Simple Spatial Domain Filtering

- **Binary Filters**
- **Non-phase-preserving Fourier transform planes**
- **Simple phase-step filters (for phase-contrast imaging)**

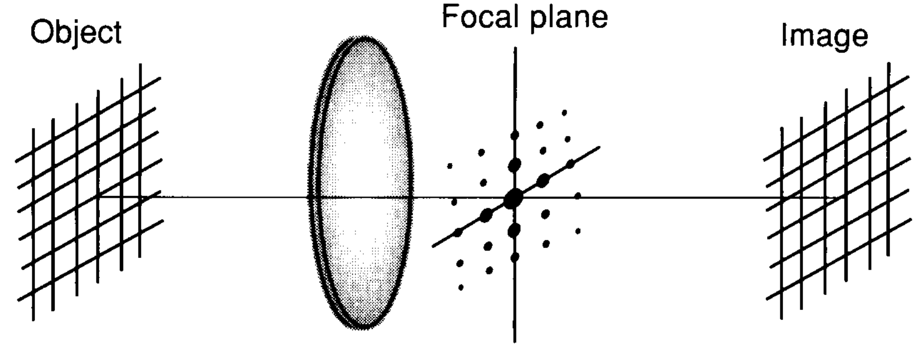


FIGURE 8.1
The Abbe-Porter experiment.

- **Amplitude "inverse" filters, related to apodization**
- **Contrast reversal if DC level is severely changed**

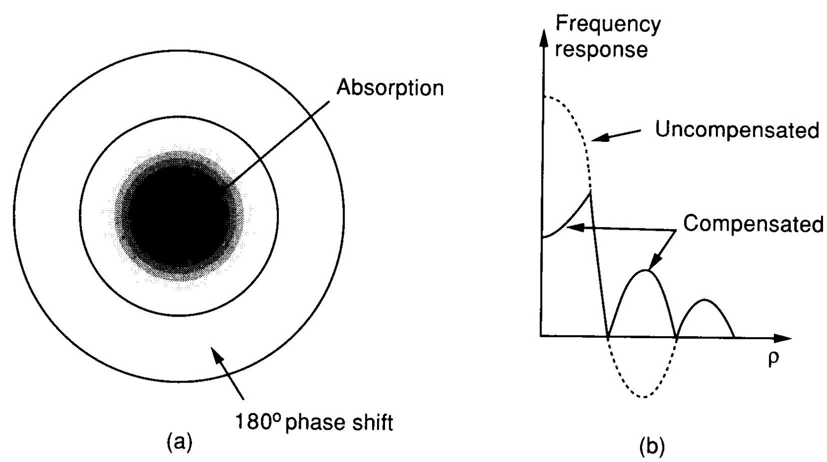


FIGURE 8.5
Compensation for image blur. (a) Focal-plane filter; (b) transfer functions.

Incoherent Processors

Convolution by "shadow casting" is the same as looking at a plane of misfocus for both inputs.

Top: scale is 1:1 between the two inputs.

Bottom: Image of input one is smaller that object 2 so scale factors include both the lens magnification of object 1 and the geometry of the rays between input 2 and the screen.

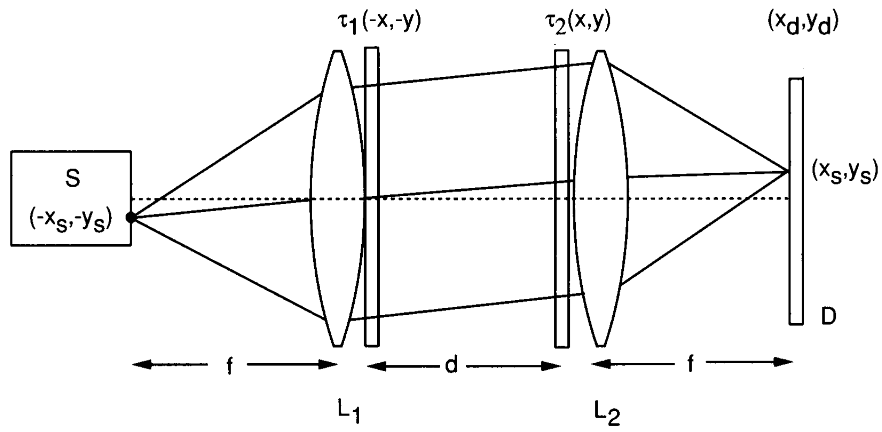


FIGURE 8.7
Systems for performing convolution without motion.

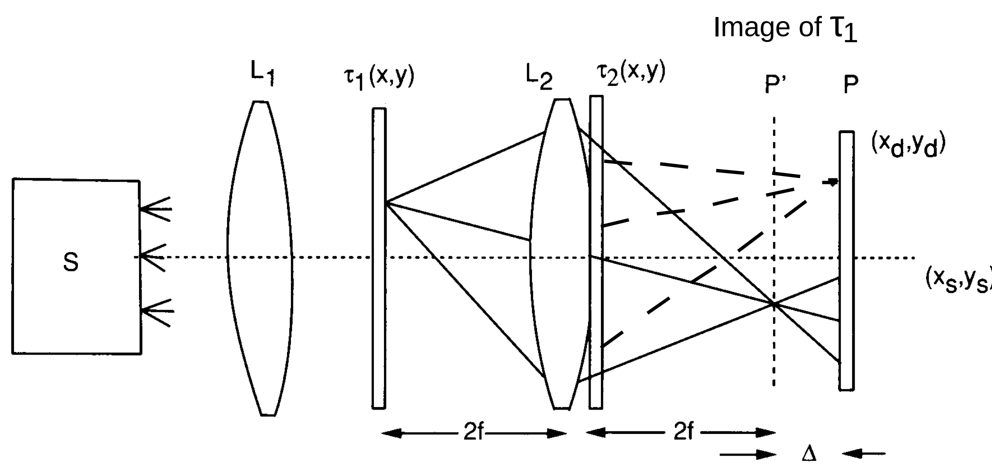


FIGURE 8.8
Impulse response synthesis with a misfocused system.

Fourier Transform Plane Filtering Configurations

1. 4-f processor, no phase errors.

2. Imaging processor, vignetting is a problem.

3. Fourier transform in converging wave with an imaging lens.

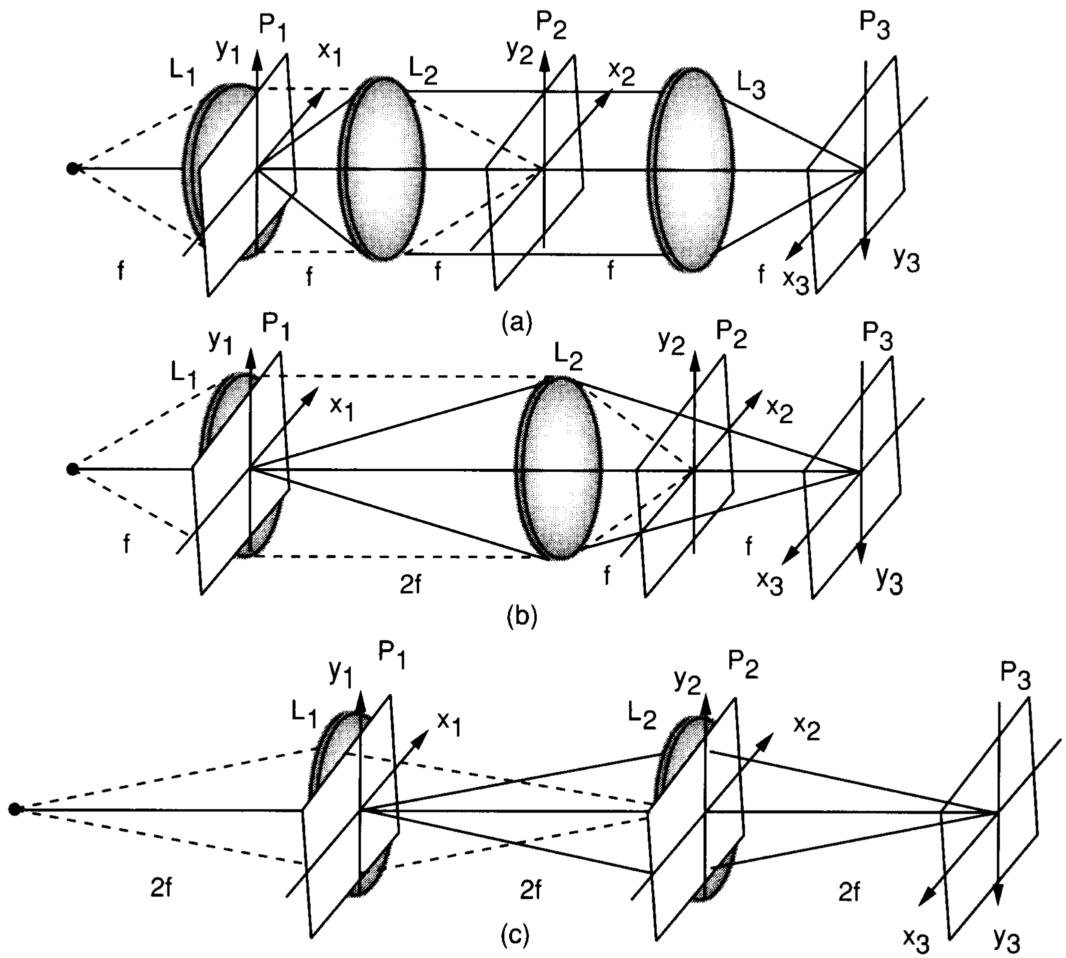


FIGURE 8.10
Architectures for coherent optical information processing.

Accessible Portions of the Complex Plane

Different filter synthesis strategies are able to access different portions of the range of complex values desired (magnitude ≤ 1 and all angles).

Phase is conventionally obtained through thickness or refractive index control, and magnitude through transmittance.

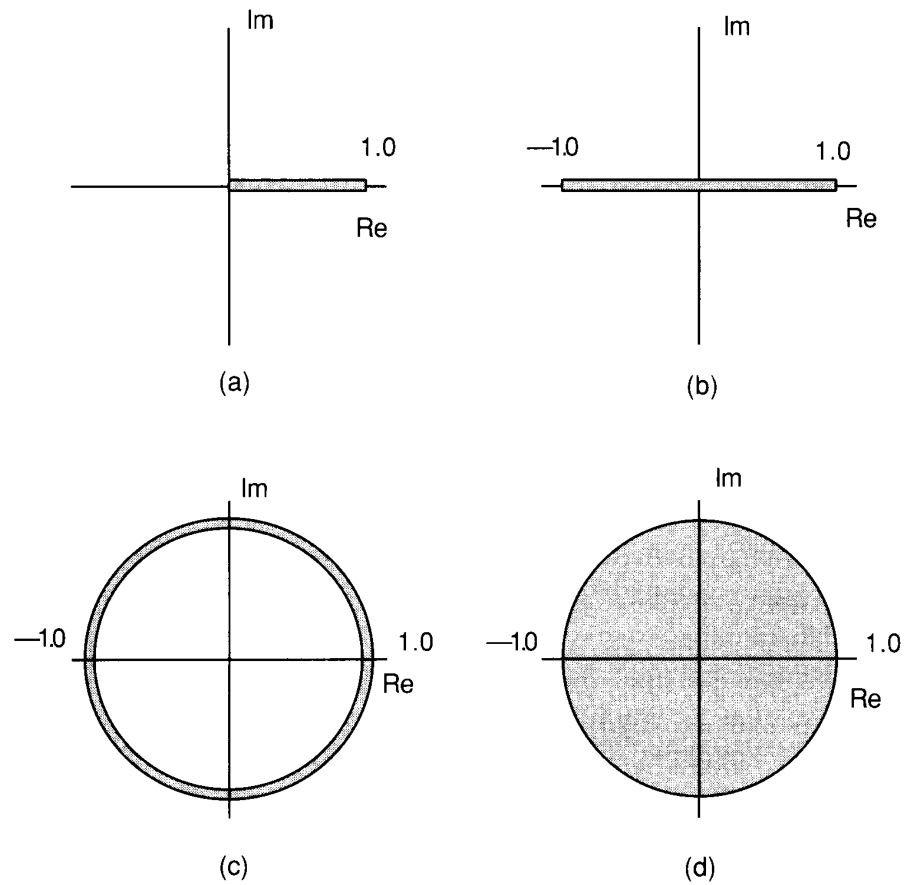


FIGURE 8.12
Reachable regions of the frequency plane for (a) a purely absorbing filter, (b) an absorbing filter and binary phase control, (c) a pure phase filter, and (d) a filter that achieves arbitary distributions of absorbtion and phase control.

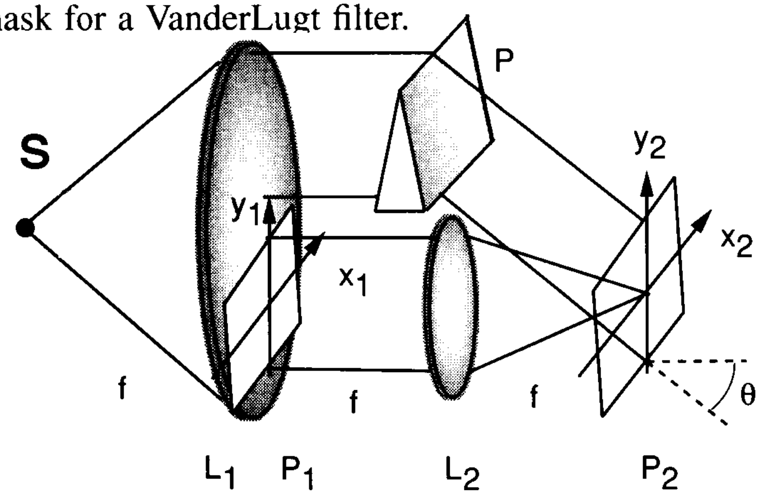
Synthesizing Complex Filters - VanderLugt Filter

Record a hologram of H (that is the F.T. of the impulse response h).

There are several ways to do this starting from h.

It is important to have the waves at an angle so as to later separate the terms in the output plane.

FIGURE 8.13
Recording the frequency-plane mask for a VanderLugt filter.



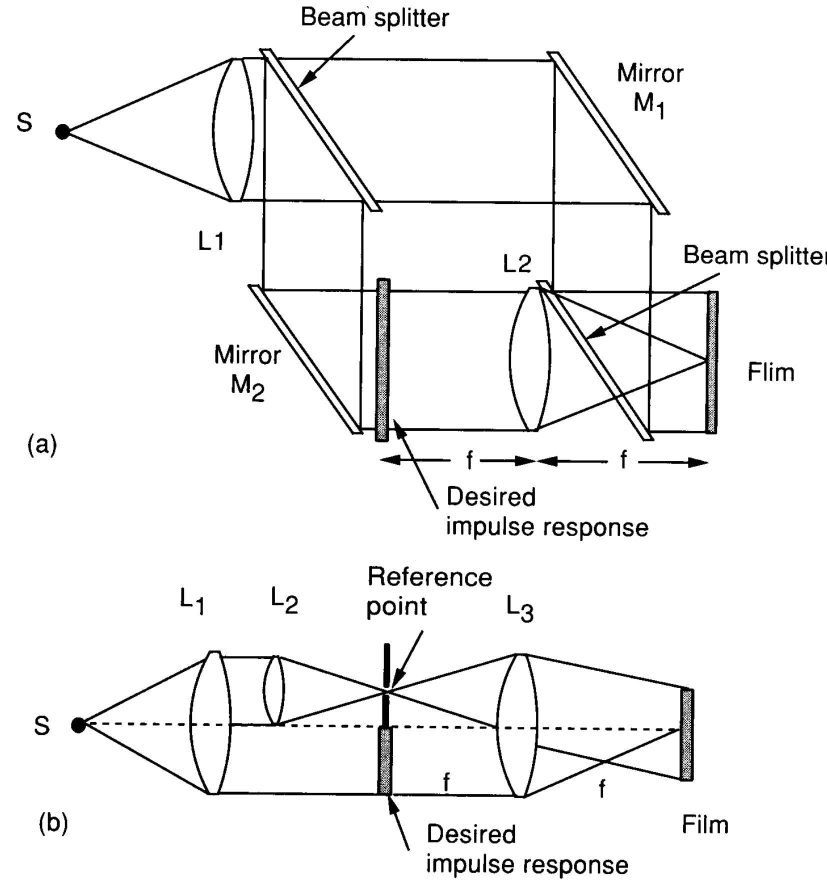


FIGURE 8.14
Two alternative systems for producing the frequency-plane transparency (a) Modified Mach-Zehnder interfereometer; (b) modified Rayleigh interferometer.

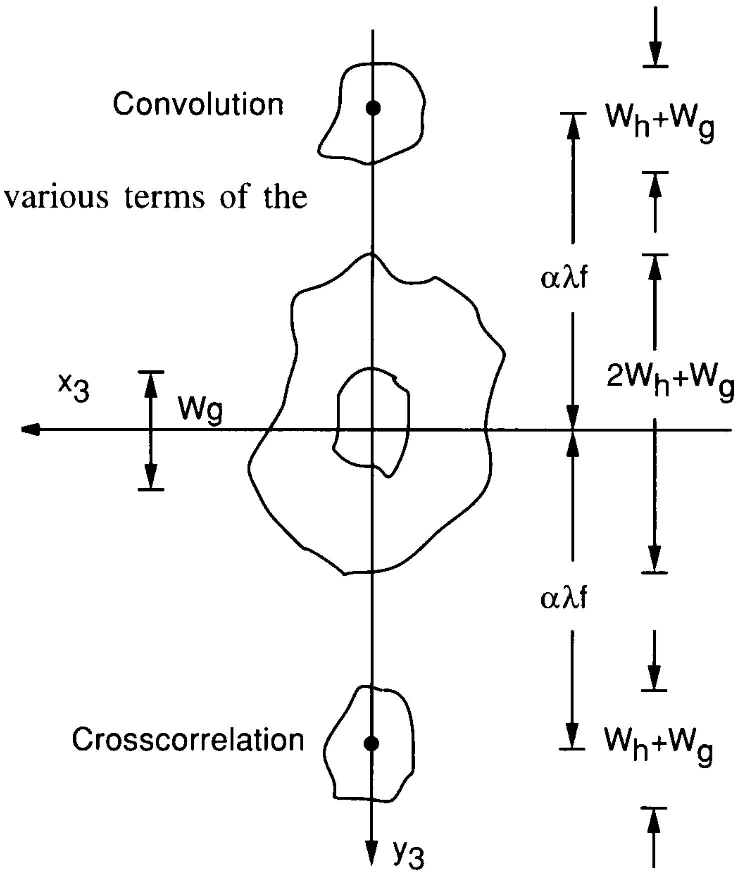
Result of a VanderLugt Filter in a 4-f Processor

• **The output plane of the 4-f processor has unwanted terms on axis.**

• **The (cross) correlation is diffracted in one direction. [No conjugate; actually the plane wave is conjugated to reverse its angle to the z-axis.]**

• **The convolution is diffracted in the opposite direction. [One term conjugated]**

FIGURE 8.15
Locations of the various terms of the processor output.



Joint Transform Correlator

In the joint transform correlator, the two space domain images are Fourier transformed first and then the illumination wave (after square law processing) is simply a plane wave.

The result is still a sum of terms, two of which are diffracted up and down and contain the desired product of the Fourier transforms. In this case, they are Fourier transformed again, in (b), to give the convolution image at two locations.

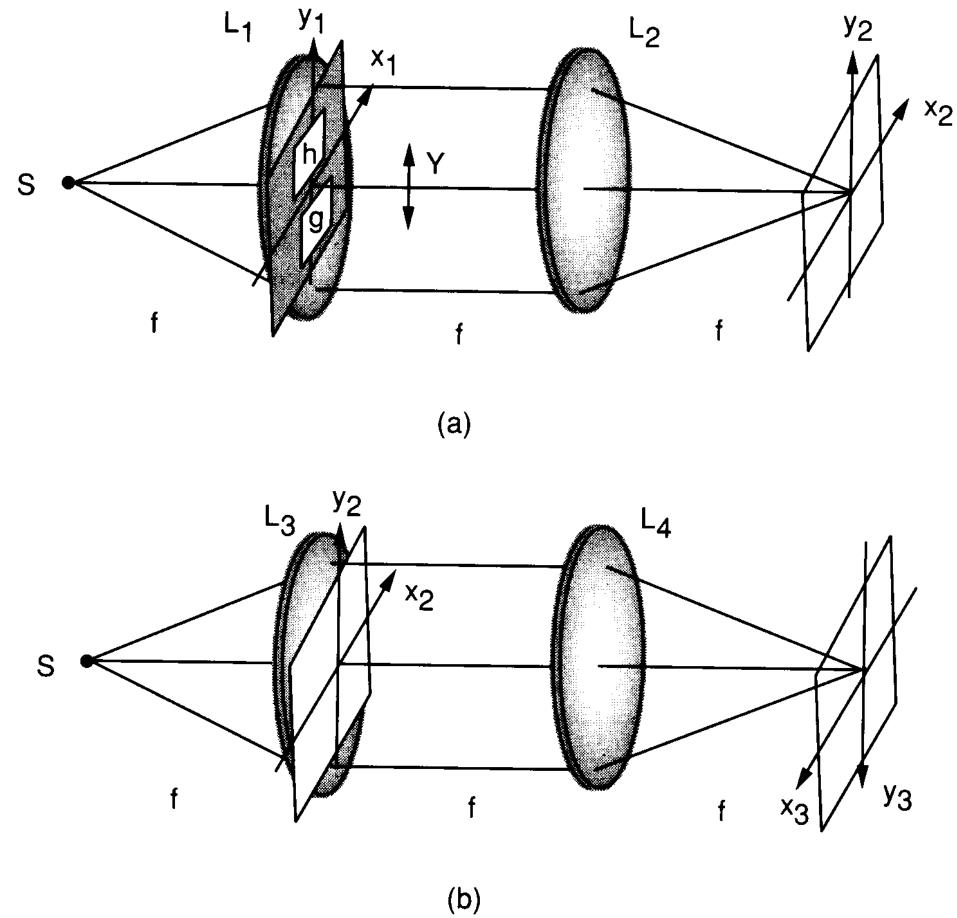


FIGURE 8.16
The joint transform correlator. (a) Recording the filter, (b) obtaining the filtered output.

Another Approach to Image Recognition: Matched Filtering

What wave when multiplied by a complex valued filter will give exactly a plane wave? The product of complex conjugates give a real value; and all real values have the same relative phase (I.e. a plane wave).

The plane wave then Fourier transforms to a point image indicating that the filter "recognized" the input object.

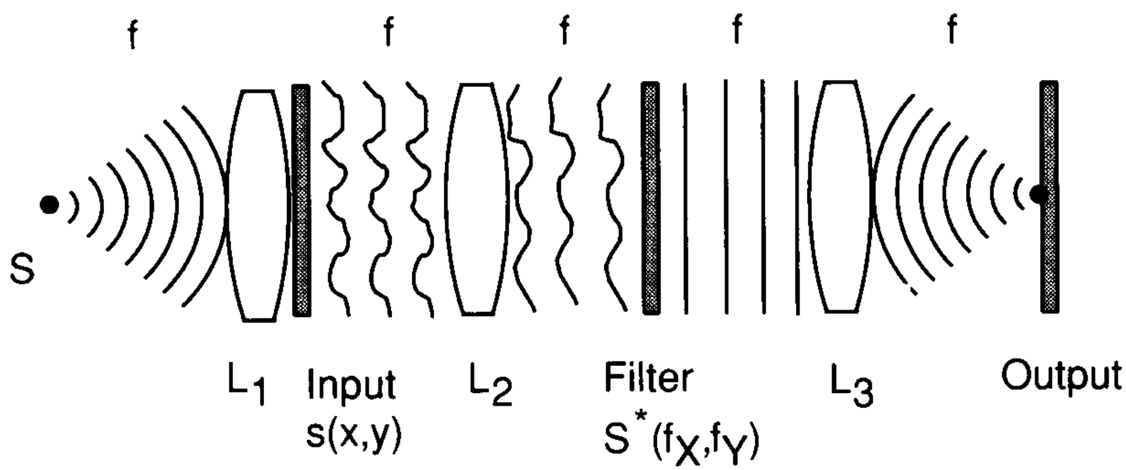


FIGURE 8.17
Optical interpretation of the matched-filtering operation.

Matched Filter Applied to Character Recognition

Synthesis of a VanderLugt filter with multiple objects in the impulse response.

The type of object is coded by position along the y-axis, so the location of the "recognition" or correlation spikes is also coded by position along the y-axis.

Image location is still mapped to the x-y plane (with some confusion possible in the y direction).

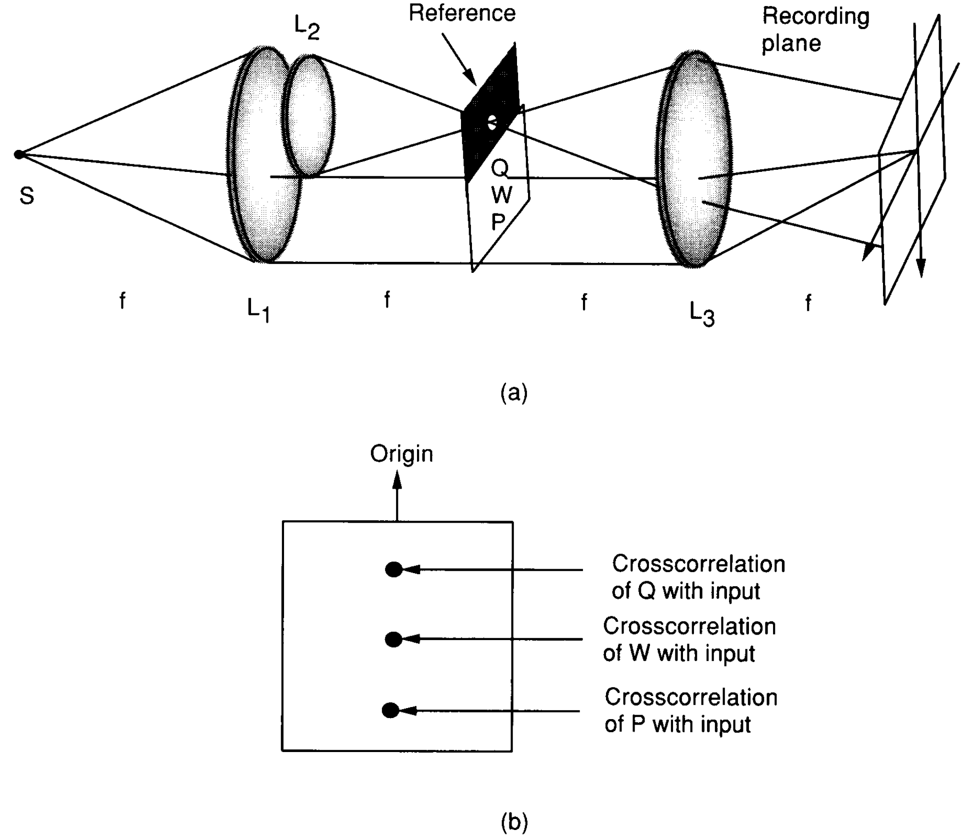


FIGURE 8.20
Synthesis of a bank of matched filters with a single frequency-plane filter. (a) Recording the frequency-plane filter; (b) format of the matched filter portion of the output.

Inverse Filter Applications

Inverse filter applied to un-do any unwanted effect. For example, you can correct:

1. Misfocus
2. Motion blur
3. Raster lines
4. High or low frequency enhancement

Problems with inverse filtering:

- Zeros in original transfer function gibe poles in the inverse filter
- Noise can easily corrupt the result near poles

Solution - Weiner filter

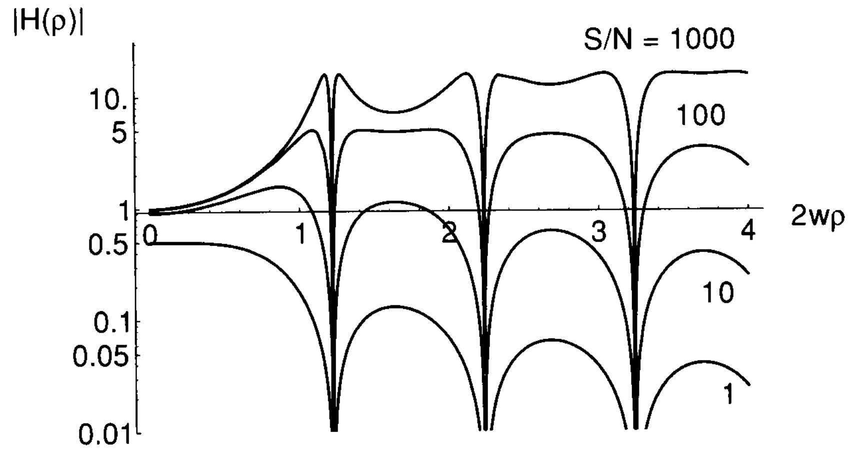


FIGURE 8.21
Magnitudes of the transfer function of a Wiener filter. The image is assumed to have been blurred by a point-spread function consisting of a circular disk of radius w. The signal-to-noise ratio is varied from 1000 to 1. The phase of the filter changes between 0 and π radians between alternate zeros of this transfer function.

A second problem arises if you do not know the original h or H. Then you have to estimate the inverse filter.

Acousto-Optic Modulators

A-O Modulator converts a voltage waveform to a 1-D moving spatial (refractive index) image.

• Piezoelectric transducer converts voltage to a travelling acoustic wave

• Acoustic wave is a moving refractive index variation

• Incident light is multiplied by the moving phase grating (thin - Raman-Nath regime or thick - Bragg regime)

Fourier transform of A-O cell gives power spectrum of input signal

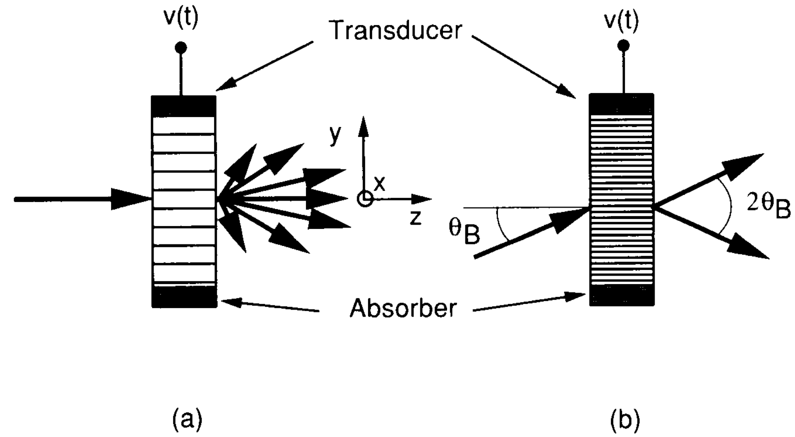


FIGURE 7.26
Acousto-optic cells operating in the (a) Raman-Nath regime and the (b) Bragg regime.

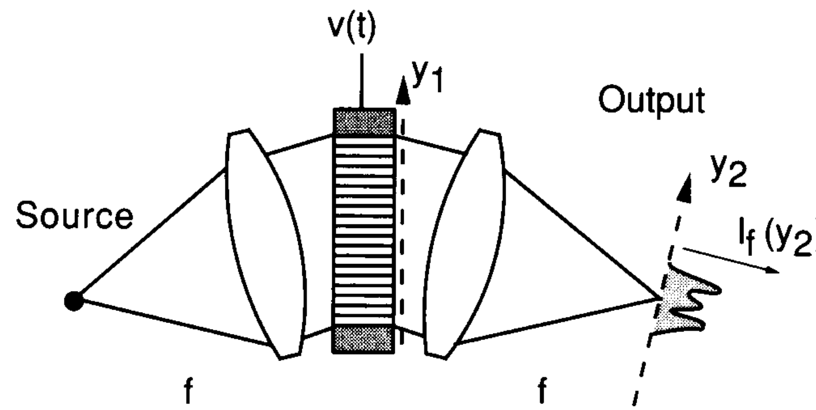


FIGURE 8.33
Bragg cell spectrum analyzer.

Acousto-Optic Signal Processing Examples

Shown here:

1. A-O cell is imaged (first order only) onto a static transparency (with a phase grating also). Single square-law detector gives correlation as a function of time.

2. In this case, a -1 order from each A-O cell is selected in the Fourier transform plane. The two signals interfere (heterodyne) in a detector array. The correlation is now a function of space (averaged over the detection time or the "time window" of the A-O cells).

3. Also possible are "triple product" processors in time or frequency

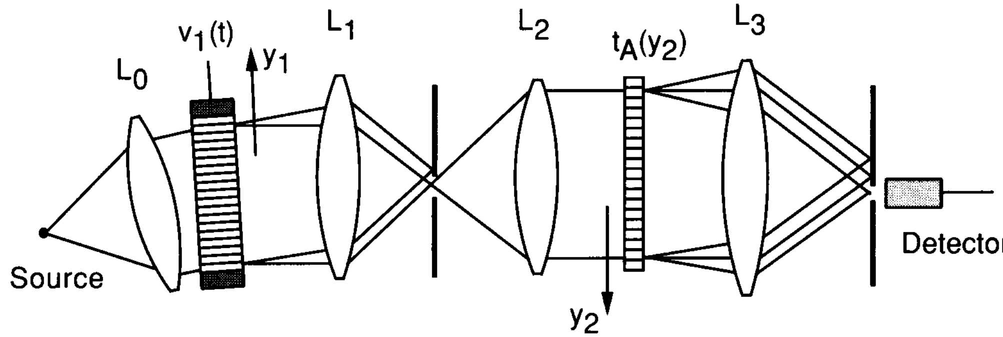


FIGURE 8.34
Acousto-optic space-integrating correlator.

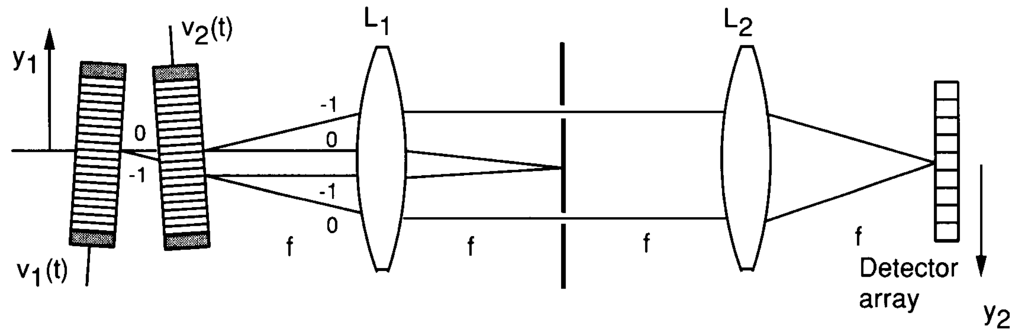


FIGURE 8.35
Time-integrating correlator.