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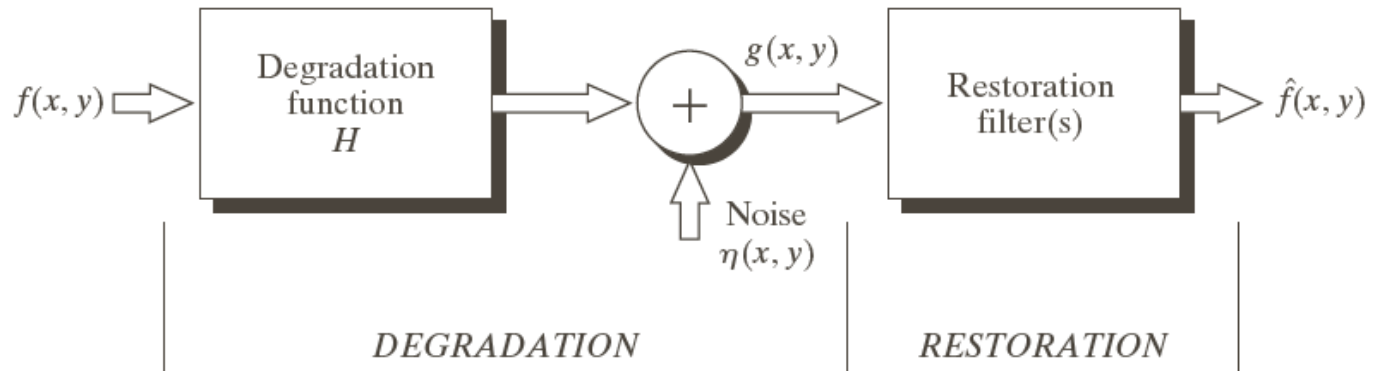
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FIGURE 5.1

A model of the image degradation/restoration process.



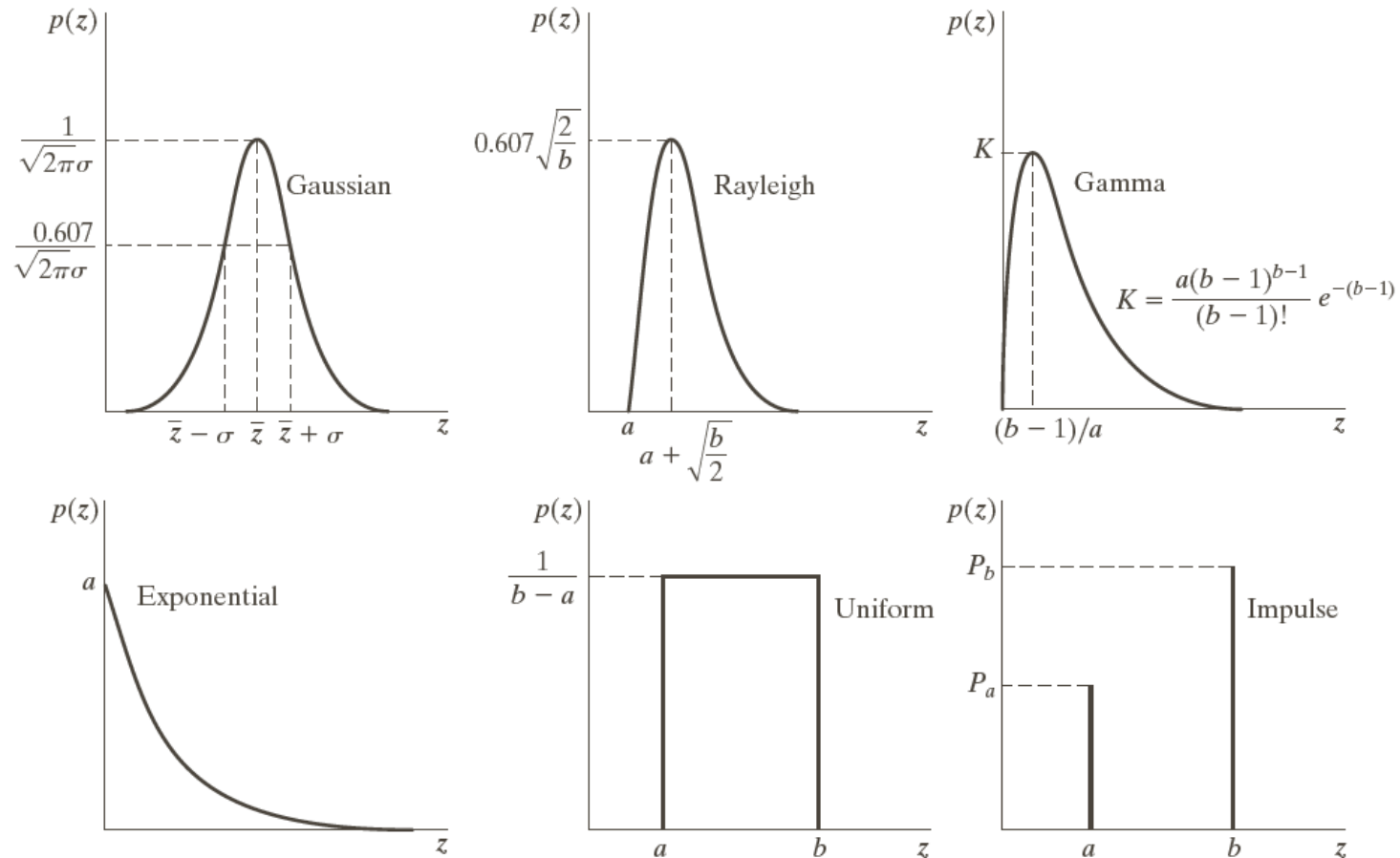


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a	b	c
d	e	f

FIGURE 5.2 Some important probability density functions.



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FIGURE 5.3 Test pattern used to illustrate the characteristics of the noise PDFs shown in Fig. 5.2.

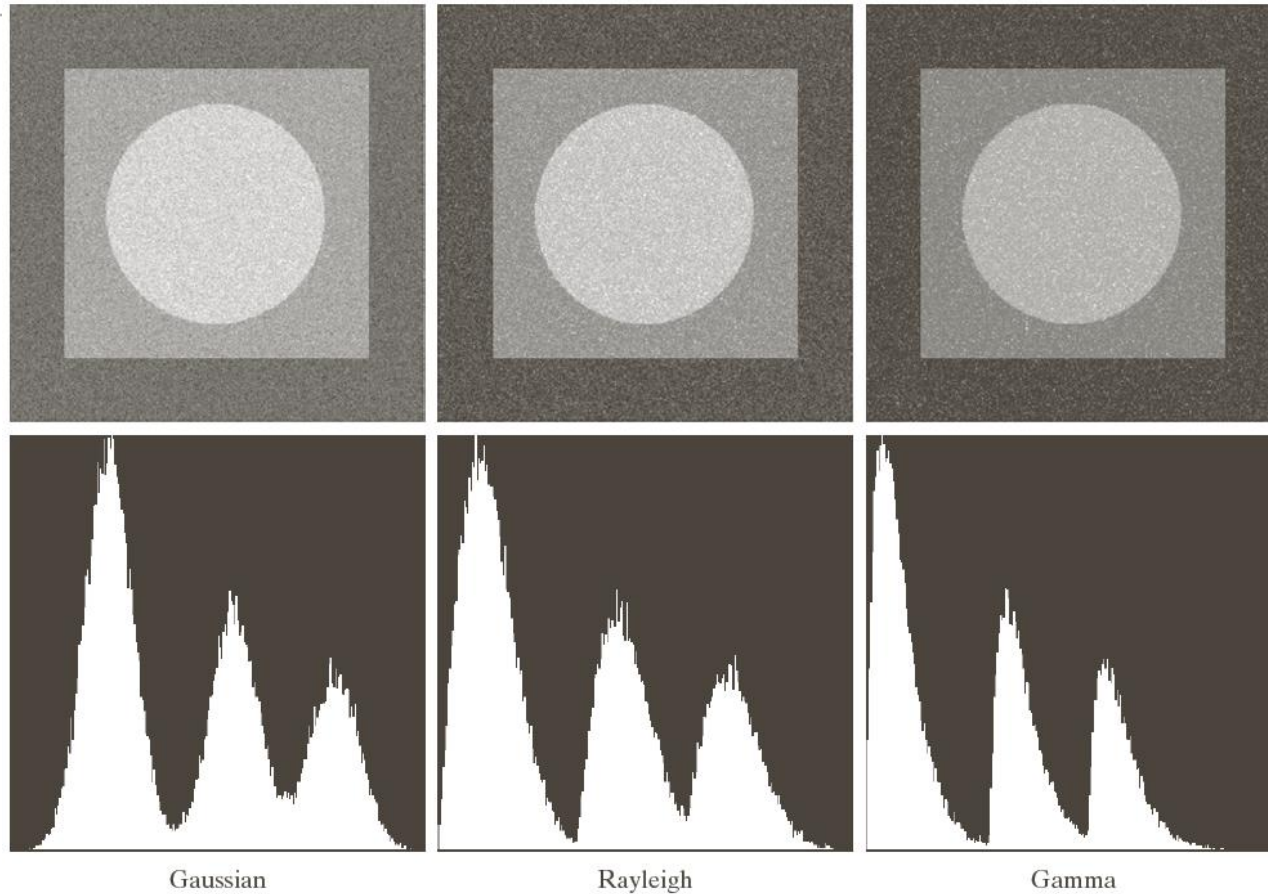


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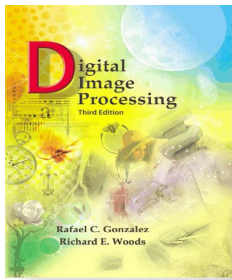
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a b c
d e f

FIGURE 5.4 Images and histograms resulting from adding Gaussian, Rayleigh, and gamma noise to the image in Fig. 5.3.

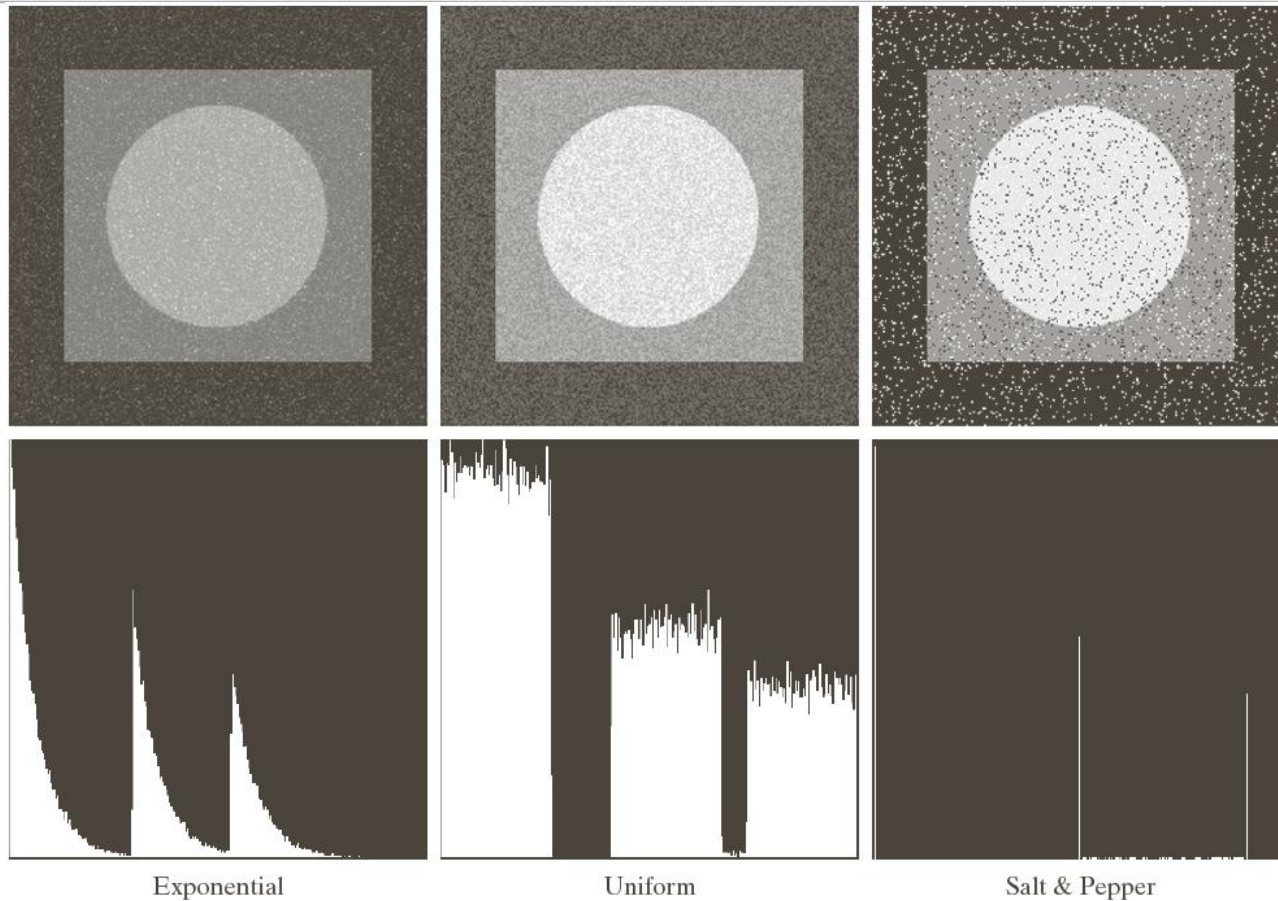


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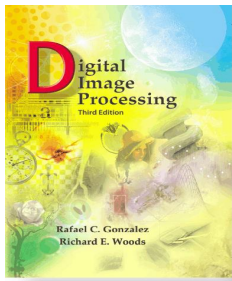
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g	h	i
j	k	l

FIGURE 5.4 (Continued) Images and histograms resulting from adding exponential, uniform, and salt and pepper noise to the image in Fig. 5.3.



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a
b

FIGURE 5.5

(a) Image corrupted by sinusoidal noise.
(b) Spectrum (each pair of conjugate impulses corresponds to one sine wave). (Original image courtesy of NASA.)



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a b c

FIGURE 5.6 Histograms computed using small strips (shown as inserts) from (a) the Gaussian, (b) the Rayleigh, and (c) the uniform noisy images in Fig. 5.4.



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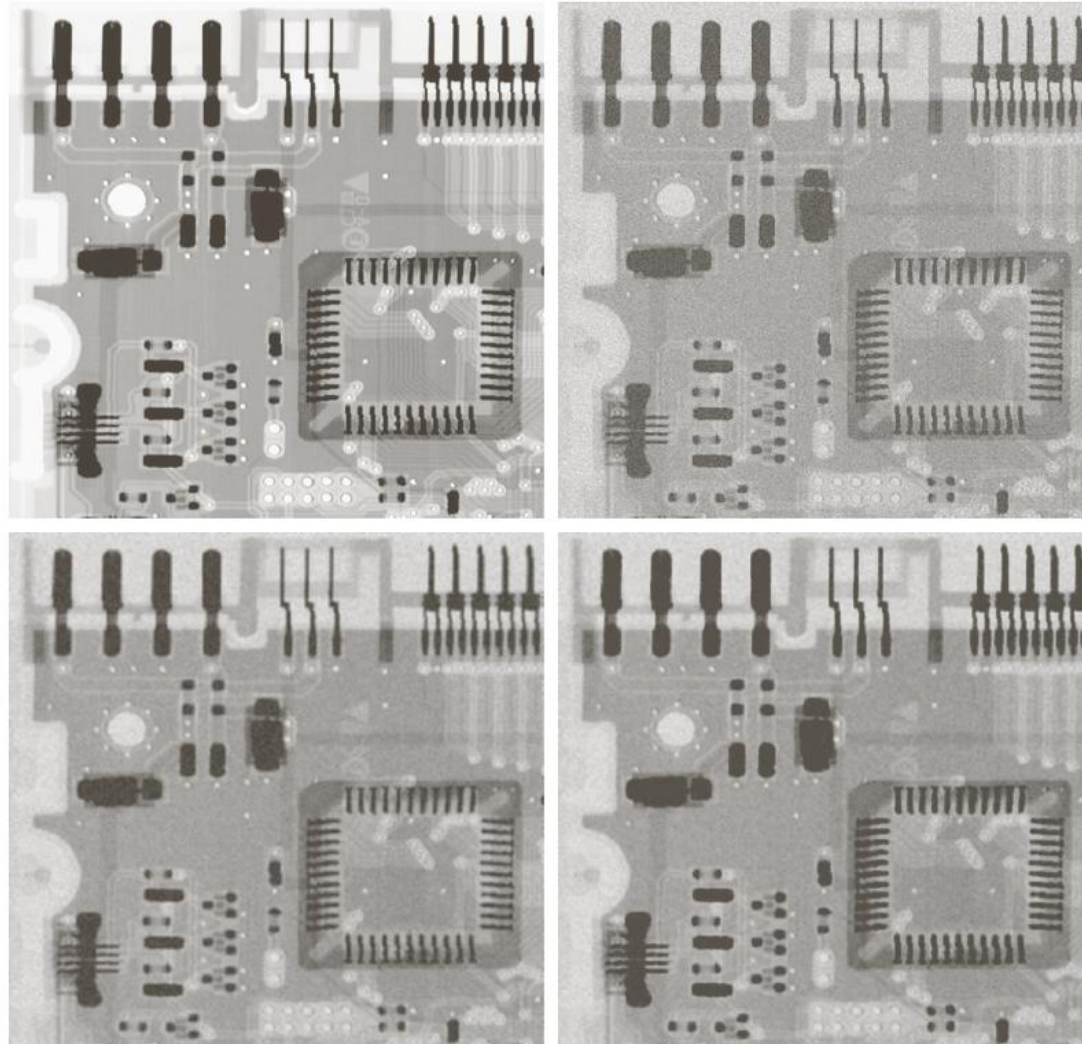
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a b
c d

FIGURE 5.7

(a) X-ray image.
(b) Image corrupted by additive Gaussian noise.
(c) Result of filtering with an arithmetic mean filter of size 3×3 .
(d) Result of filtering with a geometric mean filter of the same size.
(Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)



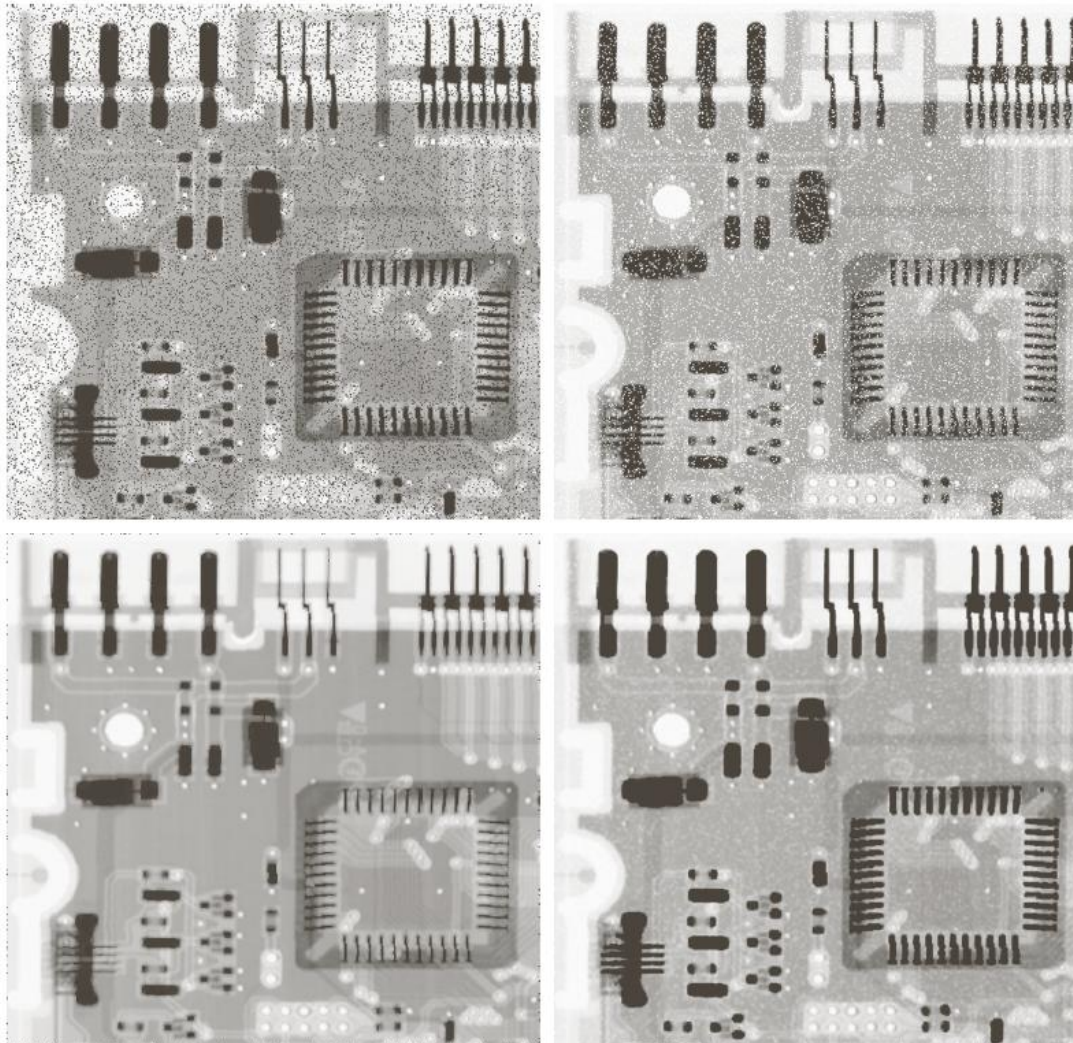


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a b
c d

FIGURE 5.8

(a) Image corrupted by pepper noise with a probability of 0.1. (b) Image corrupted by salt noise with the same probability. (c) Result of filtering (a) with a 3×3 contra-harmonic filter of order 1.5. (d) Result of filtering (b) with $Q = -1.5$.



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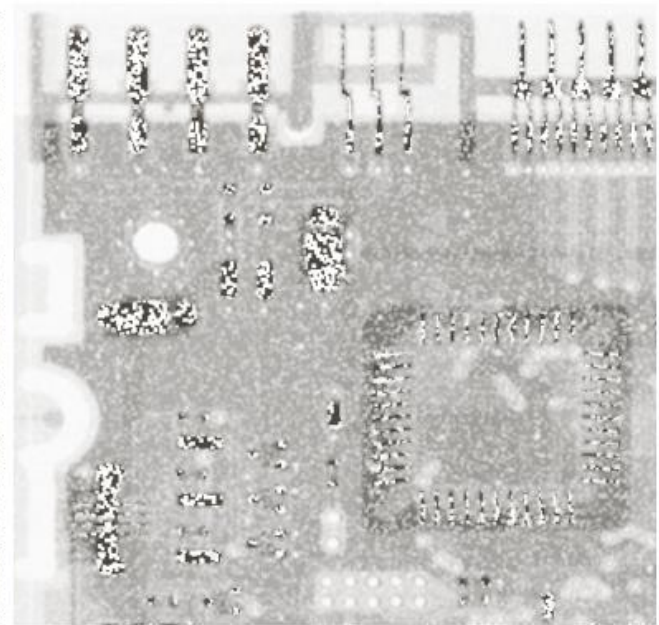
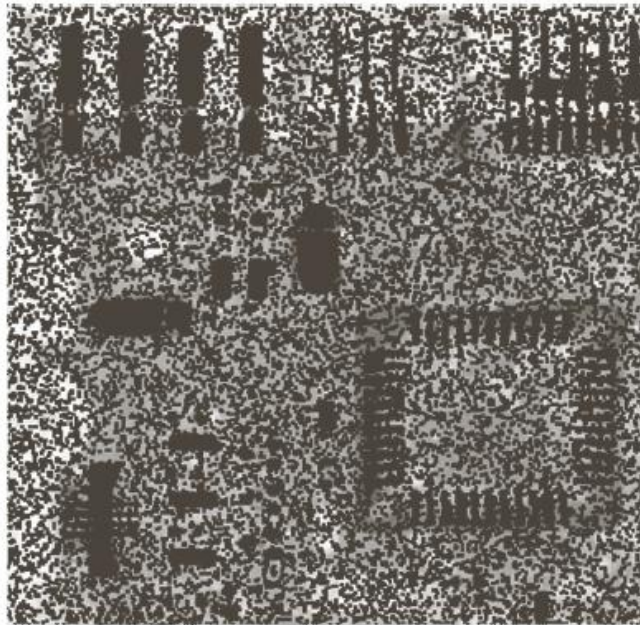
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a b

FIGURE 5.9

Results of selecting the wrong sign in contraharmonic filtering.

(a) Result of filtering Fig. 5.8(a) with a contraharmonic filter of size 3×3 and $Q = -1.5$.
(b) Result of filtering 5.8(b) with $Q = 1.5$.





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a b
c d

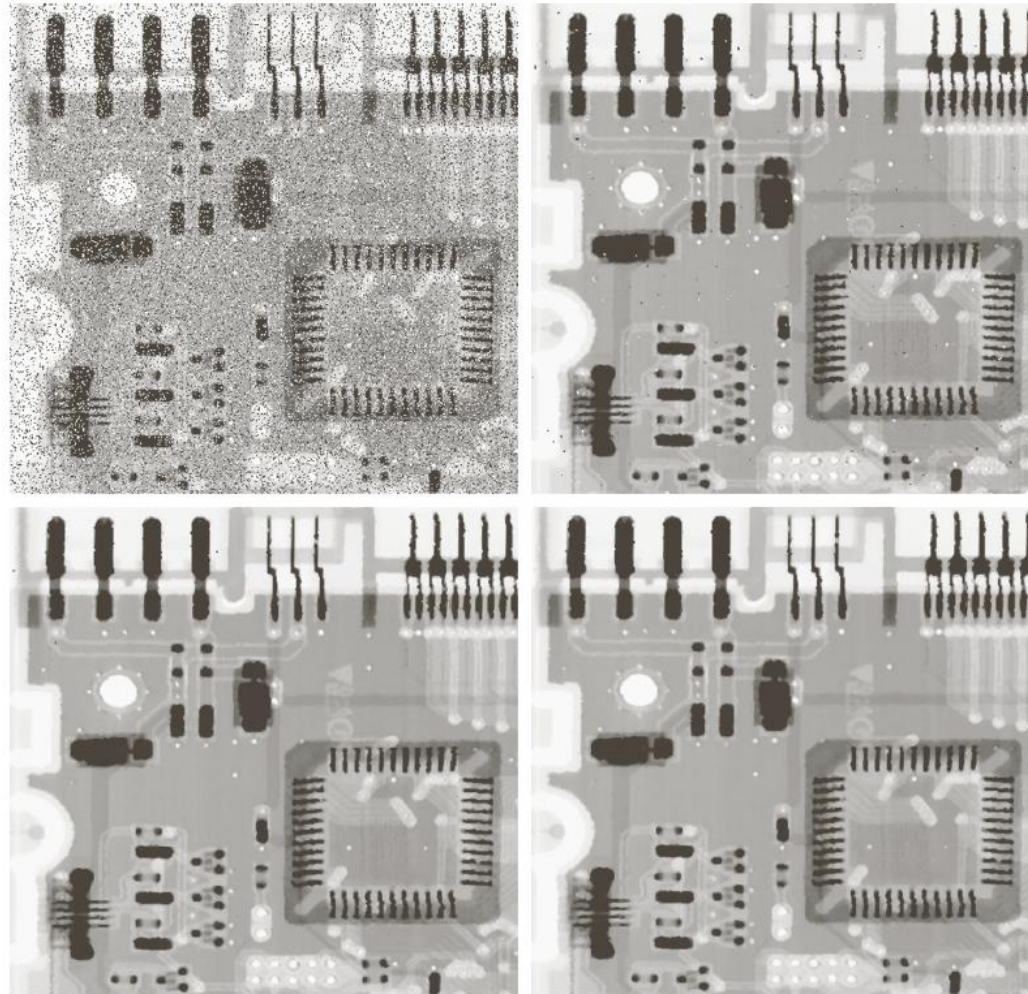
FIGURE 5.10

(a) Image corrupted by salt-and-pepper noise with probabilities $P_a = P_b = 0.1$.

(b) Result of one pass with a median filter of size 3×3 .

(c) Result of processing (b) with this filter.

(d) Result of processing (c) with the same filter.





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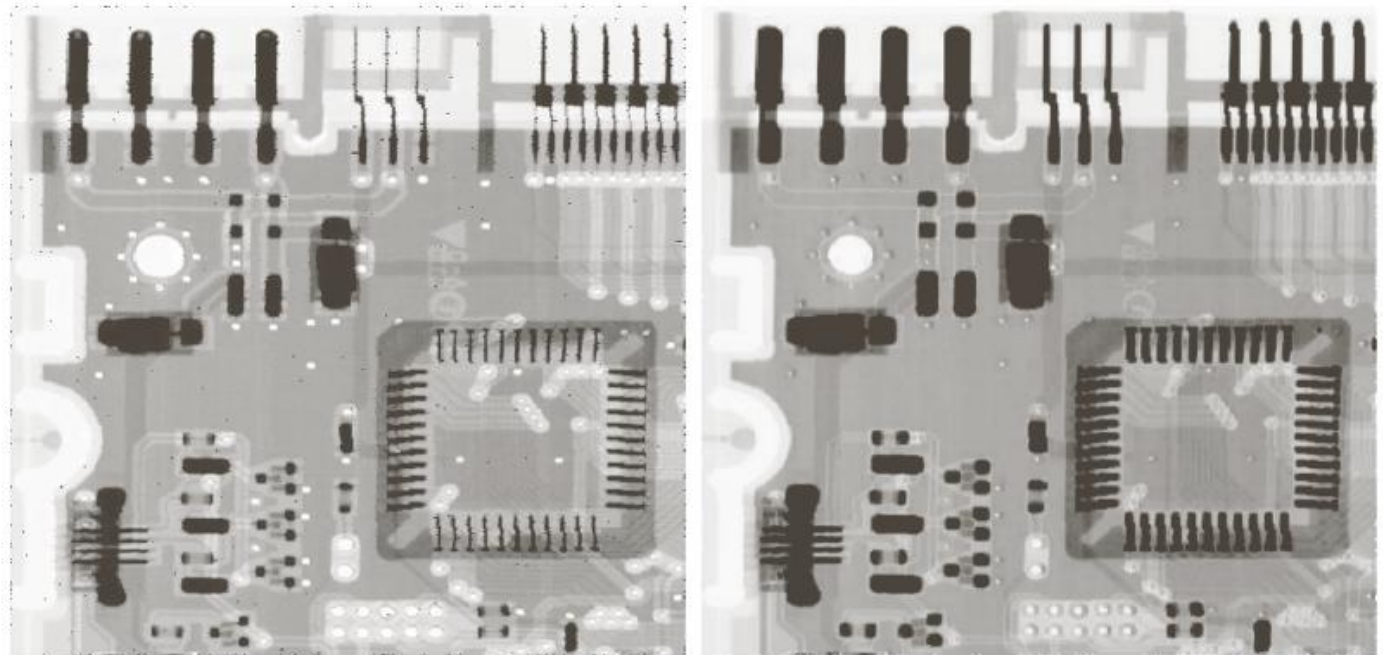
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a b

FIGURE 5.11

(a) Result of filtering

Fig. 5.8(a) with a max filter of size 3×3 . (b) Result of filtering 5.8(b) with a min filter of the same size.

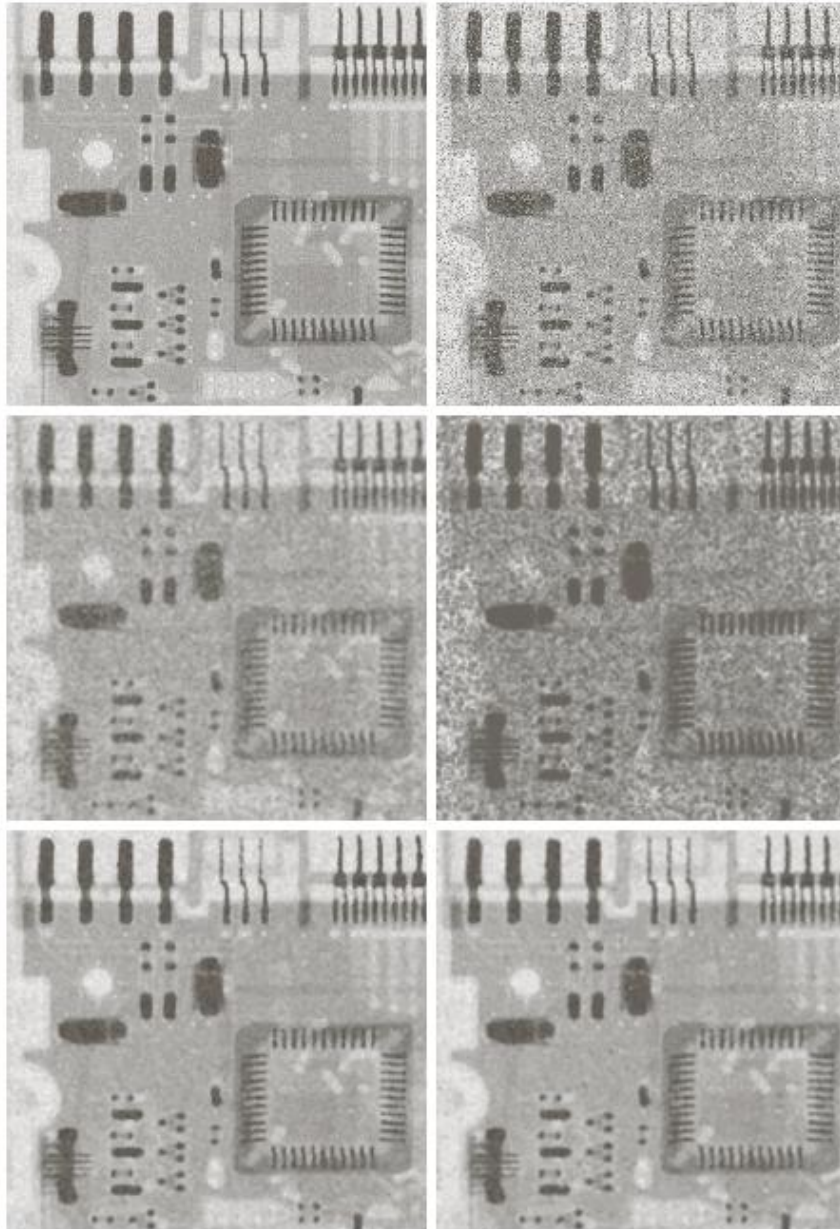




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tion

a	b
c	d
e	f

FIGURE 5.12

(a) Image corrupted by additive uniform noise.
 (b) Image additionally corrupted by additive salt-and-pepper noise.
 Image (b) filtered with a 5×5 ;
 (c) arithmetic mean filter;
 (d) geometric mean filter;
 (e) median filter;
 and (f) alpha-trimmed mean filter with $d = 5$.



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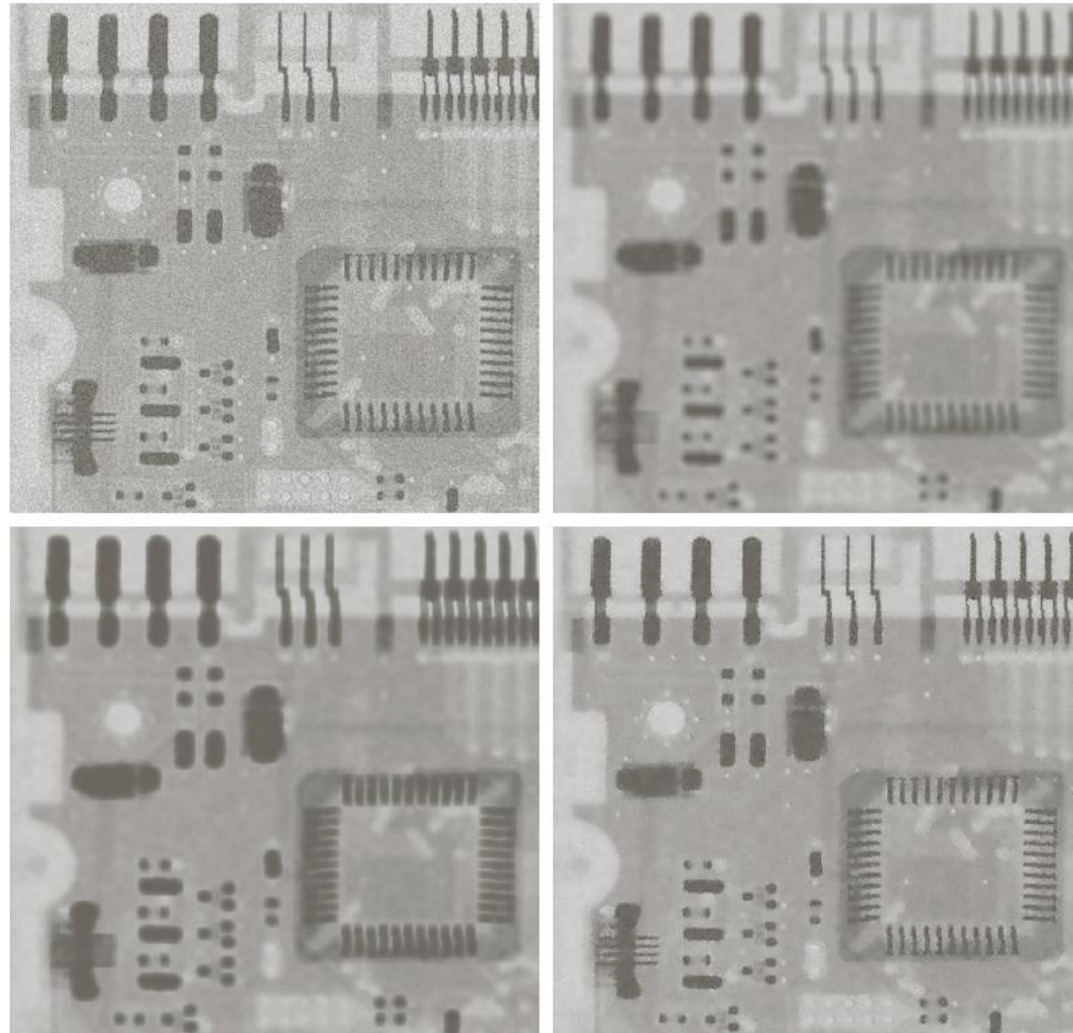
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a	b
c	d

FIGURE 5.13

(a) Image corrupted by additive Gaussian noise of zero mean and variance 1000.
(b) Result of arithmetic mean filtering.
(c) Result of geometric mean filtering.
(d) Result of adaptive noise reduction filtering. All filters were of size 7×7 .



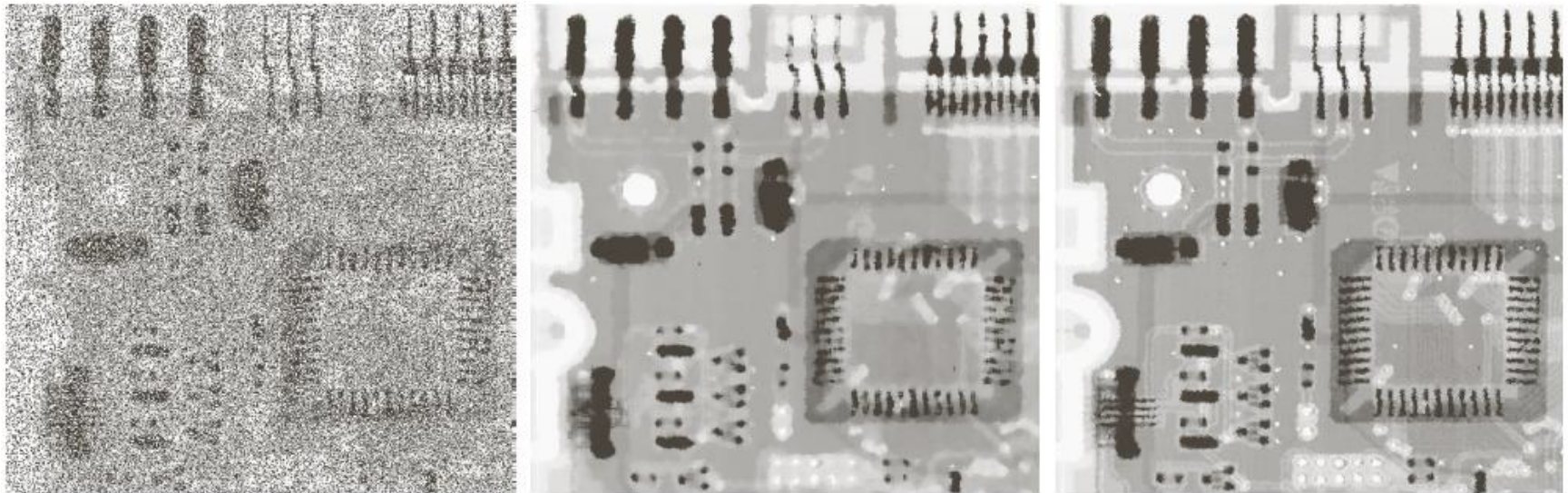


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a b c

FIGURE 5.14 (a) Image corrupted by salt-and-pepper noise with probabilities $P_a = P_b = 0.25$. (b) Result of filtering with a 7×7 median filter. (c) Result of adaptive median filtering with $S_{\max} = 7$.



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FIGURE 5.15 From left to right, perspective plots of ideal, Butterworth (of order 1), and Gaussian bandreject filters.



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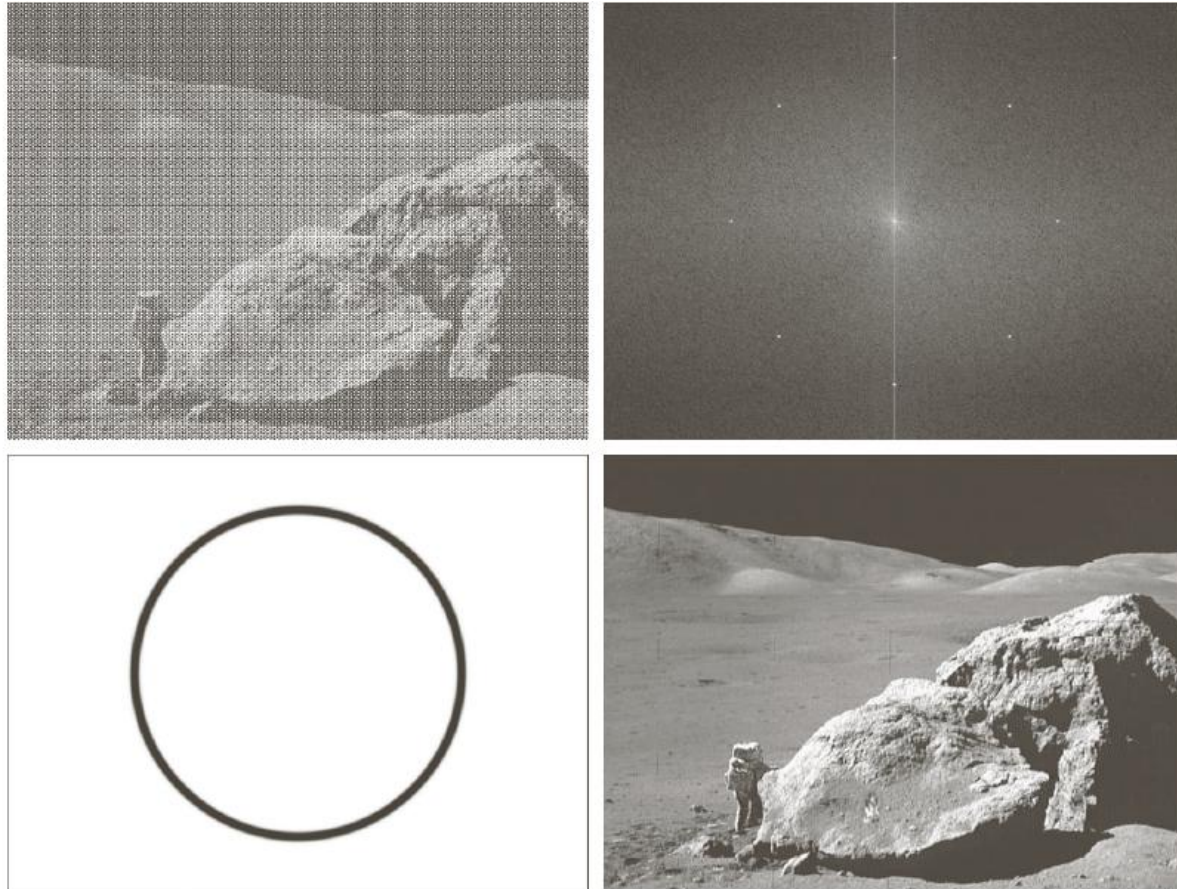
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a b
c d

FIGURE 5.16

(a) Image corrupted by sinusoidal noise.
(b) Spectrum of (a).
(c) Butterworth bandreject filter (white represents 1).
(d) Result of filtering.
(Original image courtesy of NASA.)





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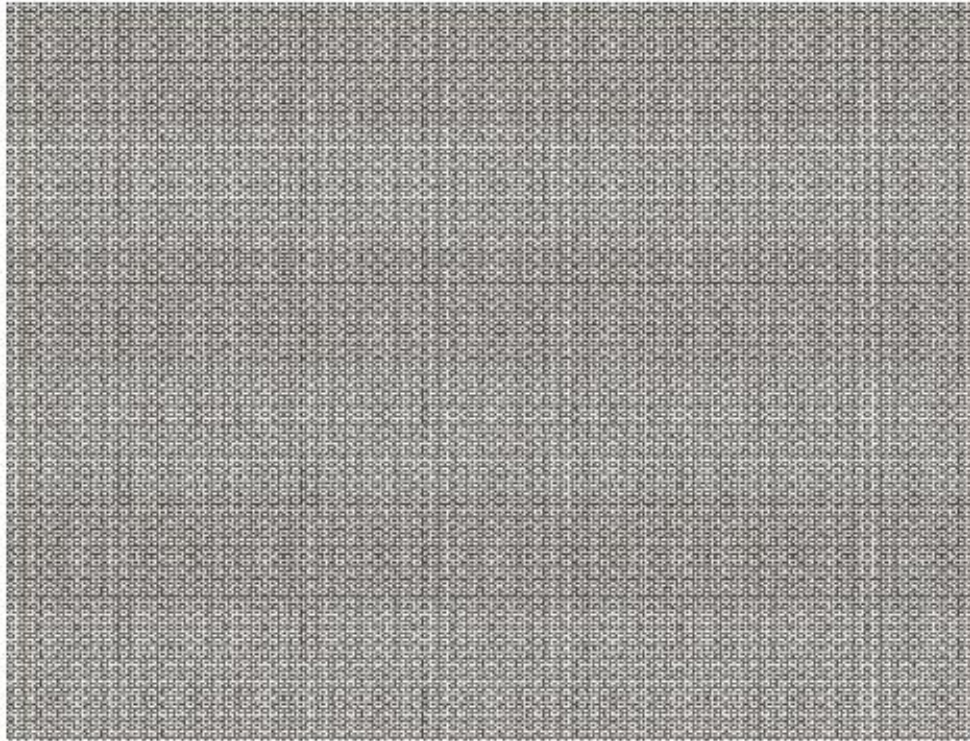


FIGURE 5.17
Noise pattern of
the image in
Fig. 5.16(a)
obtained by
bandpass filtering.



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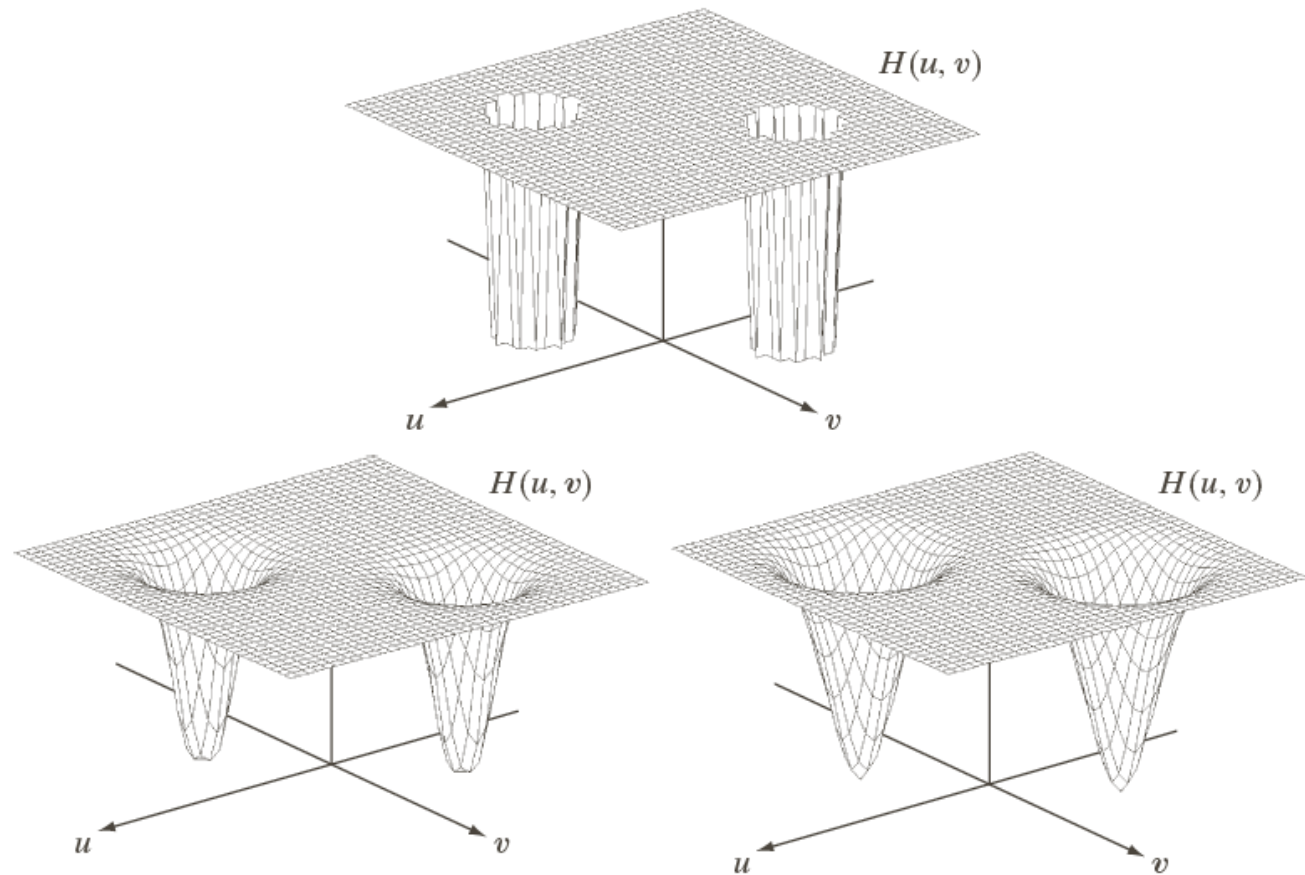
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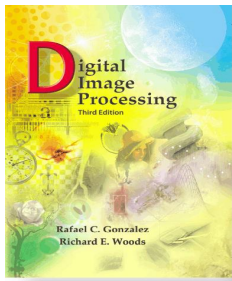
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a
b c

FIGURE 5.18

Perspective plots of (a) ideal, (b) Butterworth (of order 2), and (c) Gaussian notch (reject) filters.



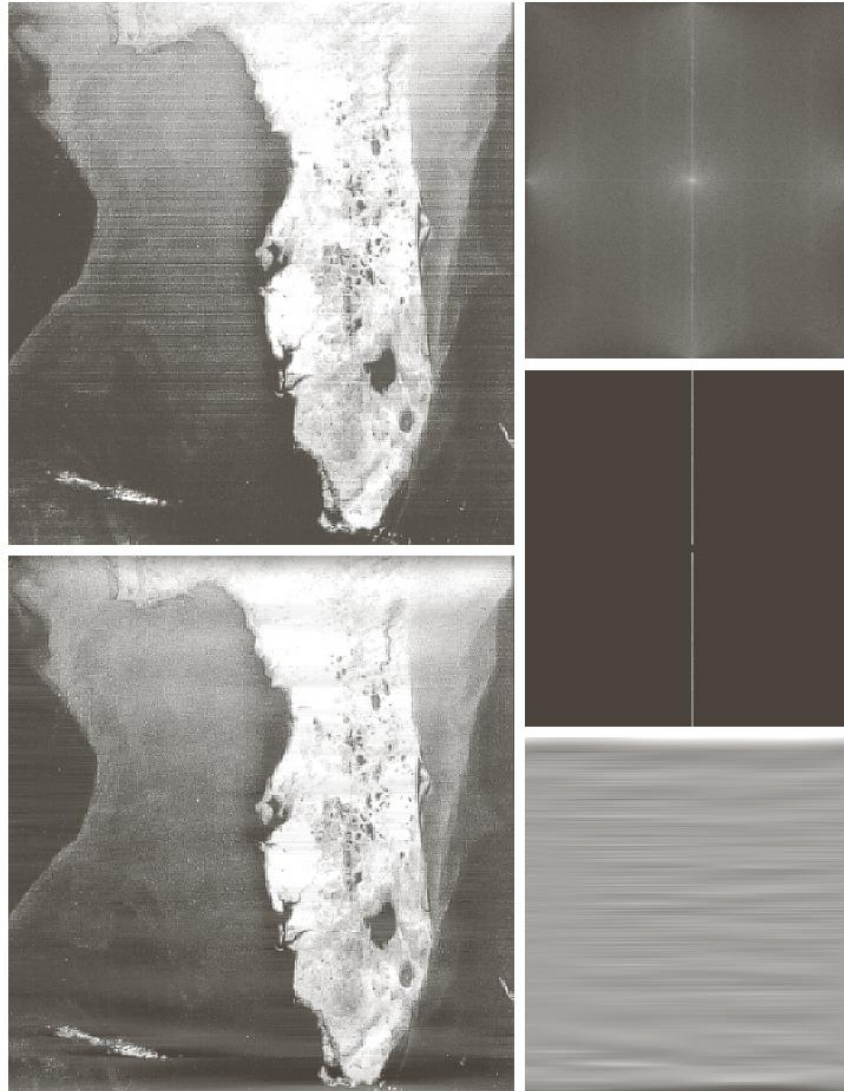


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a b
c
e d

FIGURE 5.19

(a) Satellite image of Florida and the Gulf of Mexico showing horizontal scan lines. (b) Spectrum. (c) Notch pass filter superimposed on (b). (d) Spatial noise pattern. (e) Result of notch reject filtering. (Original image courtesy of NOAA.)



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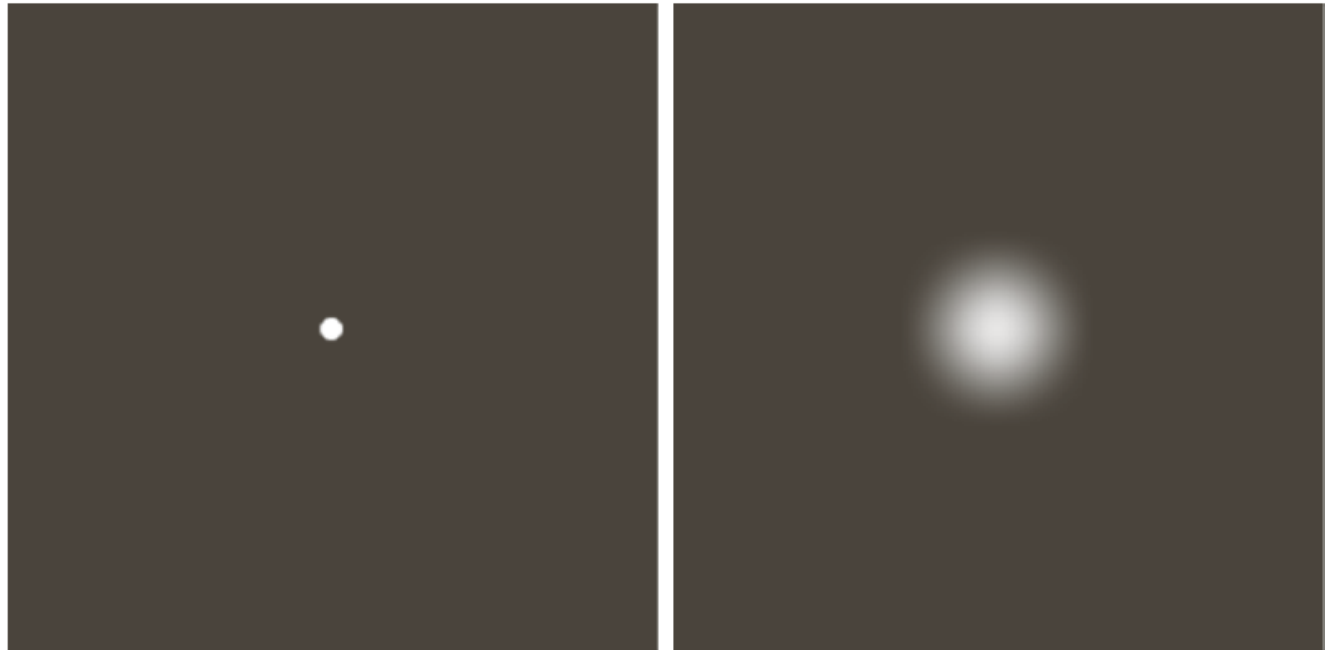
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a b

FIGURE 5.24

Degradation estimation by impulse characterization.
(a) An impulse of light (shown magnified).
(b) Imaged (degraded) impulse.





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a b
c d

FIGURE 5.25

Illustration of the atmospheric turbulence model.
(a) Negligible turbulence.
(b) Severe turbulence, $k = 0.0025$.
(c) Mild turbulence, $k = 0.001$.
(d) Low turbulence, $k = 0.00025$.
(Original image courtesy of NASA.)



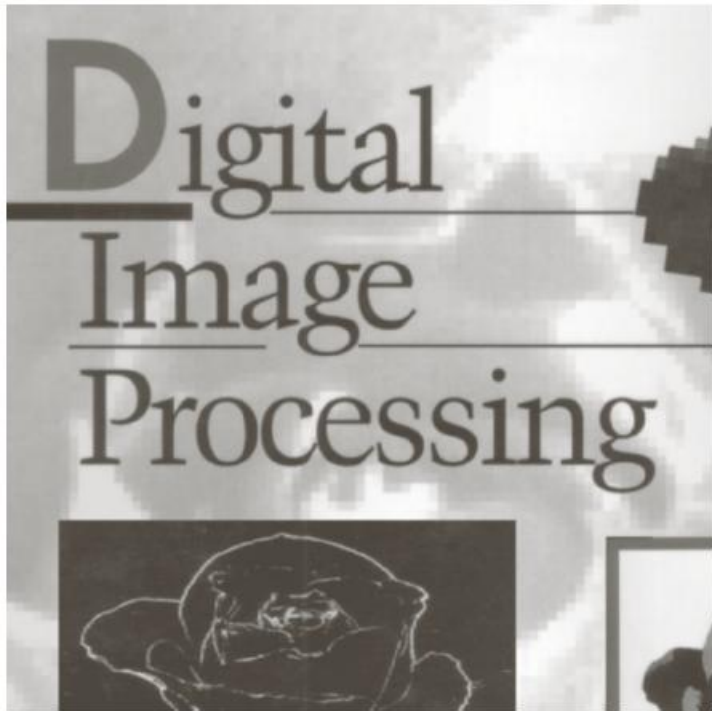


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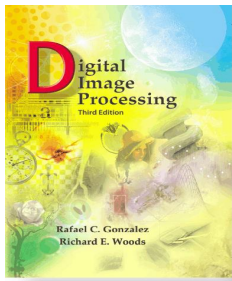
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a b

FIGURE 5.26

(a) Original image.
(b) Result of blurring using the function in Eq. (5.6-11) with $a = b = 0.1$ and $T = 1$.



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a	b
c	d

FIGURE 5.27

Restoring
Fig. 5.25(b) with
Eq. (5.7-1).
(a) Result of
using the full
filter. (b) Result
with H cut off
outside a radius of
40; (c) outside a
radius of 70; and
(d) outside a
radius of 85.





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a b c

FIGURE 5.28 Comparison of inverse and Wiener filtering. (a) Result of full inverse filtering of Fig. 5.25(b). (b) Radially limited inverse filter result. (c) Wiener filter result.



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a	b	c
d	e	f
g	h	i

FIGURE 5.29 (a) 8-bit image corrupted by motion blur and additive noise. (b) Result of inverse filtering. (c) Result of Wiener filtering. (d)–(f) Same sequence, but with noise variance one order of magnitude less. (g)–(i) Same sequence, but noise variance reduced by five orders of magnitude from (a). Note in (h) how the deblurred image is quite visible through a “curtain” of noise.