INTRODUCTION

All optical glasses are characterized by a physical quantity which is known as refractive-index. This refractive index of such a medium depends on the electrical and magnetic properties of the medium\(^{(30)}\). When the refractive index is independent of the coordinates in the medium, this medium is called homogeneous medium. Otherwise, a medium, in which the refractive index varies from point to point within the medium, is called inhomogeneous medium. The term "gradient index" or "graded index" are often used to describe such medium, i.e., GRIN medium.

GRIN glasses, may be divided into two general categories: radial and axial\(^{(20)}\). Both types of GRIN's are limited in the maximum change of the refractive index. Revolutionary new optical glasses containing very large axial property gradients have been commercially available since 1996. These glasses, manufactured\(^{(43)}\) by Light Path Technologies, Inc., are formed by a layer diffusion process. The properties, specification, and tolerances of GRIN glass are reported.

Many effective lens design examples\(^{(22)}\) using gradient-index (GRIN) materials have been reported so far. However, the GRIN materials that were used in those designs are very difficult to produce. These materials possess an index of
refraction that varies spatially \(^{(6,30)}\). By providing additional design variables, GRIN lenses can improve the optical system performance and reduce the number of the optical surfaces in such system while maintaining its power fixed\(^{(6)}\). Recently\(^{(10,28)}\), using GRIN lenses to eliminate spherical aberration and the methods of manufacturing these lenses have been reported. In order to realize these benefits, however, manufacturing tolerances for gradient-index lenses are required\(^{(34)}\).

GRIN lenses represent an interesting alternative\(^{(45)}\) to the use of aspheric surface (surface of a variable curvature) in lens design, since the lens performance depends on a continuous change of the refractive index within the lens material.

The Cooke triplet \(^{(26,27)}\) is a photographic lens design designed and patented in 1893 by Dennis Taylor. It was the first lens system that allows elimination of most of the optical aberration. This lens is composed of three elements (three single lenses). Despite the fact that the Cooke design was patented in 1893, it seems that the use of achromatic triplet designs in astronomy appeared as early as 1765. The 1911 Encyclopedia Britannica wrote\(^{(26)}\)" The triplet object-glass, consisting of a combination of two convex lenses of crown glass with a concave flint lens between them, was introduced in 1765 by Peter, son of, John Dollond, and many excellent telescopes of this kind were made by him". 
Nowadays, The design and performance of a Cooke triplet has a wide range application as a component in the electro-optical instruments\textsuperscript{(27)}. To optimize such a lens (improving its image quality), the optical designers have to vary a lot of parameters, i.e., the six curvatures of the elements surfaces and the two inner spacing between elements. This technique of lens optimization requires a lot of computational work\textsuperscript{(32)}.

In the last decades, a new technique\textsuperscript{(10)} for designing single lenses, which are made of gradient index material (GRIN) has been developed by optical designer. This technique showed its power as a good tool for reducing the geometrical aberrations of lenses. Thus, the optical performance of the GRIN optical systems has been improved to a great extent.

The goal of this research is to design a triplet lens with one or two GRIN elements which is called Hybrid Triplet Lens (HTL). Then, to optimize such design, two factors are considered: the position of the GRIN element in the HTL and the GRIN parameter of this element. The optical path length and the total powers of the target and HTL designs are kept constant.

This thesis consists of two parts: the first part presents the optical terminology required to understand the design procedures, and the second part describes the technique used to
design the HTL and the results analysis related to the HTL designs.

In chapter 1, a description of Cooke triplet design, which is used as a target lens for our study, is presented. Also, a brief discussion for the development of using gradient index in lens design and the technology of its fabrication\(^{(3,43)}\). Also, the profiles of the two GRIN medium categories, an axial and radial GRIN, are given. A mathematical form for a ray equation, which describes the path of the rays\(^{(18)}\) through this GRIN medium, and its derivation is presented.

In chapter 2, a theoretical discussion for a ray aberrations are described for the case of on and off-axis rays incident upon the optical system. Since the optimization techniques of such an optical system are based upon reducing the ray aberrations, therefore a description of such aberrations are classified and given graphically in this chapter. Also, in this chapter, a brief discussion for techniques used in optical design to evaluate images formed by such an optical system are presented. Specifically, the optical designers are using many merit functions\(^{(27)}\) to optimize such a system, i.e., RMS spot radius, wave front error and spherical aberrations (TSA and LSA).

The design procedures of this thesis is introduced in chapter 3. In this chapter, a new method for designing a hybrid triplet lens is presented. The mathematical procedures for such design
are described. The optical path length of the axial ray and the total powers for the target lens and proposed HTL are kept constant, the parameters of the HTL are specified. Many designs for HTL have been obtained, through the control of the GRIN element position in the HTL and the variation of GRIN parameters, i.e., considering the positive and negative values. Then, the layout parameters of these new designs are tabulated; namely: front, mid, back and front-back GRIN element (with positive and negative GRIN parameters). Also, in this chapter, the image quality, formed by each new design of the HTL, has been compared graphically with that of the target lens for a wide range of field angles (0°-20°). In this study, for a comparison reason, the previous well-known optical merit functions have been evaluated for this range of field angles. These comparisons predict the optimal design of the HTL, i.e., the best location of GRIN element and its GRIN parameter for this range of field angles.

In this thesis, a computational program is written (see Appendix A) to evaluate the ray trace technique\(^{(37,41)}\) in a GRIN lens. The results obtained by this program were in very good agreement with that of the software ZEMAX program\(^{(46)}\) which is used in this study for computing the previous optical merit functions.