ANALYSIS OF CHIRPED GRATING LENSES*

by

Siamak Forouhar and William S. C. Chang

Department of Electrical Engineering and Computer Sciences

University of California, San Diego, La Jolla, CA 92093

ABSTRACT

Perturbed coupled mode theory and Fourier decomposition method of analyzing optical propagation in thick holographic chirped grating lenses are discussed. The effects of the chirping rate, the groove depth and profile and the grating thickness of the field distribution of the chirped grating lens have been calculated.

In order to realize guided wave signal processing subsystems in the planar configuration such as the r.f. spectrum analyzer, thin film waveguide lenses are needed to transform the guided wave beam for imaging, focusing, Fourier analysis, etc. The lenses that have been developed so far are Luneberg lenses, geodesic lenses, and diffraction lenses.

The focusing capability of Luneberg lenses is limited in high index waveguides because of the small change of the effective refractive index that can be obtained from known materials transparent at the visible light and near infra-red wavelengths. The geodesic lens is hard and costly to fabricate because of the need for nonspherical contours. These difficulties may be overcome in the new family of diffraction lenses, e.g., the Fresnel Lens and the chirped grating lens, as shown in Figures 1 and 2. The principal potential advantages of the diffraction lenses are:

1. They can be batch fabricated at low cost with photo-lithography or electron-beam lithography.
2. They may give high signal to noise ratio and low side lobes.
3. They can be highly dispersive, producing a complex focusing effect, e.g. a frequency selective lens.

In many ways diffraction lenses are similar to one-dimensional holograms. The Fresnel lens is a "thin" phase type waveguide hologram. It has a maximum efficiency of 33%. In order to obtain higher efficiency, diffraction lenses equivalent to the volume holograms must be considered. In principle, gratings in optical waveguides with constant periodicity should have a maximum diffraction efficiency as high as 100%.

The chirped grating lens could also be very efficient when the chirping rate is very slow and when the Bragg condition is satisfied separately for each section of the lens. However as the chirping rate is increased the degradation of the phase synchronization of the radiation diffracted from different grating grooves also becomes more severe. At low F-numbers, the chirping rate may be too fast for efficient Bragg diffraction to take place. The performance of diffraction lenses will be a function of the waveguide structure, the scattering strength of the grooves, the average periodicity, the chirping rate and the thickness of the lens. So far, there has been very little work done on the analysis of diffraction type of lenses. We will present in this paper the theoretical analysis of chirped grating lenses by two different methods, the Fourier analysis method and the perturbed coupled mode analysis.

In the perturbed version of the coupled mode analysis, the chirped grating lens with slow chirp rate is regarded as a summation of horizontal sections of gratings that has approximately uniform periodicity within each section. The coupled mode analysis is used separately for each section to obtain the output beam when the incident beam satisfies the Bragg condition. Summing the contributions of the output beams from all the sections, we obtain the field distribution of the chirped grating lens in its focal plane. Numerical results that will be presented include the field distribution pattern, the focused spot size, the efficiency and the signal to noise ratio of the lens as functions of the angle of incidence of the input beam, the waveguide mode, the grating groove depth and profile, and the "thickness" of the lens.

In the Fourier analysis method, the thick grating lens is decomposed longitudinally into a series of n thin sections, each of which acts simply as a thin grating. The effect of each thin section on an incident plane guided wave is to introduce a phase transformation. The transformed output from each thin section can be represented as a summation of plane guided wave modes in different directions of propagation by the Fourier analysis. The analysis proceeds by decomposing the incident field distribution into its Fourier components, i.e., plane guided waves traveling in different directions by the fast Fourier transform method. Each Fourier component is scattered by the first thin section of the chirped grating lens into a set of Fourier components. The amplitudes of a given Fourier component produced by the thin section from all the Fourier components of

*Work supported in part by AFOSR Grant No. 80-0037.

the incident field are then summed by numerical integration to yield the total amplitude of that Fourier component. The total amplitudes of the Fourier components after the second section are obtained numerically from the Fourier components of the first section in a similar manner. Iterating the above process n times, we obtain the Fourier components of the output of the thick chirp grating. The field distribution in a given plane after the lens is simply the inverse Fourier transformation of the Fourier components. In such an analysis, the Bragg condition is not assumed and the method is applicable to any chirped or curved grating deflectors. Efficient numerical procedures now exist to handle the fast Fourier transform and the numerical integration. Numerical results that will be presented include the effects of the chirping rate, the groove depth and profile, the waveguide mode and the grating thickness on (a) the field distribution of the lens in its focal plane, (b) the focused spot size and (c) the signal to noise ratio.

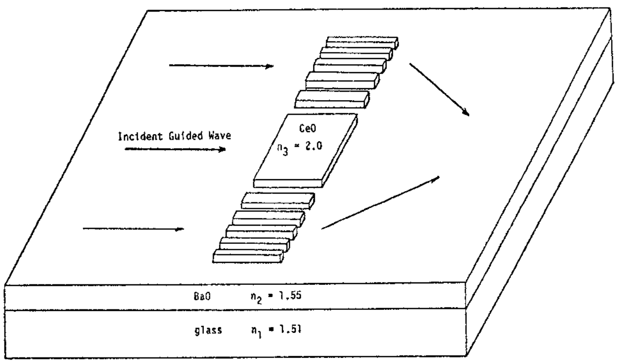

Figure 1: Illustration of a Phase Shift Fresnel Lens

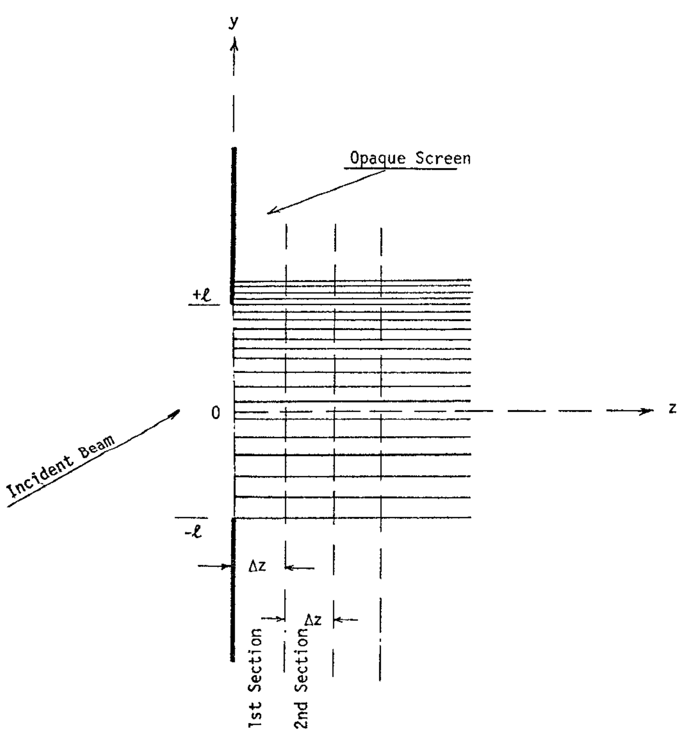

Figure 2: The Thick Chirped Grating