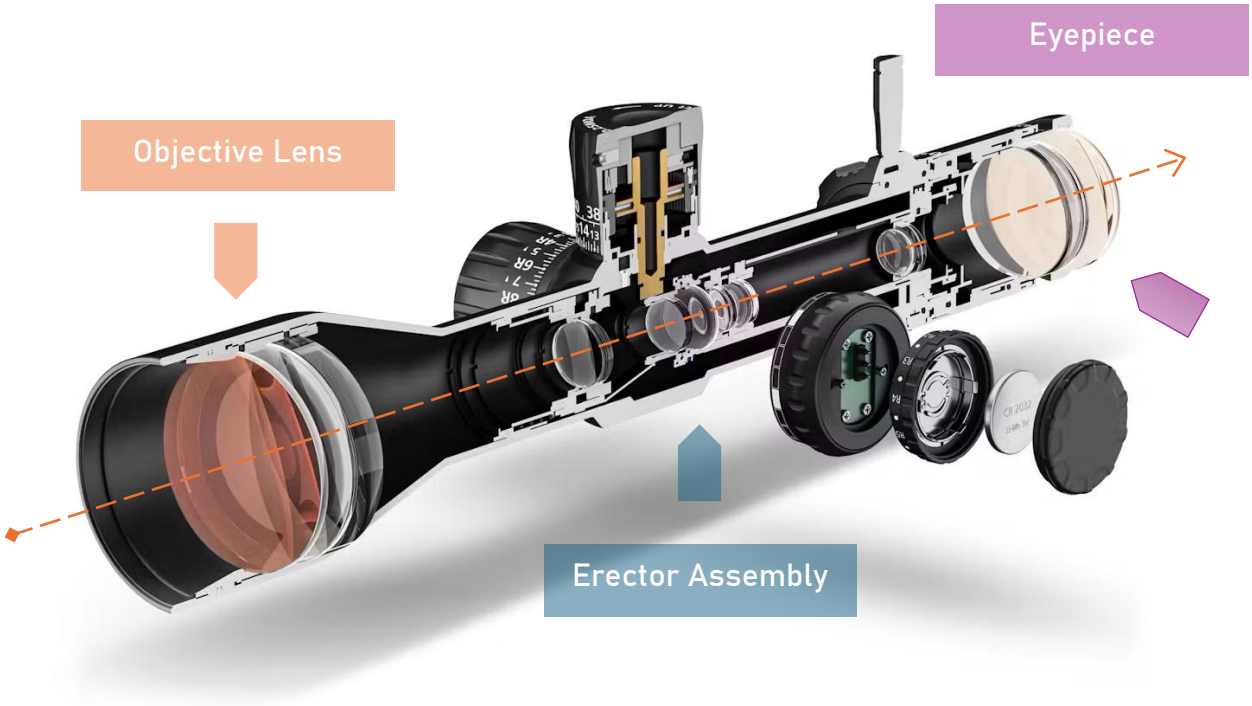

Fig. 1: A cutaway of a riflescope, revealing the lenses and erector assembly. The arrow denotes the direction of light traveling through the scope.

In Figure 1 – from left to right – we see the set of large objective lenses at the front of the riflescope, followed by the very small lenses that make up the erector assembly, and finally, the ocular/eyepiece.

In addition to the optical responsibilities of the erector assembly, it also houses the reticle. The reticle provides the shooter with a precise aiming point, and with the help of the erector assembly, can be adjusted in fine increments to ensure precise shooting.

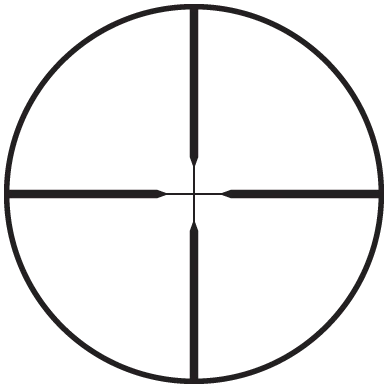

Fig. 2

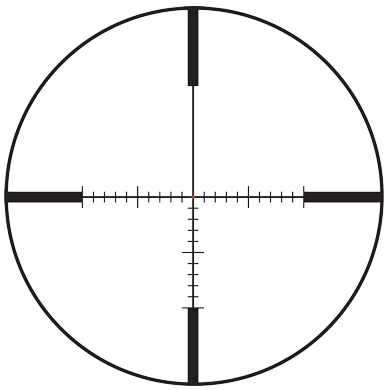

Fig. 3

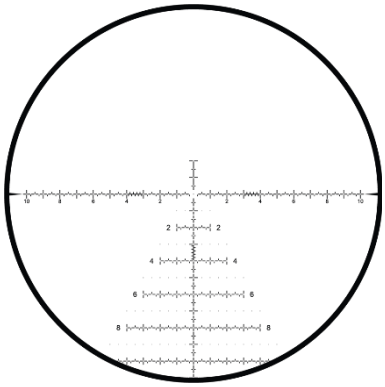

Fig. 4

Figures 2, 3, and 4 show some common reticle types, all of which serve the primary purpose of providing the user with a precise central point of aim. Some reticles will feature a lighted portion called illumination, to increase target-reticle contrast.

Reticles will also vary in shape and size. Most notably, some reticles will feature reference marks in various directions around the center point of aim. These reference marks represent very specific angular measurements, depending on the level of image magnification, as well as the exact size and position of the reticle inside the erector assembly.

Parts of a Riflescope

This section covers the main features common to most modern-day riflescopes. See Figure 5 below for a reference of the parts mentioned in this section.

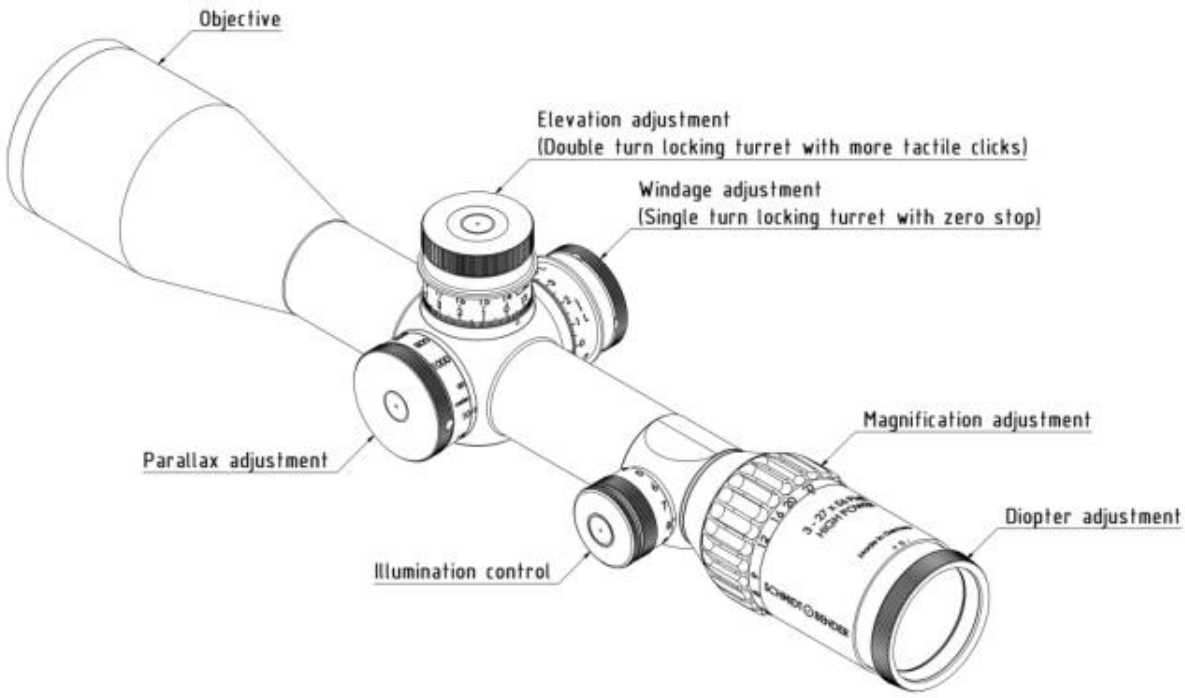

Fig. 5 depicts a riflescope, labeling some common external features.

Elevation & Windage Adjustment Turrets

A riflescope provides the user with a precise aiming point. To ensure the center of the reticle will line up with the point of impact on the target, a riflescope will have an adjustment knob – called a turret – on the top and side of the scope's main body. The turret on top will angle the erector assembly and the reticle up or down, to account for gravity pulling the bullet downward while in flight. This is called the elevation turret. Similarly, the windage turret on the side allows the scope to correct for any left or right deviation of the bullet. Setting the reticle's position so that it describes the bullet's impact at a set distance is called setting the scope's zero. The further a bullet travels from a rifle, the further it is pulled down by gravity. Therefore, a longer shot will require additional adjustment of the elevation turret to accommodate. Similarly, if the bullet is affected by particularly strong wind, blowing the projectile to the left or right, the windage turret can be adjusted accordingly.

Magnification Adjustment

The magnification of the scope is set with the magnification ring, and moves the lenses of the erector assembly closer and farther apart in order to bend the light, making the perceived image larger or smaller. A higher number magnification denotes a larger image, and a lower magnification denotes a smaller image.

Diopter Adjustment

The diopter is a rotating lens at the rear of the riflescope, which allows the user to adjust the specific optical correction needed. The scope's user may have particularly good or particularly poor eyesight – or anywhere in between. This adjustment allows the user to standardize the clarity of the image against his/her own level of eyesight. In practice, those with good eyesight may find the diopter best positioned turned in more, whereas those with poor eyesight may see just as clearly when the diopter is turned out more.

Scope Maintube

The scope body is usually made of a lightweight but durable aluminum. The main cylindrical structure that houses the erector assembly is known as the maintube. The tube has a few important functions, the primary of which being a place for the scope rings to clamp on. The scope rings are part of a mounting system that securely attaches the riflescope to a given rifle. The size of the maintube is measured across its diameter, and the size of the scope rings must match the tube, for a secure and proper fit. Common tube sizes include – in ascending order – 1 inch, 30mm, and 34mm. A larger scope tube will often allow for increased elevation adjustment for farther shots.

Advanced Riflescope Principles

This section covers some more specialized features and principles of a riflescope, such as the advanced physics of light gathering.

Parallax & Scope Cant

Parallax is the idea that objects in the foreground will appear to 'move' faster than objects in the background. This same concept can be seen when looking through a riflescope. Specifically, the shooter could move their head side-to-side, and may notice the reticle moving along with them, rather than remaining over the target. A scope is considered parallax-free at the particular distance in which the reticle does not stray from the target, but rather, acts as though it lies on the same plane. At this distance, any

movement of the eye will have no effect on the accuracy of that aiming point. Many scopes feature a set distance for parallax correction, but some have a specific adjustment, allowing for precise shooting at varying distances.

Another factor of the scope that can cause misalignment is known as scope cant. This occurs when the scope is not level, but rather is tilted slightly to the left or right. This causes the adjustment of the scope's components to also be tilted to the left or right, instead of vertically and in line with the actual behavior of the bullet due to gravity.

Clarity & Chromatic Aberration

Clarity refers to the perceived level of detail and definition a riflescope provides. Generally, the factor that has the greatest impact on the clarity of a riflescope is the glass used in the lenses, as well as the specific coatings that are applied to enhance the optical capabilities of individual lenses. Riflescope manufacturing companies typically source their glass material from one of a handful of well-known original equipment manufacturers (OEM), and apply their own proprietary coatings to the lenses. As a riflescope magnifies an image, so too will it magnify any impurities that may exist in the base glass material.

Chromatic aberration refers to the discoloration that occurs when shaped glass lenses fail to converge all wavelengths – specific colors – of the visible light spectrum to the exact same point. This normally results in an image that displays the target with a purple or green hued outline.

Light Transmission

Like clarity, the amount of visible light that makes it from the target and through the scope to the eye is heavily dependent on the quality of the glass lenses and their coatings. A scope will usually have between 7 and 12 individual lenses, and visible light must travel through each of them for the shooter to see the target. If even a small portion of the visible light that reaches each individual lens fails to make it through to the next, the resulting image will appear darker than it should. Light transmission is the proportion of visible light that passes through the entire array of the scope's many lenses to meet your eye, and is important not only for pleasure of viewing, but also because poor light transmission could result in target misidentification.

Another factor contributing to light transmission is the combination of magnification and size of objective lens. More specifically, a larger objective lens will often result in a brighter image, as will setting the riflescope on a lower magnification. This principle, however, has results that will vary with the shooter as well as the environment.

Conclusion

A riflescope is a necessary piece of equipment for a shooter to be able to make precise impacts on target at long range. The general construction of a riflescope involves a configuration of glass lenses that gather visible light and provide a magnified image of the target to the shooter. This magnification allows the shooter to feel closer to the target, increasing both target identification as well as accuracy. Advanced optical principles are accompanied by a series of special design considerations that enable effective use of the rifle, catering to many different types of shooters and encompassing many different types of shooting scenarios. All of which utilize the riflescope for target acquisition and precise aiming, often at extreme distance.

Glossary of Terms

A glossary of technical terms defined in order of their appearance.

Objective Lens – The forwardmost lens of the scope; responsible for gathering light.

Erector Assembly – A collection of small lenses that adjust for variable magnification and contain the reticle. Also adjusts to compensate for bullet drop and drift.

Magnification – Making the image appear larger or closer; zoomed in.

Ocular Lens / Eyepiece – The rearmost lens; responsible for providing the focal point.

Focal Point – The point at which the visible light that travels through the scope converges to become visible.

Reticle – A design or array overlaid on the image to provide a central point of aim.

Illumination – An optional feature of lighted sections to increase reticle contrast.

Elevation Turret – A knob to adjust for vertical change in point of aim; usually to zero the scope and compensate for gravity's effect on the projectile.

Windage Turret – A knob to adjust for horizontal change in point of aim; usually to zero the scope and compensate for the effect of wind on the projectile.

Zero – Setting the reticle's central point of aim to match the bullet's impact on target at a specified distance.

Magnification Ring – Rotating adjustment for specifying the image magnification.

Diopter – Adjusts to compensate for disparities in eyesight; part of the Eyepiece.

Maintube – The main body of the scope; houses the erector assembly and provides a place to attach mounting hardware.

Parallax – A misalignment of the reticle and target due to distance and perspective.

Scope Cant – A left or right tilt of the scope causing a misalignment of the reticle.

Clarity – The definition and detail of the magnified image.

Chromatic Aberration – A misalignment of usually green or purple hues in the magnified image.

Light transmission – The amount of visible light that passes through the scope.

References

Figure 1 (cropped and added component identifiers):

"Zeiss LRP S3." *Zeiss*, www.zeiss.com/consumer-products/us/home/local/precision-shooting/lrp-s3-riflescopes.html. Accessed 26 Feb. 2025.

Figures 2, 3, and 4 (unmodified):

"Shop by Reticle." *Leupold*, www.leupold.com/shop/reticles. Accessed 26 Feb. 2025.

Figure 5 (cropped):

Pahič, Maja. "Schmidt & Bender 3-27X56 PMII." *Optics Trade Blog*, 12 Mar. 2021, www.optics-trade.eu/blog/schmidt-bender-3-27x56-pmii-high-power-illuminated-with-double-turn-rifle-scope-instruction-manual/.