The Refractive Periscope – a Novel Concept

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Abstract. A periscope is an optical device whose function is to allow sighting of objects that are not in direct line of sight with the observer Eye/ Screen/ Detector. The concept behind the periscope is tilting the optical axis by breaking the rays of light with a mirror or prism so that the image is obtained in the desired location. The periscope has a variety of uses, many of which belong to the military realm. For example, observing from submarines above the sea level surface, looking at the war zone from inside of a tank, directing light into hidden places and more. In this article, the authors will review a new development based on wave guide concept which composes a tube with light reflective walls. This allows us to build a significantly Small-dimensional periscope with respect to a standard periscope that does not use lenses. The authors will also review a number of applications suitable for the reflection periscope.

1. Scientific Background

The simplest periscope is composed (as shown in Fig. 1) from two 45 ° rotated reflective surfaces in relation to both the observed object and the viewer's eye.

![Figure 1. Schematic Periscope.](image)

The first documented periscope was invented in the 15th century in order to watch over the heads of people in a crowd. In the 19th century, the periscope began to be used for military purposes, which received tremendous momentum in World Wars I and II, in the early 20th century [1-2].

To describe the operation of the periscope we define the following (as in Fig.1): The periscope axis (No. 1) – The horizontal line that exits from the center of the upper Mirror The Sign-in window (No. 2) – The entrance of the Sign in window The Exit Window (No. 3) – The exit from the lower Mirror.
The aperture through which the light enters the periscope. The periscope tube (No. 3) – The periscope body, in which the rays propagate after refracting.

The above structure has two major drawbacks:

1. The tube diameter must be at least the size of the incoming beam diameter, which makes the periscope a large and cumbersome tool.

2. As the length of the tube (the z-axis) increases in relation to the length and width (Plane X-Y) of the entry window, the angle in relation to the periscope axis in which the object is observed becomes smaller, because the rays are reflected from the walls of the tube.

In modern periscopes [3-4], as the one demonstrated in Fig.3, a telescope and a field lens increase the field-of-view of the periscope. This increases the system size, adds geometric distortions, and creates constraints on the length of the system and the periscope's tube diameter.
In this paper, the authors will demonstrate a new development, based on the reflective walls of the periscope. The reflective walls allow the light to propagate along the periscope in additional routes rather than the direct downward path. That suggested approach allows us to: A. use a mirror positioned at an angle different than 45 degrees in relation to the periscope axis. B. significantly reduce the periscope dimensions. C. convey the image of an object located far above the viewer or slightly below the optical axis of the periscope.

In the following paragraphs, the authors will review the four different models suggested for this periscope:

1. The basic model – A Mirrors Tube. 2. Adding a prism supplement at the edge of the periscope. 3. Adding spherical mirrors at the entrance and exit of the periscope. 4. A periscope tube based on a total internal reflection.

### 2. Different Models of The Reflective Periscope

#### 2.1 Reflection periscope - The basic model

The most basic development is a periscope whose upper mirror is tilted at an angle greater than 45 degrees with respect to the periscope's axis. The periscope consists of a rectangular tube where mirrors serve as front and back walls and where the side walls do not reflect light. At the lower edge of the periscope, there is another mirror, parallel to the upper mirror. In this structure, except for the periscope entrance and exit, the periscope thickness can be significantly reduced, as shown in Fig.4 and Fig.5.

![Figure 4](image1.png)

**Figure 4.** Mirrors tilted in 60 degrees; a beam is delivered in a tube that is half the diameter as the original beam.

![Figure 5](image2.png)

**Figure 5.** Mirrors tilted in 50 degrees; a beam transmitted by a tube that is 44% of the original beam diameter.

Figures 6 through 8 demonstrate an additional advantage of the system. Objects that are far above the periscope axis (the red line depicts a ray propagating from the object through the periscope.) may also be imaged by this periscope (Fig.6). In figures 7 and 8 one can see rays of light entering at different angles and the way they exit the Periscope.

Despite the great advantage of this system, there are also some structural problems that require attention:

1. In the meridional (horizontal) plane, only a small range of angles will pass through the periscope (depending on the relation between its length and width).
2. A major disadvantage of this system is the need for a relatively large structure at the entrance and exit of the periscope (The wall opposite to the tilting mirror should be at such a distance that a ray hitting the top of the mirror will be reflected to the wall and not above it).
3. Another problem to consider is a geometrical problem; In a long periscope there will be a large gap along the periscope between rays at different angles, this may result in some rays not hitting the lower mirror at all or hitting it at the opposite angle with respect to the vertical axis. Possible solution to these problems can be given by adding a prism at the lower end of the periscope. Below are several applications and suggested models.

**Figure 6.** An object that is at 45 degrees in relation to the optical axis exit the periscope at the angle at which it enters.

**Figure 7.** Objects at different angles and how they exit from the Periscope.

**Figure 8.** Objects at different angles and how they exit from the Periscope.

2.2 Applications

Through the years many applications for the standard periscope have been suggested [5-14], in this section we introduce application for the novel refractive periscope.

2.2.1 Transparent sealed materials. Fig. 9 shows that it is possible to create curves along the path of the rays, which can have significance in different applications of the periscope. In the setup shown in Fig. 9, the object looks transparent.

**Figure 9.** The transparent basic model plus the curve.

**Figure 10.** Periscope glass tube. Sun light to building is without imaging.

2.2.2 Transferring daylight into a windowless room. Another important application that can be improved with the model we built is daylight transfer into rooms without a window or adding it to a room and enhancing the light quality as seen in Figure 10. Although this can also be done using a standard periscope, our model is much more suitable both due to the fact it can deliver the actual
image as in a real window and due to the large range of angles of light collected there's no need for lenses, making the periscope cheaper. In such a system, where precise imaging of a specific object is not required, mirrors can be added to the sides of the periscope, allowing the propagation of a large range of incoming angles through the periscope, and by that reduce its width.

2.2.3 Reflection periscope – Prism addition. In this model, the authors add a prism (or a beam splitter) to the original model, placed at the lower end. This causes rays with large incoming angles to reflect and hit the bottom mirror again, thus that all the rays will exit the periscope at the same angle at which they entered. This model is built on the principle of total internal reflection from the prism walls. This principle and the conditions for its existence are elaborated in following models.

![Figure 11](image)

**Figure 11.** The advantage of adding a prism to the periscope's edge.

2.2.4 Reflection Periscope - Spherical or cylindrical mirrors. In this model, the upper mirror or the two mirrors, the upper and lower, are spherical mirrors. As a function of the mirror's curvature, one may gain several benefits in this case:

1. The ability to focus the image on a screen without the need for a lens add-on (Figs. 12 and 13).
2. Expansion or narrowing of the laser beam (Fig. 14).
3. Reducing the beam so that the periscope tube can be further reduced both in depth and width (Fig. 14).
2.2.5 Reflection Periscope – Transparent material. In this model, the Periscope tube is not filled by air but by a transparent material with a higher refractive index. The principle of this model is based on the total internal reflection principle based on Snell's law:

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]  

(1)

According to this principle, in the transition from a high refractive index medium to a low refractive index medium, there is a critical angle in which the ray will not penetrate the lower medium but would rather be reflected (as in a mirror) to the medium of the higher refractive index. To find the critical angle, place a 90° angle at the exit angle. To simplify the calculation, suppose that the low refractive element is air. We accept:

\[ \theta_c = \sin^{-1}\left(\frac{1}{n_1}\right) \]

(2)

One can obtain, for example, that for a refractive index of 1.5, total internal reflection requires an incident angle of 41.81 degrees. The mirror can be tilted up to 69.1 degrees (45 + 41.81/2) above the periscope axis in order to enable us to make the incoming parallel rays to be reflect within the periscope, (Attach a ray diagram). Increasing the refractive index, will result in the increase of the range of angles in which the mirror can be tilted.

Figure 14. Expansion of the beam using two circular mirrors.  
Figure 15. Narrowing the beam with two circular mirrors.  
Figure 16. Rays diagram with incident and reflect angles.  
Figure 17. Narrow periscope, glass tube. Ratio of source's radius/tube's radius = 16/10. The image splits with the top of the object at the bottom of the image.
There are several advantages to this model. First, the mirror-reflecting rays can hit the periscope's entrance aperture yet stay inside the periscope, allowing a much narrower structure for the periscope. This comes in addition to the advantages mentioned above for Model 2, at the output of the periscope. Second, this model enables the incoming rays to have larger angles on the horizontal plane that can propagate through the periscope, since according to Snell's law, the beam within the periscope will propagate at a lower horizontal angle.

![Figure 18. Narrow periscope, glass tube. Ratio of source's radius/tube's radius = 25/10. 8 upper mm exit with a vertical angle (seemingly should have another internal reflection)](image18)

![Figure 19. Periscope glass tube. Horizontal entrance angle of the blue ray: 30 degrees.](image19)

2.3 The mirror tilting angle as a function of the refraction index

At this point we calculate the length-to-width ratio allowed in the basic model. We examine an incident ray of light that has a zero vertical angle with respect to the optical axis, and a five degrees horizontal angle. The top mirror is tilted at an angle of 65 degrees with respect to the axis. The light hits the right side of the entrance aperture.

The angle of the ray in the vertical axis after hitting the mirror will be 50 degrees ((90-65)+(90-65)=50). We expect the length of the tube to be 8.79 times bigger than its width (sin 50/sin 5). On the other hand, if the ray passes through glass with a refractive index of 1.8, according to Snell's law the new angle in which the ray propagates will be 2.77 degrees which allows the length of the periscope to be 15.85 (sin 50/sin 2.77) times bigger than its width.

3. Conclusions and summary:

In this work the authors examined a variety of periscope models and discussed the advantage and disadvantages of using different materials and elements. This research brings a new approach for the known periscope concept. The standard periscope transfer image using mirrors in 45 degrees and pipe that blocks stray light from the outside. Moreover, the now days periscopes are based on lenses or 45 degrees prisms. In solar energy field some companies use light pipes to transfer sun light into closed space rooms but needs to be close to ceiling and don’t have the ability to transfer image. Our novel approach of transferring image is based on mirror waveguide with suitable angle which reduce the periscope size but preserve the image same as in standard periscopes. Future tests will examine the light efficiency of the suggested periscope to ensure an improvement compared to standard periscopes. The authors would like to acknowledge the Jerusalem College of Technology – Lev Academic Centre, for enabling us to use the TracePro© Software for design and analysis of illumination and optical systems.
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