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Application of Optical Instrumentation In Medicine-II

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Introduction

There is a pressing need for improved communication among individuals and groups involved in the design, development, production, use, quality control, and maintenance of instrumentation for medical imaging. Representatives of business, government, medical research, and clinical communities must talk more openly with each other about their capabilities, needs and desires concerning medical equipment. Even within one community, the need to exchange ideas and share aspirations is becoming increasingly acute. In recognition of these needs, a second Technology Utilization Seminar on "Application of Optical Engineering in Medicine" was sponsored by the Society of Photo-optical Instrumentation Engineers in Chicago in November, 1973. The proceedings of that seminar comprise the contents of this volume.

The papers and discussions recorded in this volume reflect the medical benefits which modern science and technology offer, or of promise to offer, to society at, in most cases, a reasonable cost.

To the authors of these papers, and to the participants in the discussions, we offer our thanks for their contributions to the program and to the proceedings.

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Nuclear Medicine Imaging

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USE OF AN ARRAY OF THREE OFF-AXIS ZONE PLATES FOR LARGE FIELD OF VIEW GAMMA RAY IMAGING

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Abstract

A coded aperture consisting of a planar array of three off-axis zone plates oriented at 120° with respect to each other has been used to image gamma-ray sources up to ten inches in diameter. The zone plates do not have a common axis, and the high frequency zones of each zone plate are located in the central region. The maximum radius and fringe spacing are chosen so that the spatial frequency bandpasses for the individual zone plates do not overlap, and a hexagonal array of holes is used as a sampling screen (half-tone) to shift the object spectrum into the bandpass of the three zone plates. The aperture configuration permits more uniform sampling of a large object as compared with a system consisting of a single large off-axis zone plate. Design parameters are discussed, particularly those related to the imaging of bar phantoms and the generation of coherent artifacts. Reconstructed images of gamma-ray sources using the three zone plate system are presented.

Introduction

In the last few years a great deal of research has been done in the field of coded aperture imaging of gamma-ray sources for use in nuclear medicine. (Refs. 1-4) This application is based on the earlier work of Mertz and Young. (Ref. 5) The use of an off-axis zone plate has been well documented by Barrett and has been shown to be capable of imaging small organs well, for example the thyroid. However, if coded aperture imaging is to find wide use in nuclear medicine it must be able to image the larger organs. Brain imaging, for example, makes up more than 50% of all clinical nuclear medicine studies.

Two problems are present in the use of off-axis zone plates, especially when large objects must be imaged:

1. The sensitivity is not uniform, due to $\cos^4\theta$ effects, if the object diameter appreciably exceeds the aperture diameter. (Assuming, of course, that one maintains a small object to imaging system spacing for high overall sensitivity.)

2. The frequency response is not uniform due to severe geometric collimation in the high frequency region of the zone plate.

We propose here a multiple zone plate coded aperture which samples the gamma-ray source more uniformly than a single large zone plate. Design considerations and parameters will be discussed relating to a three zone plate aperture. We will then discuss sampling problems which must be considered in the use of all zone plate coded apertures, and in particular the three zone plate aperture. Lastly we will present reconstructions of extended gamma sources up to 25 cm in diameter.

Design Considerations and Parameters

In order to minimize some of the problems mentioned in the previous section when imaging large objects, one is attracted to the use of multiple off-axis zone plates. Figure 1(a) illustrates a possible configuration. We have shown the general case in which the axes of the zone plates are non-coincident. Figure 1(b) illustrates a modification of Figure 1(a) in which the high frequency zones are located in the center of the aperture. This configuration is the one we have used, since the average collimation effect of the high frequency zones will be less severe for all points of the object. This system differs, in important aspects, from the array of four zone plates of De Meester et al. (Ref. 6) The design parameters of this configuration are made clearer if we examine the spatial frequency response of this system. The principal consideration here is that the first order bandpass of each zone plate should not

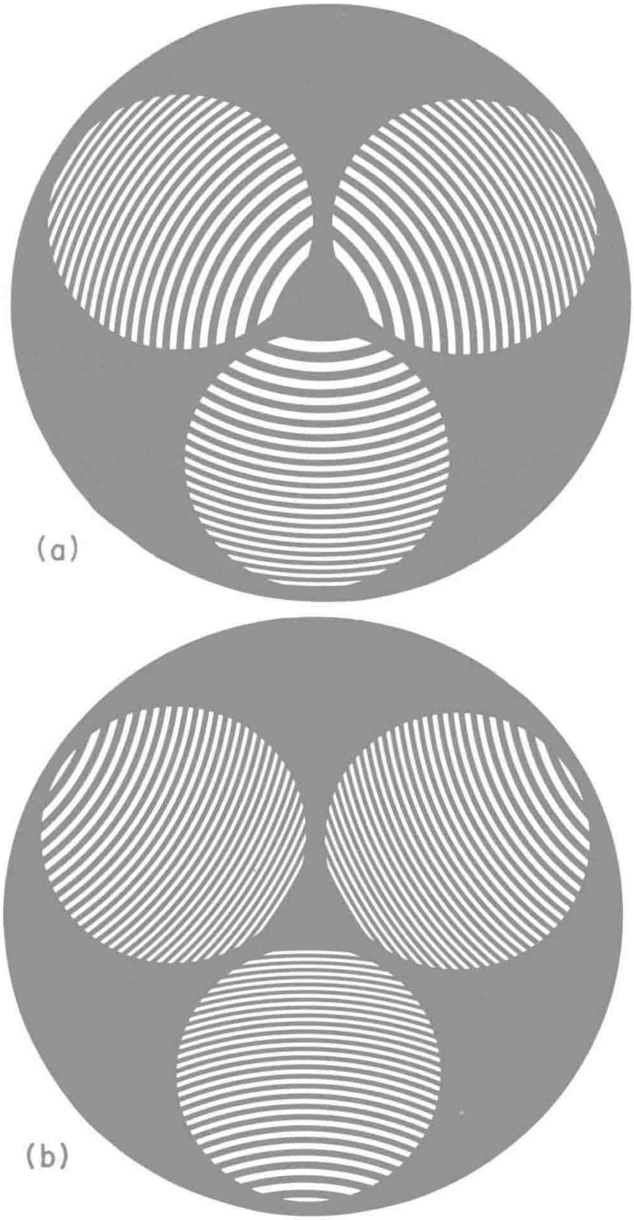


Fig. 1 (a) Possible configuration of a three zone plate aperture. (b) Configuration used in this work, showing high frequency zones centrally located.

overlap that of any other, otherwise interference will result. The mathematical expression describing this condition is $\Delta f \leq \bar{f}/2$ where Δf is the frequency sweep and $\bar{f}$ is the center frequency of each zone plate. Figure 2 shows the spatial frequency plane for $\Delta f = \bar{f}/2$, which makes optimum use of the available frequency plane. It is necessary to use a half-tone screen to heterodyne the object spectrum into the passband of the zone plates.

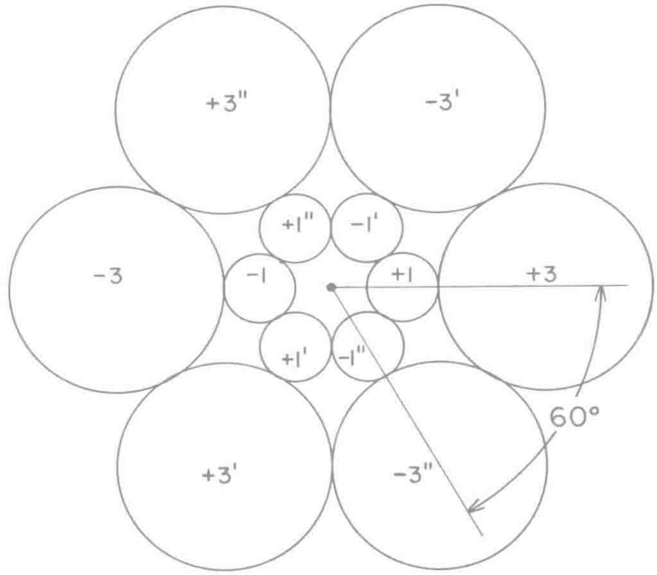


Fig. 2 Fourier transform of the three off-axis zone plate aperture. Primes indicate passbands related to each (unprimed, primed and double primed) zone plate.

Figure 3 shows the necessary frequency response of the half-tone screen. A screen which has a suitable frequency response consists of a hexagonal array of holes as illustrated in Figure 4. The hole diameter in this sampling screen is determined

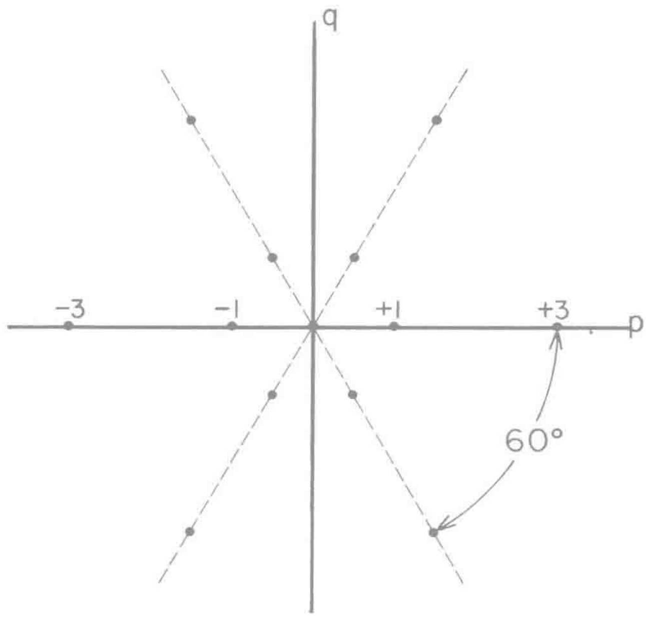


Fig. 3 Fourier spectrum of a sampling screen necessary for three zone plate aperture.

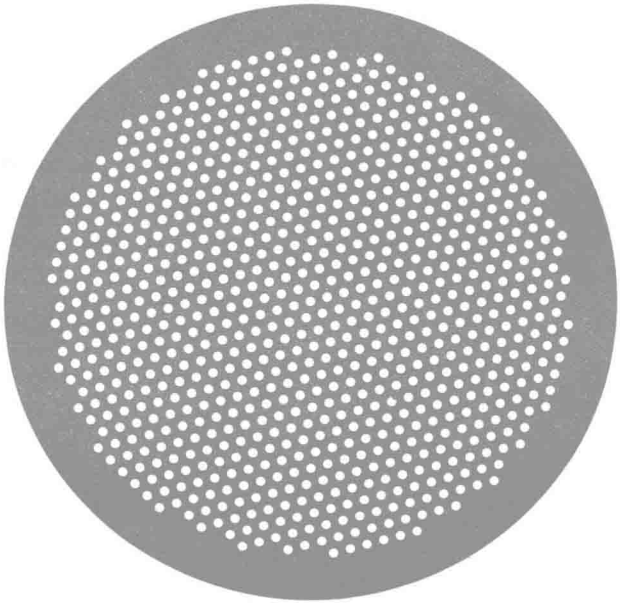


Fig. 4 Half-tone screen used with the three zone plate aperture.

by maximizing the spectral power of the heterodyned object in the first order bandpass of the zone plate. This results in a "half-tone" screen of 40% transmission.

The imaging system we have been discussing can be represented mathematically

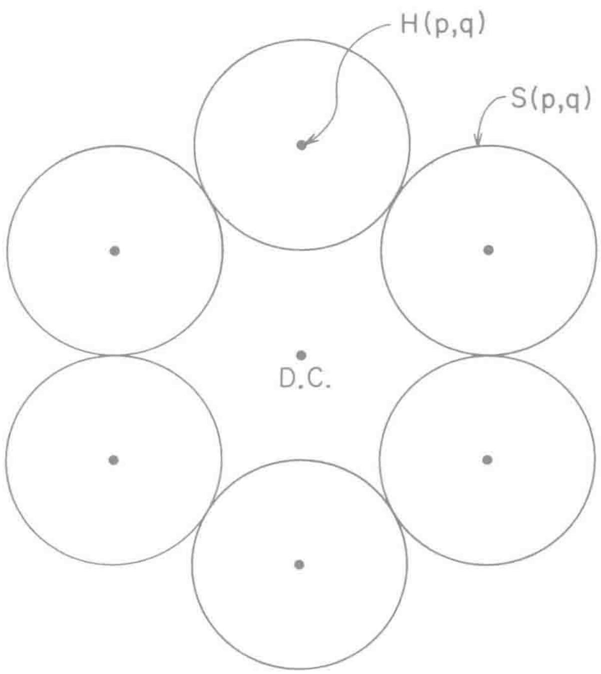


Fig. 5 Frequency bandpass of three zone plate apertures showing mathematical relationships.

as follows:

$$i(x, y) = o(x, y) \cdot h(x, y) * s(x, y)$$

o = the object being imaged
h = the half-tone screen
s = the coded point spread response
i = the resultant coded record

In the frequency domain we have

$$I(p, q) = O(p, q) * H(p, q) \cdot S(p, q)$$

The above mathematical expression of the spatial frequency for the three zone plate aperture is illustrated pictorially in Figure 5. We assume, of course, that the object spectrum is completely contained within the first order bandpass of the aperture. Let us assume for a moment that the object spectrum contains frequencies outside the bandpass of the coded aperture. This is illustrated in Figure 6. The result, of course, is that the object is aliased by frequencies not only from the adjacent first order pass-

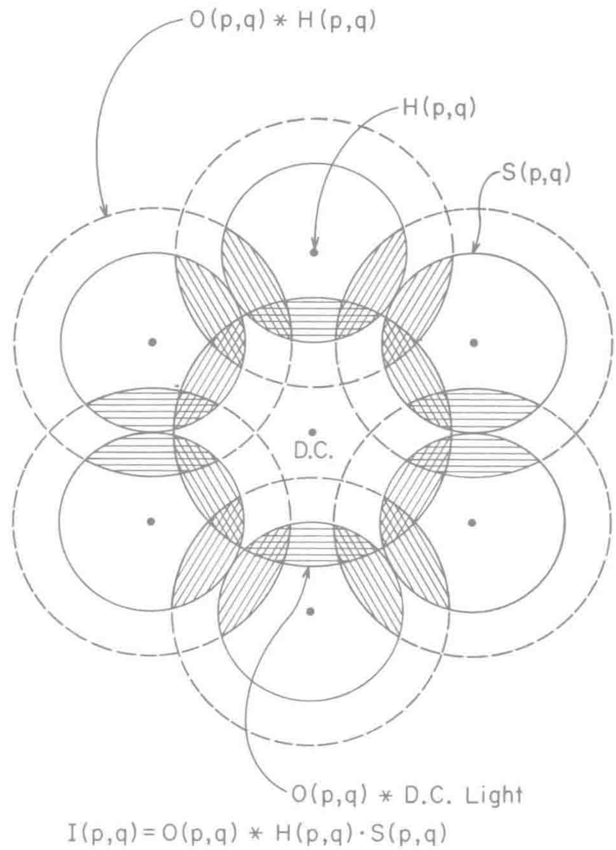


Fig. 6 Aliasing in three zone plate apertures with insufficient bandpass for object being viewed. Shading indicates regions in which aliasing occurs.

bands but from the passbands of the DC and third orders as well. Obviously one must design the system so that such a situation does not arise in the course of imaging actual clinical cases.

It is customary to test system performance by the use of phantoms. Bar phantoms and the Picker thyroid phantom, which are commonly used for such tests, have extremely high frequency content because their edges have a square cross-section. This is not the case for most nuclear medical objects, since much high frequency content is effectively low pass filtered by patient motion.

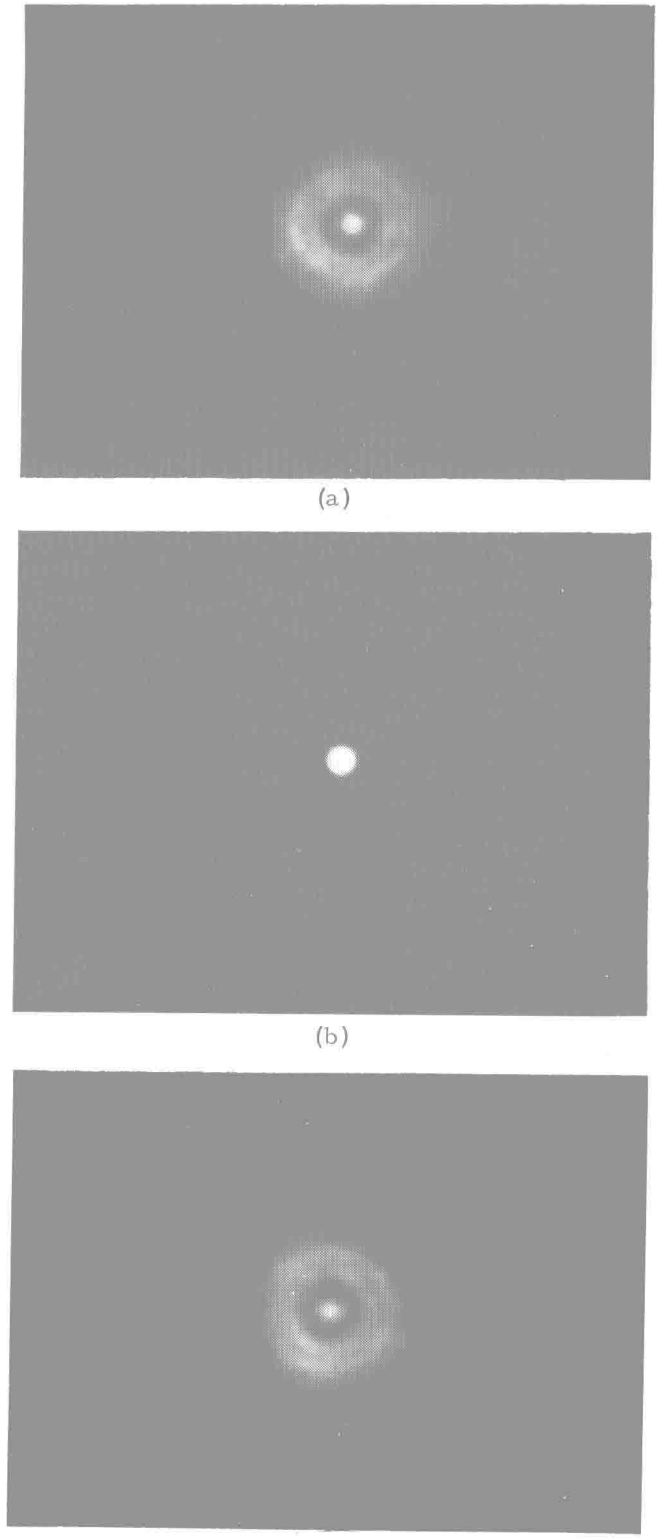
In order to eliminate the problem of possible aliasing when testing system performance with bar phantoms, we have constructed bar phantoms of lucite which have a sinusoidal cross-section, similar to the familiar "washboard road." When these phantoms are filled with solutions containing radionuclides, such as ^{99m}Tc, the intensity of the gamma emission is effectively sinusoidal across the phantom.

We should point out that the aliasing problem with phantoms is by no means restricted to our three zone plate aperture, but a single off-axis zone plate can suffer from aliasing between DC and first order and between the first and third order frequencies. It should be noted that we have not concerned ourselves with second order frequency generation which can be caused, for instance, by gamma-rays striking the coded aperture or half-tone screen at an oblique angle causing a change in the line to space ratio. In our experience aliasing due to second harmonic generation appears to be negligible.

Results

The data presented here were recorded on 43 cm x 43 cm (17 inch x 17 inch) Kodak RP Royal X-Omat film using a pair of DuPont Lightning Plus intensifying screens. The half-tone to zone plate spacing was 22 cm, while the zone plate to detector spacing was 11 cm. The diameter of each lead zone plate was 12 cm, with a 4.2 cycle/cm center frequency and a 2.1 cycle/cm frequency sweep. This results in a resolution of about 1 cm in the object plane. Typical encoded records were made with a time integrated flux of 5×10^{7} gamma photons (140 keV) per square centimeter incident on the detector plane.

Reconstruction of the encoded record is carried out by standard laser techniques.

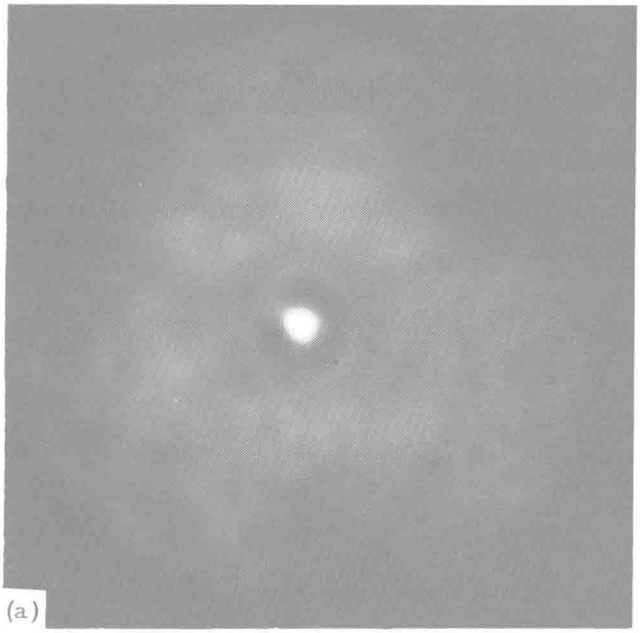


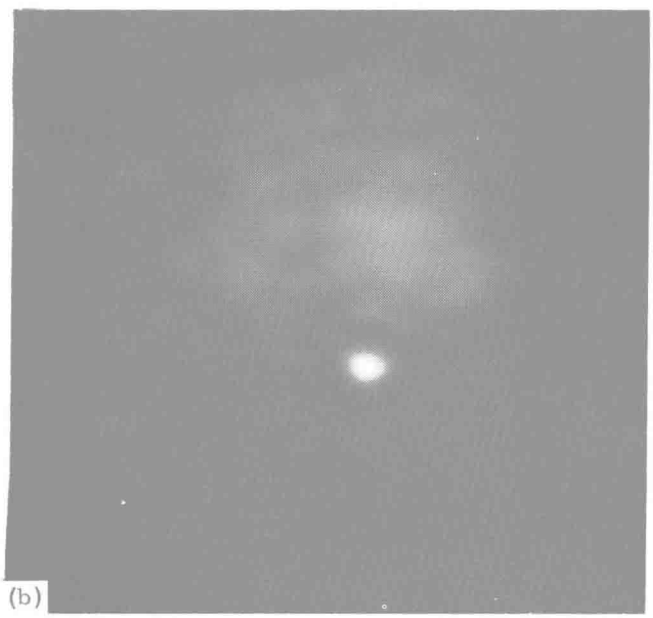
(a) (b) (c)

Fig. 7 Reconstruction of point source at various focal planes. Point source (a) in front of focal plane, (b) in focal plane, (c) in back of focal plane.

The reconstructed image from each zone plate appears in spatially separated regions of the output plane. While it is possible to design apparatus to coherently combine the images, for example, matched filters, it is relatively simple to photograph the three images and combine them incoherently. (Ref. 7) For this purpose we make an underexposed photograph, cut out the three images, superimpose them and project the result. This method is useful since artifacts in each image caused by the coherent reconstruction tend to be averaged out. The multiple incoherent-wave noise suppression method of Upatnieks and Lewis is somewhat similar. (Ref. 8) The process of superimposing the images, while unrefined, does give an image which is much more uniform. Our preliminary results indicate the capabilities of the system.

A set of standard tests to be performed on coded aperture imaging has been suggested and we have made those tests which our present equipment allow. (Ref. 9)


(a)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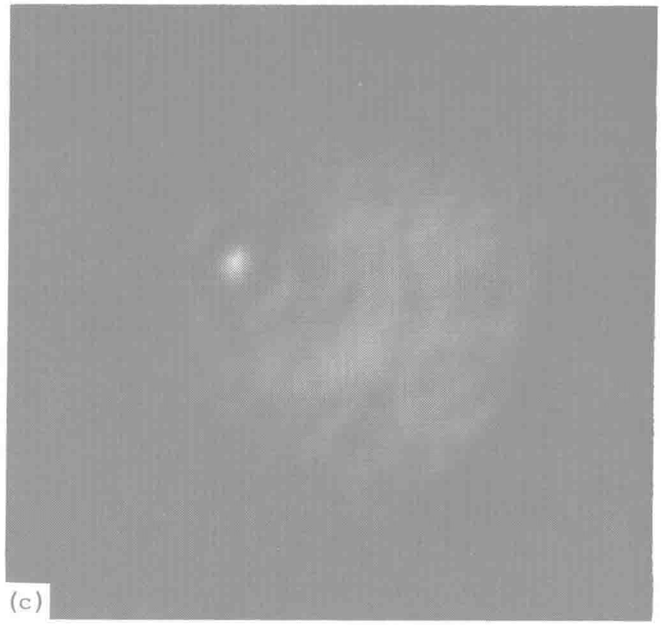
(c)

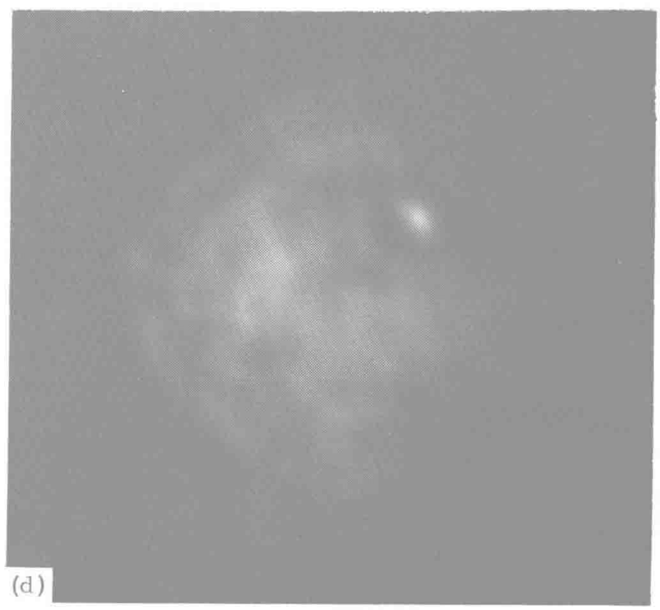
(d)

Fig. 8 (a) Three superimposed views of point source on a uniform background. Point source strength equal to strength of one resolution element of background. (b, c, d,) Individual views of point source on uniform background.