A STUDY OF THE INFORMATION CONTENT IN THE HARMONICS OF THE SPATIAL FREQUENCY SPECTRA OF HALFTONE IMAGES USING COHERENT OPTICAL COMPUTERS

S. V. PAPPU*, C. A. KUMAR AND S. D. MEHTA

Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore 560 012

ABSTRACT

The results of a systematic study made by using a Coherent Optical Spatial Frequency Processor (COSFP) about the information content in the various harmonics of the spatial frequency spectra of halftone images are discussed. It is observed that the circular shape of the halftone dot gets corrupted in undersampled images, whereas it is preserved to a large extent in correctly sampled images. It is also found that from these studies the correctly sampled images can be identified rather effortlessly.

It is envisaged that studies of this kind could lead to the development of new methodologies for Image Quality assessment and Video Information transmission.

INTRODUCTION

HALFTONE process is commonly employed in graphic arts and printing industry for the reproduction of continuous tone images. Halftone images are produced by photographing the continuous tone image through a screen (known as halftone screen) with a high contrast film. Such screens are commercially available and they consist of a periodic array of black dots. The blackness variation across a dot is more or less Gaussian[1]. A halftone screen, in the ultimate analysis, is nothing but a two-dimensional grating and it can easily be obtained in the laboratory by the appropriate superposition of two one-dimensional gratings of desired periodicity. The period of the dot array can be so manipulated (by a proper selection of the halftone screen) as to make the halftone image appear as a continuous tone image at normal viewing distances. Recently interest in the age-old halftone technique has been revived because of its potential utility in the achievement of nonlinear operations with coherent optical computing systems[2,3] and in other applications[4-7].

It is an experimentally observable fact that a continuous tone image located at the input of a Coherent Optical Spatial Frequency Processor (COSFP) will yield a nondiscrete (or continuous) spectrum in the so-called Fourier (or diffraction or spatial frequency) plane; whereas a halftone version of it will yield a discrete spectrum.

In the language of communication systems and image processing, it can be stated that the superposition of halftone dot structure on a continuous tone image will result in, (*a*) the sampling of the object distribution; (*b*) the accentuation of higher frequencies in the object and (*c*) the spatial separation of various harmonics from the central region in the spatial frequency spectrum of the object.

The aspect (*c*) mentioned above allows the facility to handle the harmonics either individually or collectively in order to determine the information content in them. This in turn is intimately connected with the aspect, (*a*) (*i.e.* the sampling) *via* the Whittaker–Shannon theorem[8]. Both these aspects are important in so far as video information transmission is concerned. And the aspect, (*b*) mentioned above can lead to a better understanding of image quality. In view of these advantages, it appears that a systematic study of the spatial frequency spectra of halftone pictures is warranted. As we are pursuing R & D programmes in the areas of image quality assessment, Video Information transmission using optical fibers, spatial frequency analysis, for image processing and remote sensing, we have undertaken a study of the information content in the spatial frequency spectra of halftone images. Several interesting results obtained from this study are presented here.

To the best of our knowledge only Marquet and Tsujuichi[9] have done some work along these lines long time ago. They attempted to explain their results on dot removal in terms of diffraction theory by assuming the shape of halftone dot to be circular. Our studies reveal that this assumption is of conditional validity.

EXPERIMENTAL

The experiments have been carried out using a COSFP system shown schematically in Fig. 1 and the system is powered by a spectra physics

* To whom all correspondence should be addressed.

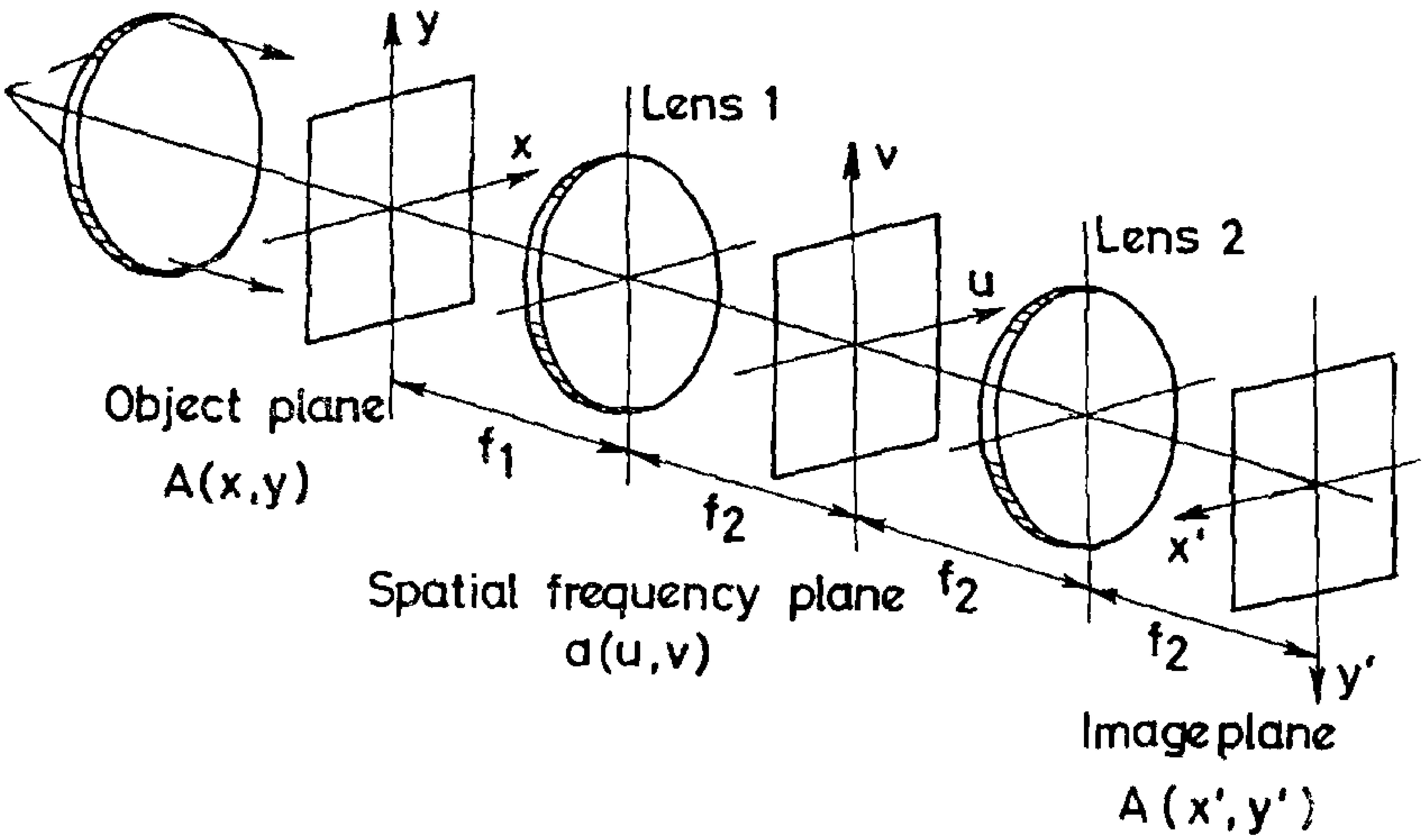


FIG. 1. Schematic of a Coherent Optical Spatial Frequency Processor (COSFP).

model 155 He–Ne laser. The selective transmission of the desired harmonics, from the frequency plane to the image plane, is achieved by the location of a suitable aperture in the Fourier plane. The spectrum is magnified sufficiently so that apertures of appropriate dimensions could be used as spatial frequency filters without themselves causing diffraction effects of their own. All the inputs to the COSFP system are in the format of 35 mm.

The spectra of a good number of halftone pictures have been looked at and from amongst them three representative pictures have been chosen for the present study. The three pictures are categorized as Coarse (C), Medium (M) and Fine (F), based on the period of their dots array. The three pictures along with their spectra are shown in Fig. 2. Also the sketches of the spectra are shown in Fig. 3 with the appropriate nomenclature for the various harmonics written therein. As the diffraction pattern is symmetrical about the central spot we have indicated the nomenclature in only one quadrant.

RESULTS AND DISCUSSION

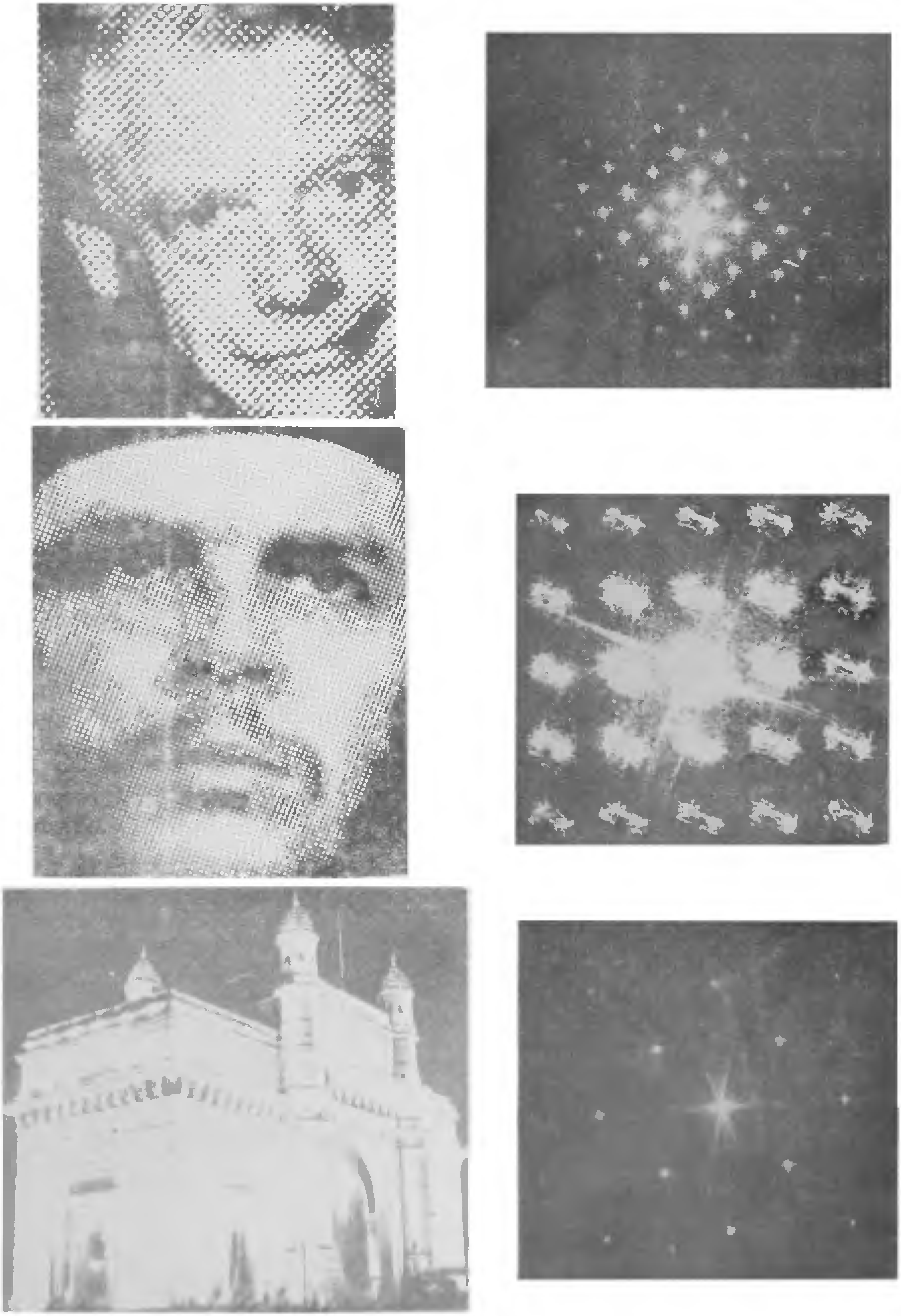
1. The shape of the diffraction spots obtained from the C, M and F type pictures is diamond, hexagonal and circular respectively. This difference is attributed to the corruption of the halftone dots from their original circular shape in the cases of C and M type pictures and we have confirmed this to be true by microscopic examination of the halftone pictures. In this context it may be recalled that it is a well established fact that the shape and the size of halftone dot is dependent upon the gray level distribution in the continuous tone image. From these observations we conclude that the assumption of Marquet and Tsujuichi[9] about the halftone spot being circular is only conditionally valid.

2. A uniformly illuminated patch is obtained as the image when the DC alone is passed with a 25 μm pinhole as spatial filter (*see* Fig. 4 *a*). This is consistent with the theoretical prediction that the Fourier transform of DC should lead to no information.

3. The results of the passage of the central spot (00) is the familiar low pass image (*see* Fig. 4*b*).

4. The F type picture has a much wider spectrum and its harmonics are all almost of the same intensity when compared with the spectra of C and M type pictures. In the case of C and M pictures, the intensity falls off rather rapidly as we move away from the central (00) spot.

These results, we interpret, are suggestive of the facts that the information content in the various harmonics of the F type picture must be nearly the same, whereas it is not so in the case of the spectra of the C and M type pictures. In



(a)

(b)

(c)

FIG. 2. Halftone inputs and their spatial frequency spectra for (a) C-type, (b) M-type and (c) F-type pictures.

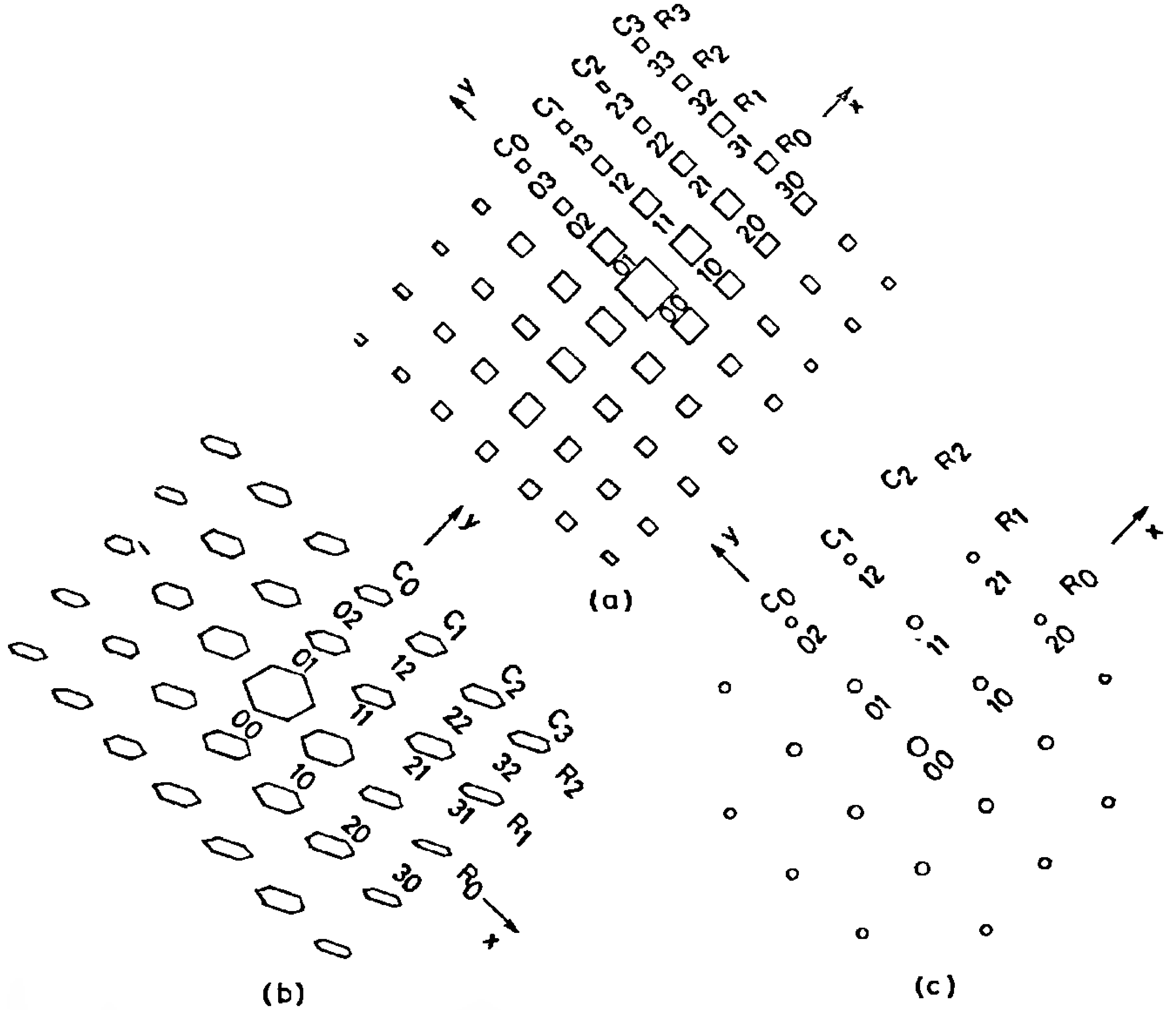


FIG. 3. Sketches with nomenclature of spatial frequency spectra for (*a*) C-type, (*b*) M-type and (*c*) F-type halftone inputs.

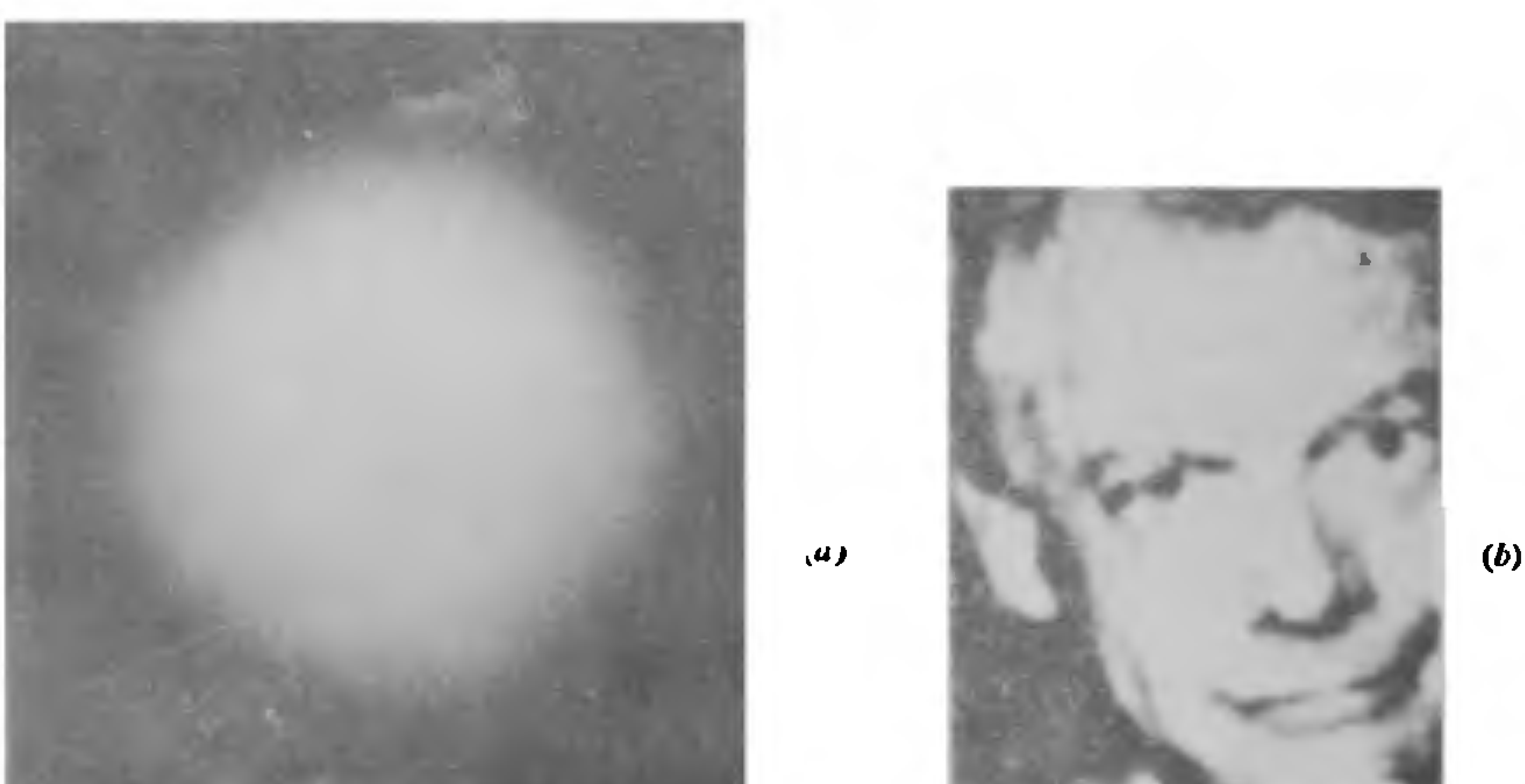


FIG. 4. (*a*) Image obtained when DC alone is passed. (*b*) Image obtained when central spot (00) is passed. The result is similar to all pictures.

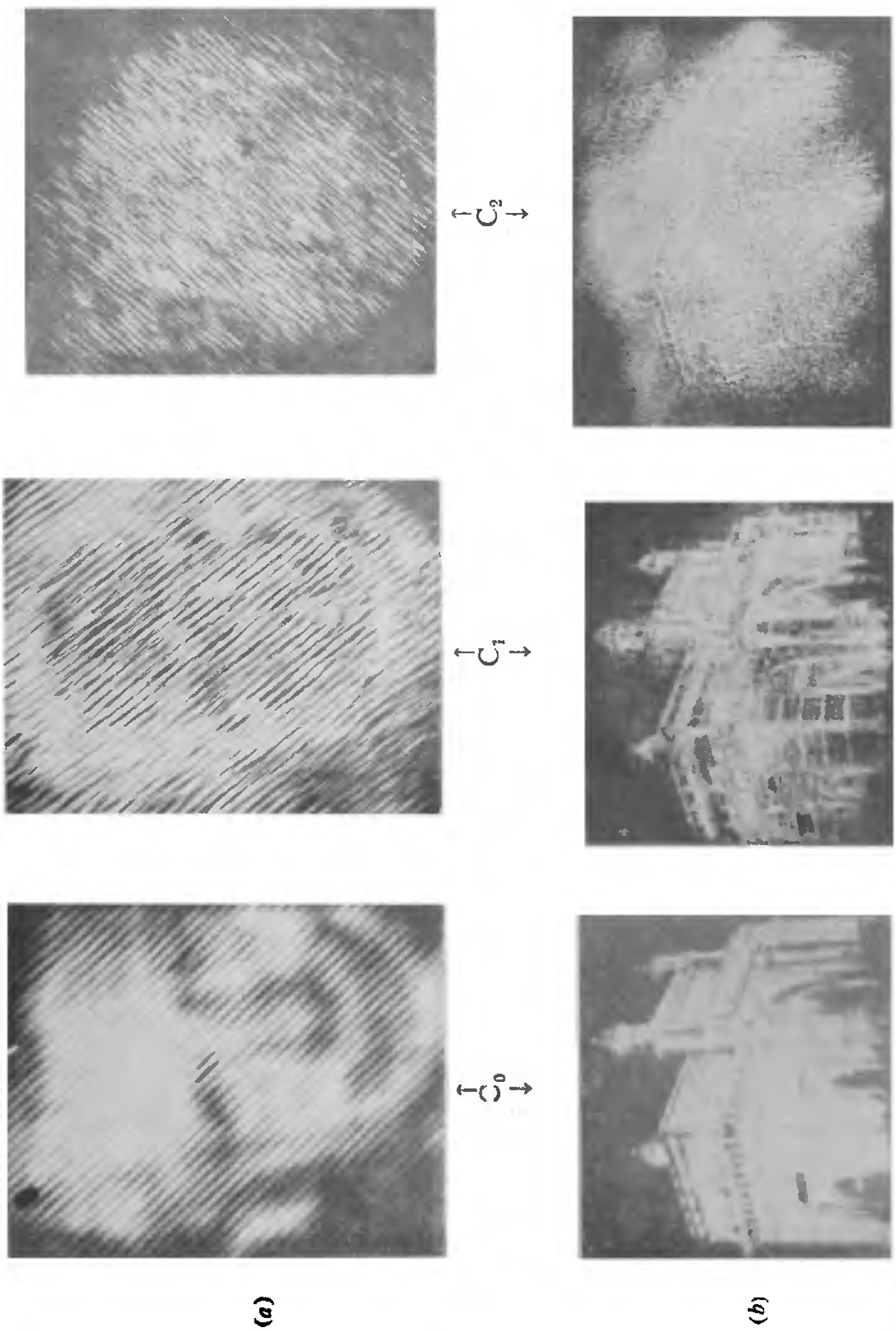


FIG. 5. Images obtained when harmonics corresponding to columns C_0 to C_2 are passed in the case of (*a*) C-type and (*b*) F-type pictures. The results for M-type are similar to the C-type. Further in all cases similar results are obtained when rows of harmonics R_0 to R_2 are passed.

other words, the F type picture comes close to being sampled according to Whittaker–Shannon theorem[8]; while the C and M type pictures are undersampled. The validity of these inferences is established by the following results, which are obtained by the method of image reconstruction *via* the route of the passage of desired harmonics using the COSFP setup shown in Fig. 1.

For instance the passage of harmonics such as 10, 20, etc., individually has yielded very noisy images in the case of C and M type pictures. In the case of F type picture, however, the image is as good as the low pass image. Further the results obtained with C and M pictures in regard to the passage of columns (C_0 to C_2) and rows (R_0 to R_2) of harmonics are similar. For example the information content degraded and the images became very noisy as we move away from C_0 to C_2 (or from R_0 to R_2). In addition, the results for the passage of harmonics in column C_0 (or from row R_0) is similar to that obtained from passing the (oo) spot. This is to be expected in view of the fact that in column C_0 (and in row R_0) the (00) spot is included. In the case of F type picture, however, the degradation of information content as we move from column C_0 to C_2 (or from row R_0 to R_2) is *not at all as severe* as in the case of the C and the M type pictures (*see* Fig. 5).

Yet another result in support of the abovementioned inference is obtained by the passage of all the harmonics from a quadrant. The result again is noisy images in the case of C and M type pictures, while the F type picture yielded an image as good as the low pass image.

5. Only in the case of M type picture, an intriguing result by way of an edge-enhanced picture is obtained when the diffraction spot (11) is passed (*see* Fig. 6). It is believed that this result is due to some artefact of the particular halftone structure; since similar result could not be obtained with the other two types of pictures studied here.

Epilogue

The halftone method appears to be an easy and efficient way of sampling images for purposes of applications such as Video Information transmission.

A systematic study of the information content in the harmonics of the spatial frequency spectra of halftone images can be effortlessly made using a COSFP system. Such studies can be utilised for the purpose of the identification of correctly sampled pictures.

Fig. 6. Image obtained in the case of M-type halftone picture when only the harmonic (11) is passed.

Our study indicates that the circular shape of the halftone dot is preserved to a large extent only in correctly sampled pictures.

We suggest that a possible method of transmitting the desired video information is by recording holographically the information in the harmonics. It is proposed that an integration of the COSFP with a holographic system might be the right thing to do to achieve this.

1. Wesner, J. W., *App. Opt.*, 1974, 13, 1703.
2. Kato, H. and Goodman, J. W., *Ibid.*, 1975, 14, 1813.
3. Liu, H. K., Goodman, J. W. and Chan, J. L. H., *Ibid.*, 1976, 15, 2394.
4. Kermisch, D. and Roetling, P. G., *JOSA*, 1975, 65, 716.
5. Allebach, J. P. and Liu, B., *Ibid.*, 1976, 66, 909.
6. Roetling, P. G., *Ibid.*, 1976, 66, 985.
7. —, *Photgr. Sci. Eng.*, 1977, 21, 66.
8. Goodman, J. W., *Introduction to Fourier Optics*, McGraw-Hill, New York, 1968, p. 21.
9. Marquet, M. and Tsujuichi, J., *Opt. Acta*, 1961, 8, 267.