OPTICAL TECHNIQUES FOR IMAGE SYNTHESIS IN RADIO ASTRONOMY

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I. Introduction

The complex visibility $\hat{\mu}(u,v)$ obtained from a correlation interferometer telescope allows one to visualize the brightness of the sky $B(x,y)$ thanks to the VAN CITTERT-ZERNIKE theorem(1). $B(x,y)$ is obtained by the Fourier transformation of $\hat{\mu}(u,v)$. This mathematical operation can be performed by either a digital computer (i.e., FFT) or a analog computer (i.e., coherent optical processor). The first is well known to radioastronomers. It is used when the amount of data is limited. When the amount of information is very large, the analog computer can save a lot of time in the processing of these informations. The optical processor is attractive if the accuracy of the "optical operation" is equivalent to the accuracy of the data obtained from the telescope and if the concept of time accuracy is introduced to compare the cost effectiveness of the process.

When a coherent beam is diffracted by a two dimensional transparency $f(u,v)$ the amplitude distribution observed at infinity is

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(1) See for example Born & Wolf, Principles of Optics, Chapter 10.4 "partially coherent light".

proportional to the Fourier Transform of f(u,v)

$$F(x,y) \alpha \text{ F.T.}[f(u,v(] \alpha \iint_{-\infty}^{+\infty} f(u,v) \exp j2\pi(ux,vy)\, dudv.$$

The lens, which is introduced in optical computers, is used to bring this distribution to focus in the back focal plane. It is called a Fourier transform lens (F.T.) but it only focusses the light.

<u>How to obtain an exact optical Fourier transform?</u> In optics there is a Fourier transform relationship between the exit pupil of a lens and an image surface. The location of the Fourier domain (image surface) depends on the type of illumination. With a thin lens and a transparency adjacent to it, Figure 1a, the complex amplitude distribution observed in the image plane is proportional to the Fourier transform of the transparency. It is, however, multiplied by a spherical phase factor. If (u,v) are the coordinates in the exit pupil, t(u,v) the amplitude distribution in this plane, and (x,y) are the coordinates in the Fourier plane, the amplitude distribution in the output plane is:

$$a_1(x,y) = \frac{j}{\lambda z_o} \exp\left\{-j \frac{\pi}{\lambda z_o}(x^2+y^2)\right\} \iint_{pup} t(u,v) \exp\left\{j\frac{2\pi}{\lambda z_o}(ux+vy)\right\} dudv.$$

The spherical phase factor can be determined and corrected either by a corrector plate (field flattener), a spherical sensor instead of the classical flat area detector or by introduction of a spherical reference wave.

Many authors$^{(2)}$ have shown that it is possible to obtain an exact Fourier transform in the back focal plane of a lens when the transparency

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(2) See for example "Optical Holography" R. J. Collier <u>et al.</u> Chap. VI, pp. 112-136, Academic Press, New York 1971.

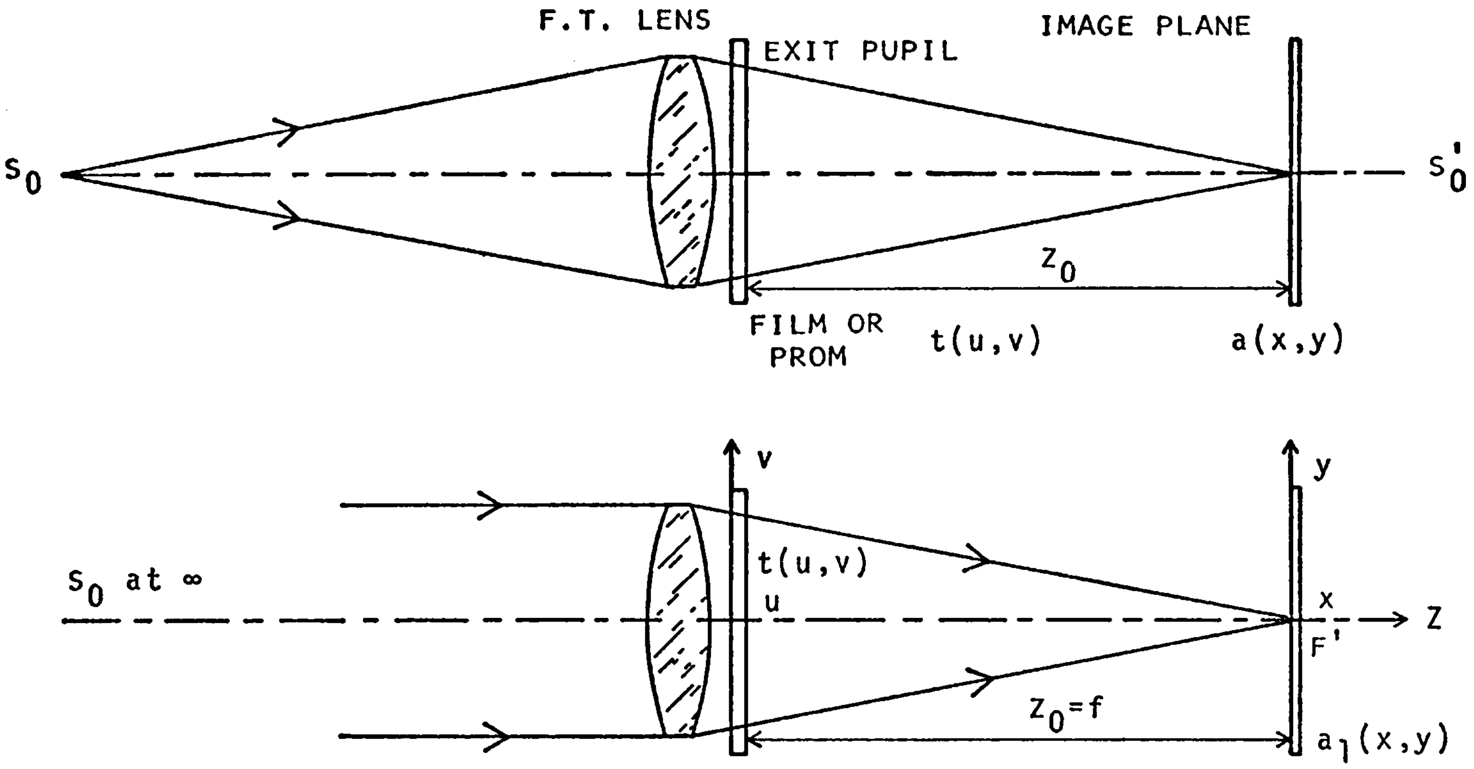

Figure 1a. $a_1(x,y)=\frac{j}{\lambda z_0}\exp\left\{-\frac{j\pi}{\lambda z_0}(x^2+y^2)\right\}\iint t(u,v)\exp\left\{j\frac{2\pi}{\lambda z_0}(ux+vy)\right\}dudv$

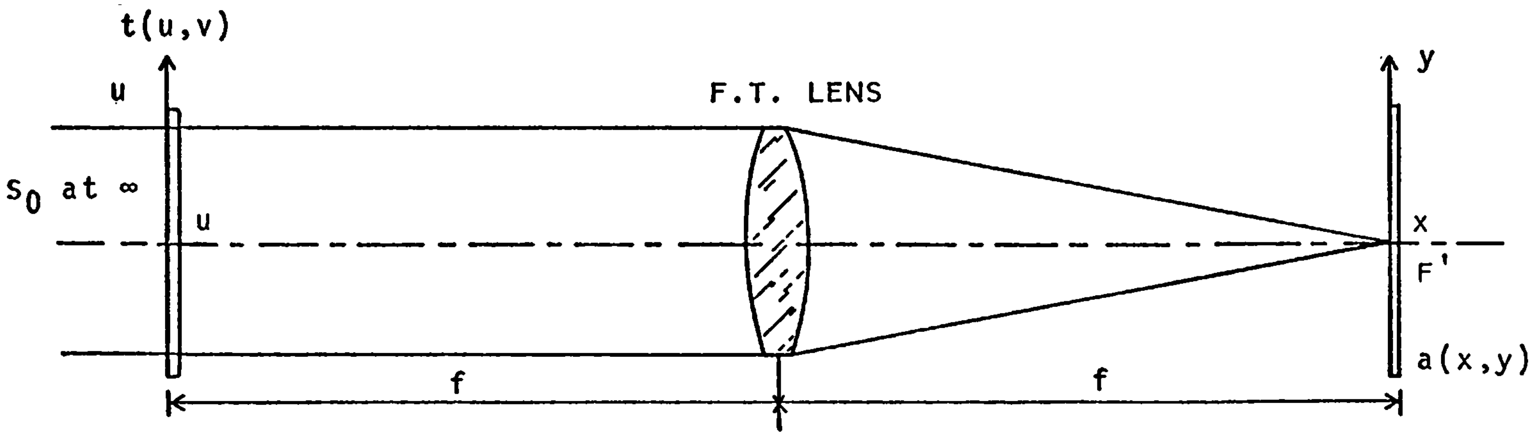

Figure 1b. $a_2(x,y)=\frac{j}{\lambda f}\iint_p t(u,v)\exp\left\{j\frac{2\pi}{\lambda f}(ux+vy)\right\}dudv.$

t(u,v) is in the front focal plane and the illuminating beam is a plane monochromatic wave (Figure 1b). In that case the phase factor is avoided and a(x,y) is:

$$a_2(x,y) = \frac{j}{\lambda f} \iint_{pup} t(u,v) \exp \{j\frac{2\pi}{\lambda f} (ux+vy)\} dudv.$$

Many processors work with this configuration. If B'(x,y) is the radio brightness, the image B(x,y) is:

$$B(x,y) = B'(x,y) \circledast h(x,y), \text{ (} \circledast \text{ indicates convolution)}$$

where h(x,y) is the impulse response of the aperture synthesis correlation telescope.(*) This h(x,y) is positive and negative. The photodectors can not distinguish the difference because they respond to $|B(x,y)|^2$.

II. Linear Output Maps

To avoid this problem, a holographic technique can be used. The amplitude distribution B(x,y) can be obtained two ways if we introduce a reference wave R(o,o) to the Fourier domain. In the input plane one has:

$$\hat{\mu}(,v) + r(o,o)$$

in the Fourier Plane, the power spectrum is:

$$I = |F.T.[\hat{\mu}(u,v)] + F.T.[r(o,o)]|^2$$

$$I = |B(x,y)|^2 + |R|^2 + 2RB(x,y)$$

if the phase $\phi_B = \phi_R + 2n\pi$

(*) The effect of the convolution by h(x,y) can be cancelled by deconvolution made in a computer or by means of an adapted optical filtering if the impulse response of the radiotelescope is known and stationary.

Let us consider the last equation; there are two cases:

Case (1): We have at time t_1 and intensity distribution

$$I_1 = |B|^2 + |R|^2 + 2RB$$

and at time t_2 by means of a π phase shift

$$I_2 = |B|^2 + |R|^2 - 2RB$$

These intensities are stored and the difference $I_1 - I_2$ gives:

$$I = I_1 - I_2 = 4\ R.B(x,y)$$

B(x,y) is then obtained after calibration; $4R_o$ is known.

Case (2): We can record and store $I_1 = |B(x,y)|^2 + |R|^2$. If $I_2 = |B(x,y)|^2 + |R|^2 + 2R.B(x,y)$ is also stored, the difference $I_2 - I_1$ gives:

$I = 2R.B(x,y)$ without phase shifting.

For both, the difference $I_1 - I_2$ is made with an electronic device and the signal RB(x,y) which can be $\gtrless 0$ in the (x,y) plane is carried by the electric signal. Thus, a bipolar map is obtained with the analog optical processor.

To obtain an exact Fourier transform, it is absolutely necessary to avoid all aberrations. The accuracy of the transform can be defined by means of the Strehl ratio. When aberrations are very small ($W_p \leq \lambda/10$) the Strehl ratio is defined by(3)

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(3) See in appendix Note 1; Aberration function and accuracy in the Fourier plane.

$$i(p) \approx 1 - (\frac{2\pi}{\lambda})^2 \; (W_p)^2$$

where $(W_p)^2$ is the mean square deformation of the wavefront. $i(p)$ is the normalized intensity at P, its value is 1 only if the aberrations W_p are negligible. Figure 2 shows the variation of the normalized intensity as a function of r.m.s. phase aberration.

The value $i(p) = 0.99$ corresponds to $(W_p)_{rms} = \lambda/62.8$

$i(p) = 0.98$ corresponds to $(W_p)_{rms} = \lambda/44.5$

Thus, the required accuracy (e.g. 1%) determines the allowable aberration. This means that the aberrations introduced by all optical components must be very small if we are to transform data accurately.

III. Processors-Configurations and Aberrations

To determine the specifications for the Fourier transform lens and the best optical configuration, it is necessary to know which transducer will be used to introduce $\hat{\mu}(u,v)$. Indeed the spatial bandwidth of the information is connected with the space bandwidth product of the transducer. The optical performance of the F.T. lens are related to the width of its bandpass. See for example the specifications reported in the Table 1.

The aberrations can be very small if the number of optical elements is minimized and if the bandpass is limited. To have W_{rms} less than $\lambda/62.8$ the aberrations of each component

(i) must be very small

or (ii) must be optically cancelled

or (iii) must be well corrected

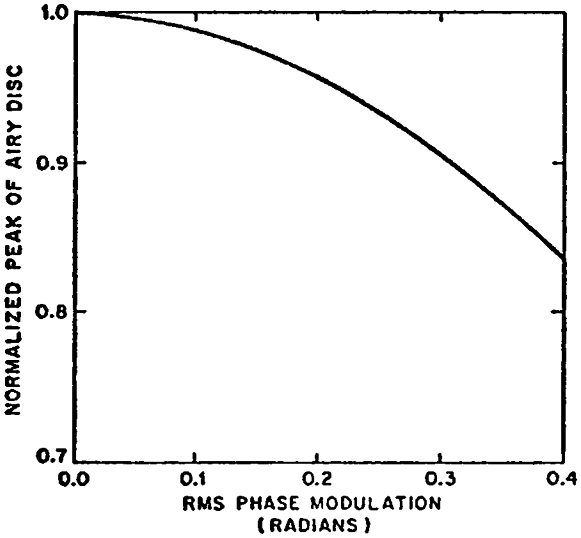


Figure 2. Falloff in focal-point light intensity as a function of rms phase modulation.

	λnm	v	sinΘ	f(mm)	A(mm)	B	B^2	Image Quality Peak to Valley
Tropel 700-6338	632.8	76	0.0481	609.0	58.5	4.44×10^3	1.9×10^7	$\lambda/8$
710-6338		90	0.0570	861.	98.2	8.8×10^3	7.74×10^7	$\lambda/4$
Harris Design[2]	500	150	0.075	1000	150.0	2.25×10^4	5.06×10^8	$\lambda/4$
Wynne's Designs[3,4]	633	47.4	0.033	1000	60.0	2.84×10^3	8.07×10^6	0.14λ
" Steel - Doublet[3,4]	"	63	0.040	500	40.0	2.5×10^3	6.25×10^6	0.16λ
Steel Triplet[5]		63	0.040	500	40.0	"	"	0.25λ
Perkin Elmer	632.8	200	0.062	600	40	$8. \times 10^3$	6.4×10^7	$\lambda/20$ rms
Perkin Elmer	632.8	100	0.062	600	40	$4. \times 10^3$	1.6×10^7	$\lambda/20$ rms

TABLE 1

References:

1. K. vonBieren Appl. Opt. 10, 2738, (1971).
2. T. Harris, Haverford Conference, June 1975.
3. C. G. Wynne I Optics Communications, 12, 266, (1974).
4. " II " " , 12, 270, (1974).
5. W. H. Steel, Journal of Optics 2, 36, 1974.
6. E. C. Fox, R. C. A. Review 33, 131 (1972).
7. A. L. Flamholz, IBM Journal of R&D 17, 509 (1973).

(i) Depends on the designer and on the manufacturer;

(ii) Depends on the optical configuration (plane or spherical reference wave, cross-product, aberration cancelled if the signal and reference wave both pass through the F.T. lens).

(iii) Depends on the possibility of using a good corrector plate (field flattener and compensator to correct the spherical aberration and the beam splitter aberrations...). It also depends on the possibility of a servoed aberration correction introduced by means of the input transducer. For example, one transducer is currently being developed with this feature.

Present users of the optical computer do not require an absolute accurate for the amplitude distribution in the Fourier plane. For most users, a relative value of the power spectrum is sufficient and the commerical state-of-the-art reflects this fact. The existing state-of-the-art can support the optical perfection required of the coherent optical computer. It will be necessary to experimentally demonstrate and evaluate this when new transducer data becomes available(*). Current data about the Coherent Light Value (CLV); the Pockel's Readout Optical Modulator (PROM) and the photosensitive materials or photographic emulsions (P.E.)

(*) The up to date information and reasonable prospects will be given by General Electric for CLV and by Itek Corp. for PROM in the next months (November or December, 1975).

are given in Table 2. These data reflect the user interest in power spectrum; they are not sufficient for our application. These transducers are being rapidly improved and will be suitable for use in an accurate optical computer in the near future.

The choice of the transducer determines the Fourier transform lens and the optical configuration. In the absence of the future data concerning the transducers it is necessary to consider several different optical configurations for each transducer. The chief point is: the aberrations introduced by all components have to less to $\lambda/62.8$. In the note 2, see appendix, the different components which are generally used in a diffraction setup are briefly described. It points out that the most important aberrations are introduced by:

- the collimator
- the beam splitter, if it is put between the input and the output planes;
- the transducer
- the Fourier transform lens

The effects of these aberrations are not equivalent, they depend on the configuration adopted for the coherent optical processor.

Table No. 3 gives an idea of the different components which can be used with each transducer, but to discuss these components it is necessary to specify the optical configuration.

	C.L.V.	P.R.O.M.	Photosensitive Materials
Modulation	Phase	Amplitude or phase	Amplitude or phase
Optical Aperture	Now 20 x 20 mm Near future 26 x 26 mm	30 x 30 mm 40 x 40 mm	very high unlimited
Resolution (linear)	now 50 c/mm near future ≃ 125 c/mm	coherent recording 580 c/mm incoherent imaging 100 c/mm	> 10^3 c/mm
Space Bandwidth	$10^5 - 10^6$	10^7	> $10^9 - 10^{10}$
Dynamic Range	40 - 50 dB	60 dB	30 - 40 dB*
Linearity	Good	Good	Fair
Modulation raster	Electron beam (electronic supply)	Laser beam (mechanical or acousto-optical device)	Electron beam (EBR) or laser beam (LBR)
Carrier frequency	2.5 to 3 cycles/samples	3 to 4 c/s	10 c/s or more
Raster	dynamic (decay time)	Dynamic	Dynamic or stationary
Aberrations	Oil film + substrate vacuum windows (unknown)	Crystal $\lambda/20$ rms can be polished like glass, coating + polarizer	Film + substrate + liquid gate with 2 liquids ≃ $\lambda/20$ rms
Correction	Can be corrected by a servo control of the phase	Can be reduced by polishing of the crystal	Can be reduced by polishing of the substrate and the windows and/or by a servo in the case of E.B.R.
Bandpass of the F.T. Lens (c = cycle/mm)	100 c (20 x 20) 76 c (26 x 26)	66 c (30 x 30) 50 c (40 x 40)	50 c (40 x 40) 40 c (50 x 50)
Lifetime	1000 hours or more	No known limit	Unlimited
Optical Setup	F plane at 1 f. with a complex lens and a beam splitter	F plane at 1f, 2f or anywhere with a simple or complex lens	F plane at 1f, 2f or anywhere with a simple or complex lens

* The optical computers using a liquid gate in radar processing have a dynamic range for all components about 70-80 dB.

TABLE 2

TRANSDUCERS	CLV	PROM	PHOTO. MAT.
Modulation	Phase	Phase or amplitude	Phase or amplitude
Real Time	Yes	Yes	No
Collimator	1	1 or 0	1 or 0
Add. Lens	0	1 or 0	1 or 0
Beam Splitter	1	0 or mirror	0
Bandpass F. T. Lens	100 c/mm 75 c/mm	66 c/mm 50 c/mm	50 c/mm 40 c/mm
F. T. Lens	Complex	Fair / Simple	Simple

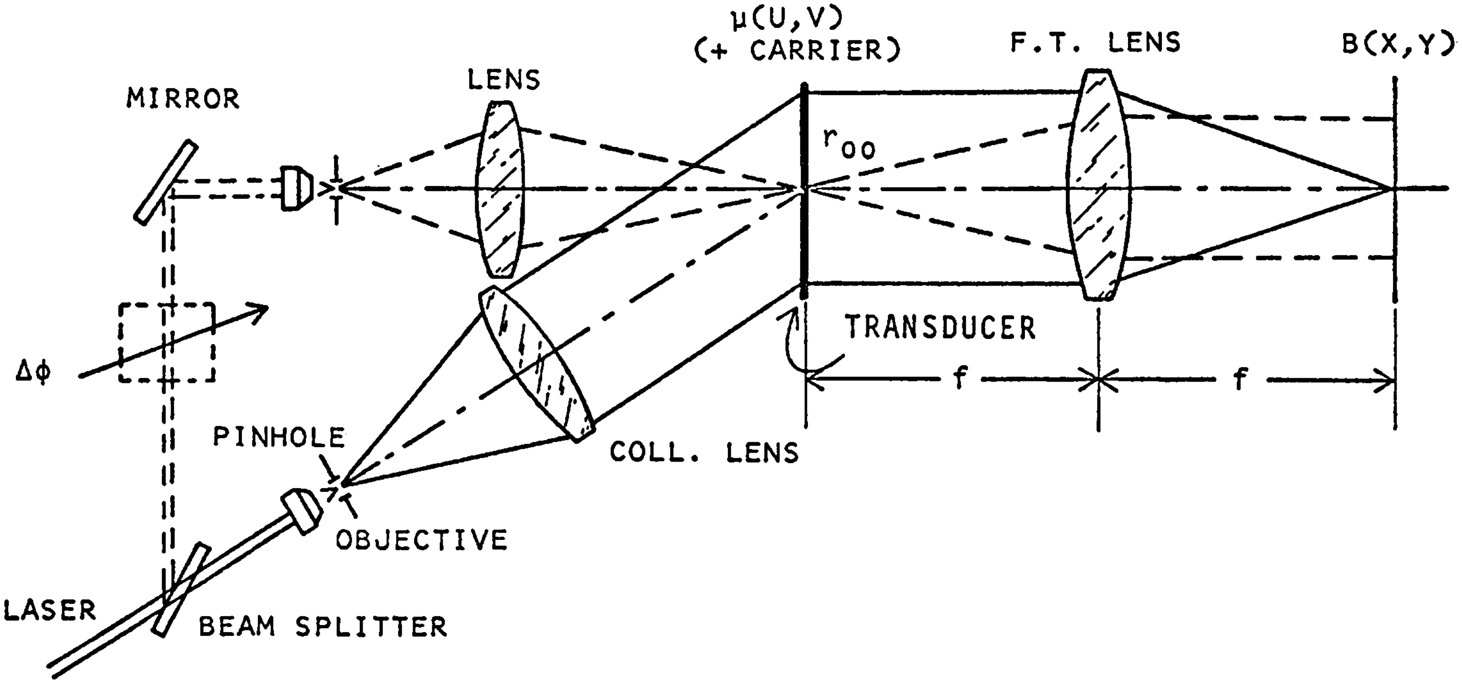
TABLE 3

In the following sections we describe and discuss five possible optical processors. Their positive and negative attributes are tabulated and a specific configuration is found to be optimum.

CONFIGURATION I (Figure 3)

The input is located at the front focal plane of the F. T. lens. The output is at the rear focal plane. There is no spherical phase factor in the output of this classical Fourier processor. The required numerical aperture of the lens is determined by the spatial resolution of the transducer.

The complex visibility data are introduced by means of a carrier frequency. The modulated carrier contains the complex information corresponding to $\hat{\mu}(u,v)$. That is the amplitude of the carrier is proportional to the amplitude of $\hat{\mu}(u,v)$ and the phase of the carrier is proportional to the phase of $\hat{\mu}(u,v)$. The input plane is illuminated with a



CONFIGURATION I

Figure 3.

coherent plane wave and light is diffracted into several orders. The useful information is in the first order. The carrier frequency is limited by the linear resolution of the transducer. Amplitude linearity is obtained by the superposition of a plane reference wave coming from one point source on the optical axis.

Advantages AI1) PROM and film modulators can be used.

AI2) If the size of the isoplanetic domains are large enough the aberrations of the Fourier Transform lens are constant for all the optical rays. In that case the cross-product B.R* + B*R (where B* is B conjugated) cancels the aberrations of the F. T. lens: $W_{signal} = W_{reference}$ = constant. This can be obtained with a Fourier transform lens if all the principal rays are perpendicular to the Fourier plane and it is well corrected for spherical aberration and satisfies sine condition (see Tropel and Perkin Elmer lens design).

AI3) There is not beam splitter inside the coherent optical computer

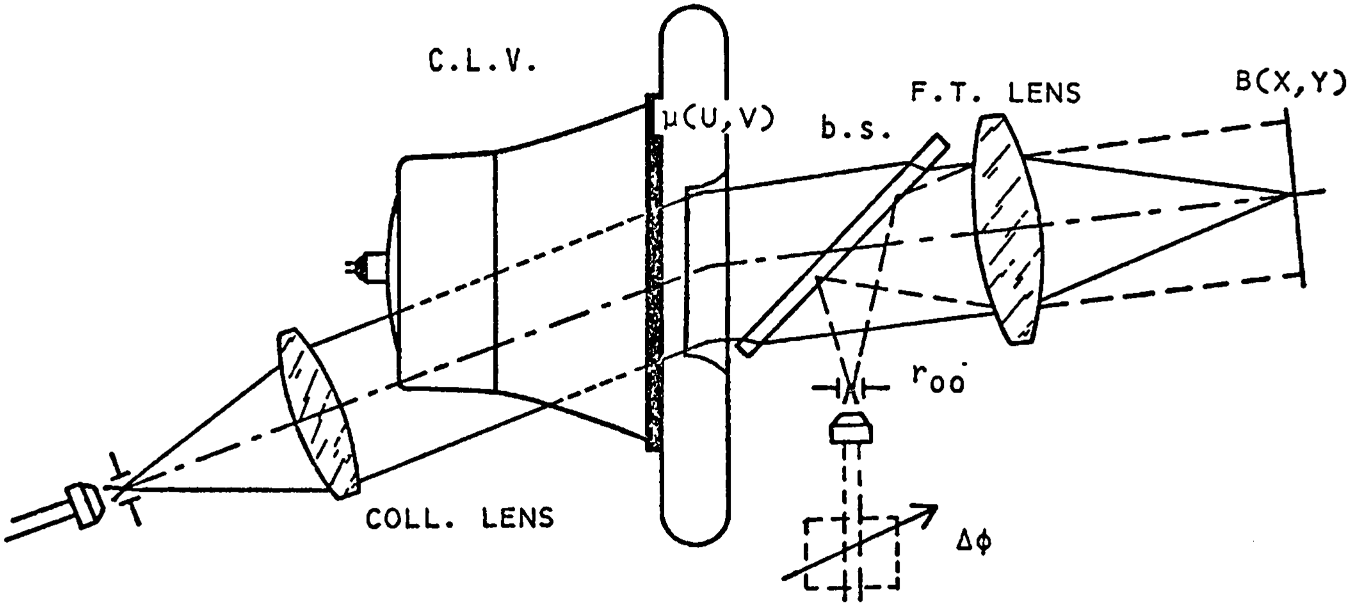
Disadvantages DI1) The processor has a bandpass which is limited by the F. T. lens aperture.

DI2) An additional lens is required to generate and introduce the reference point source. r_{oo} must be on the optical axis.

DI3) It is not certain that the isoplanetic patches of the F. T. lens are as large as the input and the output planes.

CONFIGURATION II (Figure 4)

This configuration is similar to the preceeding, but it is specifically designed for the coherent light valve transducer. The Fourier transform is in the back focal plane of the lens. This lens must have



CONFIGURATION II

Figure 4.

a higher (than I) numerical aperture because the working area in the CLV is smaller than PROM or film.

The complex visibility is introduced by the coherent light valve as an optical phase modulation. It is also possible to introduce aberration compensation by means of an error control servo.

The reference wave is a plane wave. It is inserted in the setup by means of a beam splitter situated inside the coherent optical computer.

Amplitude linearity is obtained by the same technique as in the setup number I.

Advantages AII1) Electronic aberration compensation is the only significant advantage of this configuration.

Disadvantages DII1) The Fourier transform lens may cause vignetting (as D. I1).

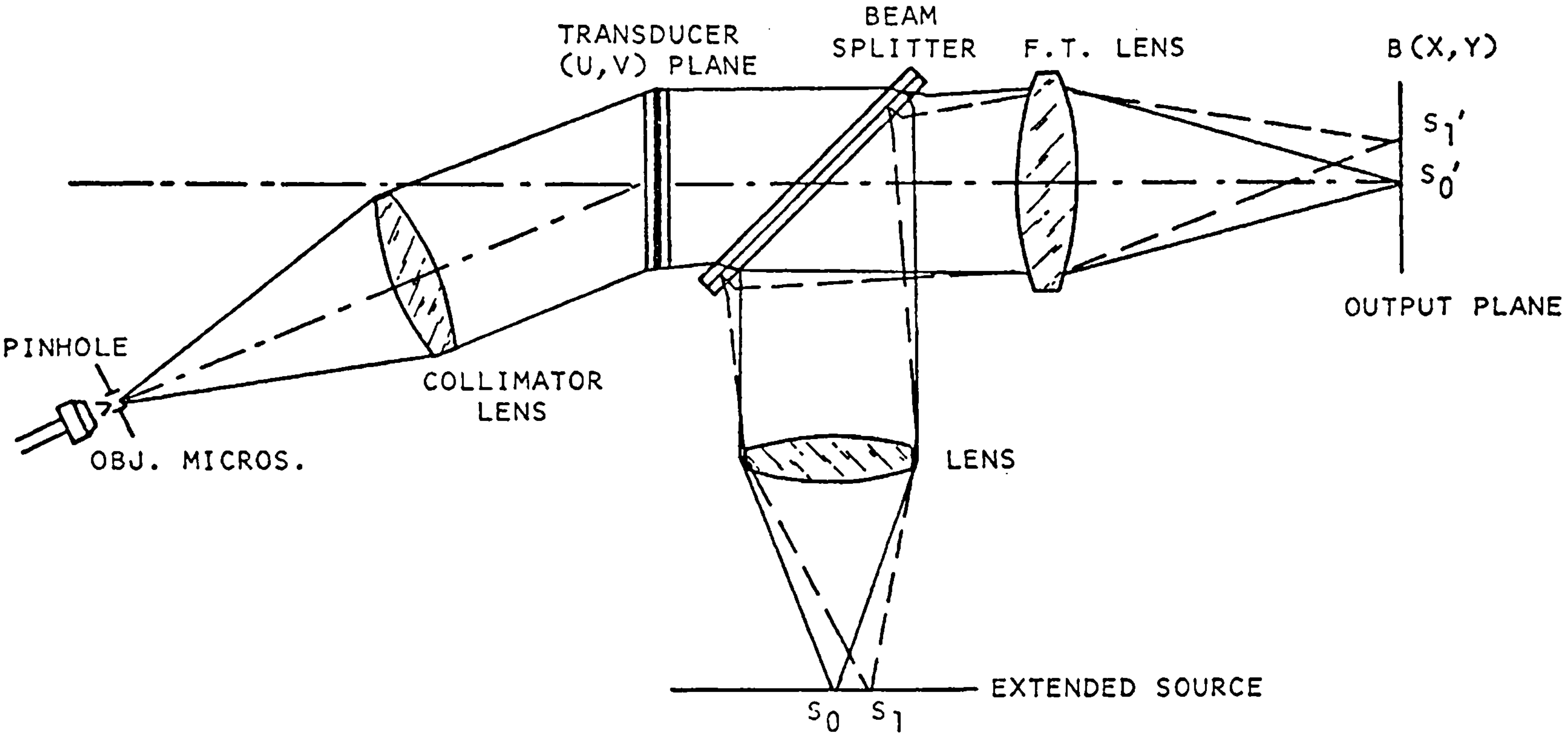
DII2) The beam splitter is the source of additional aberration.

DII3) The size of the isoplanetic domains are probably less than the size of the input and output apertures (as DI3).

DII4) The bandpass of the F. T. lens must be large. This leads to larger aberrations and lower dynamic range.

CONFIGURATION III (Figure 5)

This configuration is designed to use (instead of a plane reference wave) several spherical reference waves; each being matched with a given spatial frequency. (See note 6) The conceptual goal is to exactly cancel the aberrations of the F. T. lens. If the reference wave covers



CONFIGURATION III

Figure 5.

the same optical path through the F. T. lens as the signal wave, the aberrations introduced by the lens are exactly the same for the two beams. In this case, even if the aberrations are not constant (but vary across the pupil) the cross product B(x,y).R(x,y) is free of aberration. Thus the isoplanetic patch can be smaller than I and II.

It is not obvious that the advantage obtained concerning the aberrations of the F. T. lens is not completely lost by the aberrations bring about the beam splitter which must be used between the input plane and the F. T. lens. All three transducers can be used.

Advantages AIII1) Each frequency in the output plane is associated with a specific reference wave coming from the extended discrete source.

AIII2) The aberrations of the F. T. lens are avoided completely.

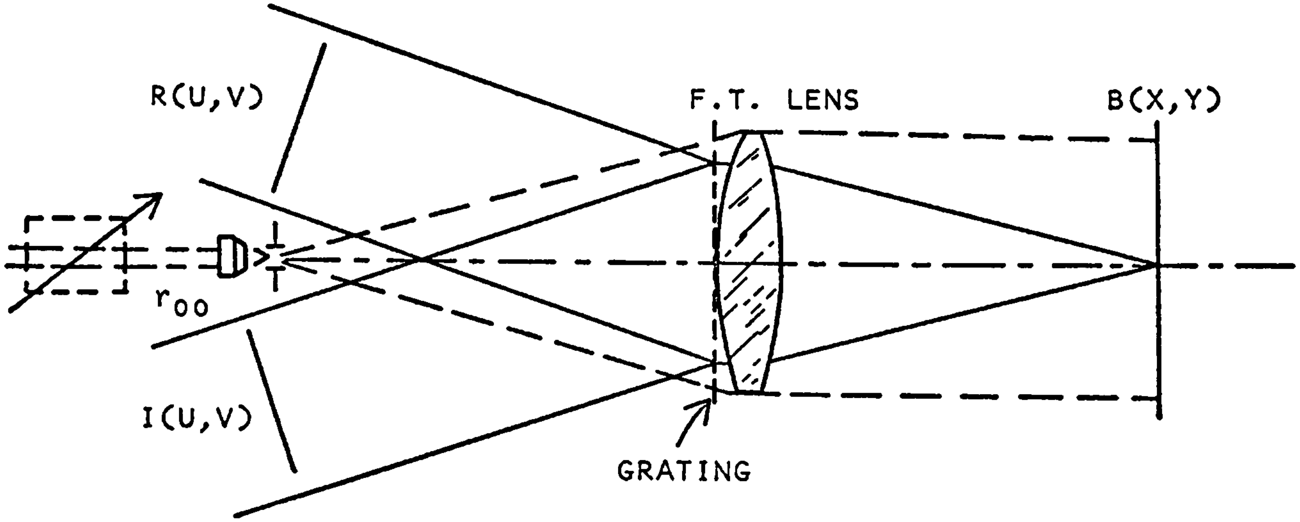
AIII3) At any time the transducer can be removed and another whose performance is better substituted.

Disadvantages DIII1) The F. T. lens may cause vignetting.

DIII2) An additional lens and a beam splitter are used to bring in the reference wave. Even a perfect beam splitter introduces some aberrations; they can be minimized with a very good beam splitter (e.g. Michelson interferometer) but their influence must be determined.

CONFIGURATION IV (Figure 6)

This configuration is designed to independently process the real and imaginary parts of the complex visibility. The aim is to avoid the use of a carrier frequency (required for complex data) and to substitute addition in the (u,v) domain for analog superposition in (x,y) plane.



CONFIGURATION IV

Figure 6.

That is to say:

$$\hat{\mu}(u,v) = R(u,v) + jI(u,v)$$

$$B(x,y) = \text{F.T.}[R] + \text{F.T.}[jI] = r+i \text{ is a real function}^{*}$$

The superposition is achieved by means of a grating (amplitude or phase) put in the front of the Fourier transform lens.

The linearity in amplitude is obtained as in all preceeding cases, by means of the reference bias $b_{(oo)}$.

The plane reference wave is given by a point source $b_{(oo)}$. A discrete extended source can be also used instead of the point source to work with many spherical reference waves. A collimating lens must then be joined in the setup between the extended source and the Fourier transform lens.

In this setup it is preferable to have two transducers to reduce the number of operations required to obtain $B(x,y)^{**}$.

<u>Advantages</u> AIV1) The carrier frequency is not required. Therefore, it is possible to operate with a much simpler addressing device. For example 1:10,000 instead of 1:150,000. The transducer space bandwidth is also smaller, 10^6 instead of 3.10^6, for instance.

AIV2) This technique gives the result directly from R(u,v) and jI(u,v) without making the superposition R(uv,) + jI(u,v) before processing. The superposition is carried out in the output plane of the coherent optical computer.

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[*] See note 4 in appendix.

[**] See note 7 in appendix.

Disadvantages DIV1) The setup runs with two transducers. This point is not critical if the transducers are photographic materials or PROM but the cost is higher if the transducers is CLV.

DIV2) The phase grating put in front of the F. T. lens can introduce some aberrations. The actual quality of holographic gratings recorded on thin film resin is very high and these effects are small.

CONFIGURATION V (Figure 7a)

This configuration is designed to work with a simple Fourier transform lens (doublet with a long focal length). The image plane, perpendicular to the optical axis at S'o, is the Fourier plane. When the transducer is located at z_o, there is, in addition to the Fourier transform in the output plane, a spherical phase term. The curvature of this phase term is $1/z_o$(4). The number of optical components is reduced at minimum and the bandpass of the processor is not limited by the F. T. lens. This configuration does not introduce vignetting. The aberrations of a such very well corrected lens (in the image plane) are smaller than the aberrations of a complex lens designed with 4 or 5 elements. The net aberrations for this optical processor are also smaller than those in other configurations due to the absence of collimators and beam splitter.

The spherical phase term being well known (see Figure 1a) can in principal be cancelled by a corrector plate (field flattener or hologram),

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(4) See J. W. Goodman "Introduction to Fourier Optics", Chapter V, Section 5.2, p. 88.

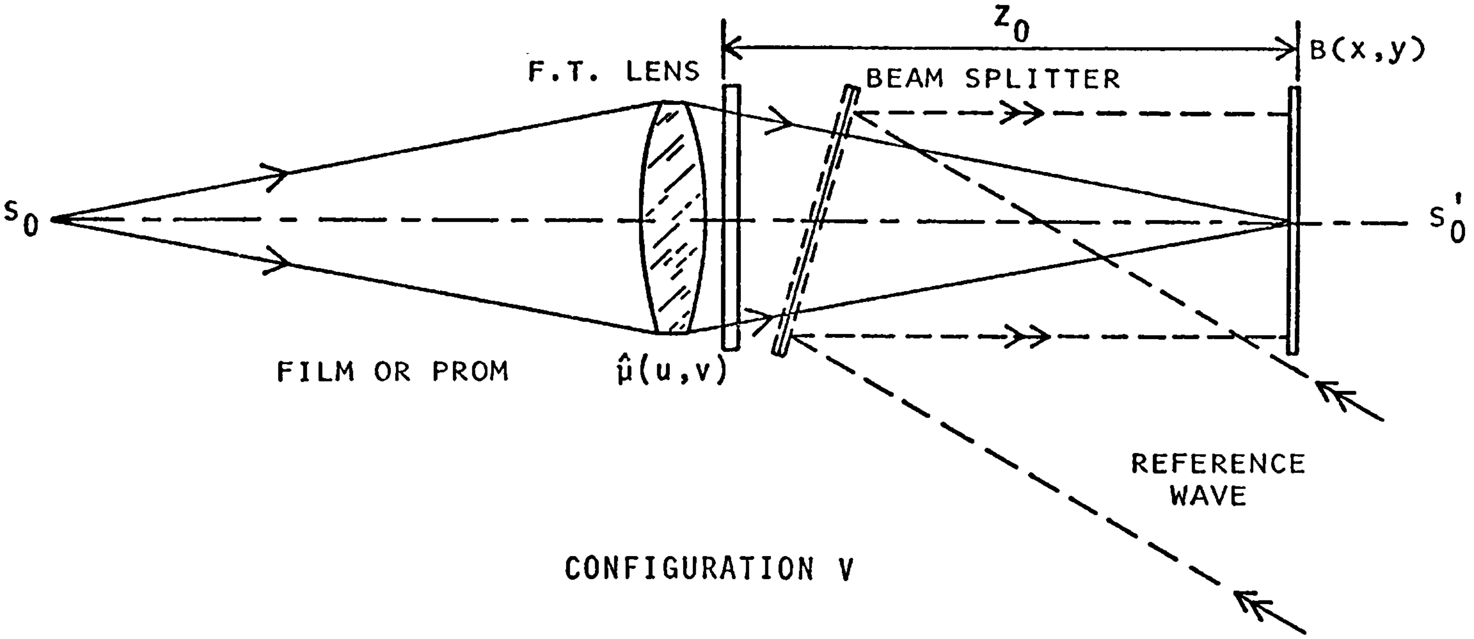

Figure 7a: The spherical phase factor must be corrected: field flattener or spherical sensor or thanks to the spherical reference wave.

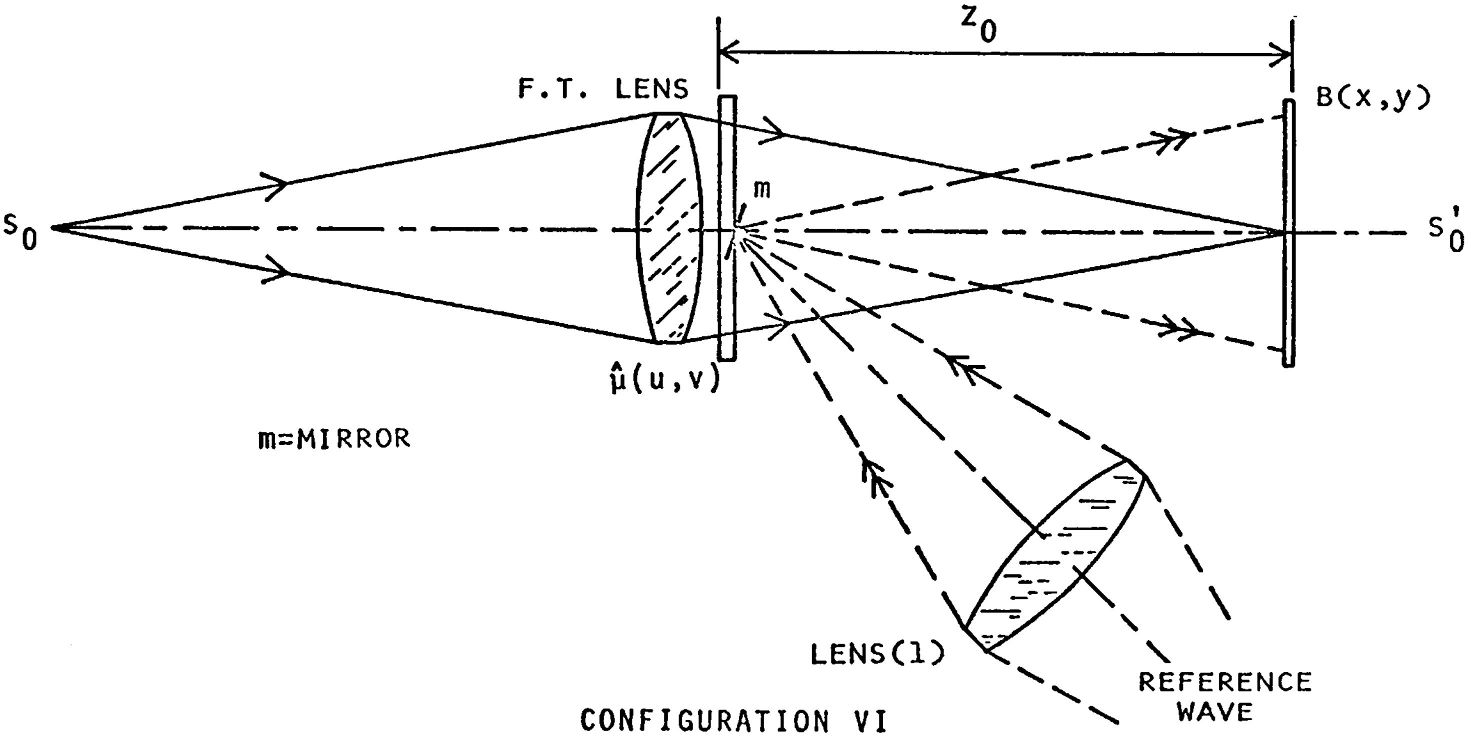

Figure 7b: Diverging reference wave.

by a sensor array whose shape is matched with this curvature, or by a spherical reference wave.

The Figure 7b shows the latter concept. The Fourier transform is obtained with a simple lens and the transducer is put between the exit pupil of the F. T. lens and the image plane. The reference wave is a diverging spherical wave. It is obtained from a simple lens which is well corrected on the optical axis.

The little mirror m put on the transducer does not disturb the input information because the central part of the u,v plane does not contain any information about the brightness of the sky. The design of this mirror must be considered in detail. The concept is practical and attractive, but details must be determined.

In Figure 8 an optical setup suggested by Itek for working with a PROM transducer is drawn. The first beam splitter introduces a scanned argon laser writing beam. This beam writes the complex visibility data on the PROM. The beam splitter (1) is then removed to obtain the Fourier transform of $\hat{\mu}(u,v)$ (with a He-Ne laser). The compensator corrects the aberrations due to the second beam splitter. The field flattener, represented in front of the sensor plane, corrects the curvature of the spherical wavefront, its position in front of B(x,y) is appropriate for the information beam but the wavefront of the reference beam must be adapted to give a flat wavefront in B(x,y) plane.

Advantages AV1) The Fourier transform lens is a simple lens. There is no bandpass limitation by the lens.

AV2) The absence of a collimator lens and beam splitter minimizes aberrations.

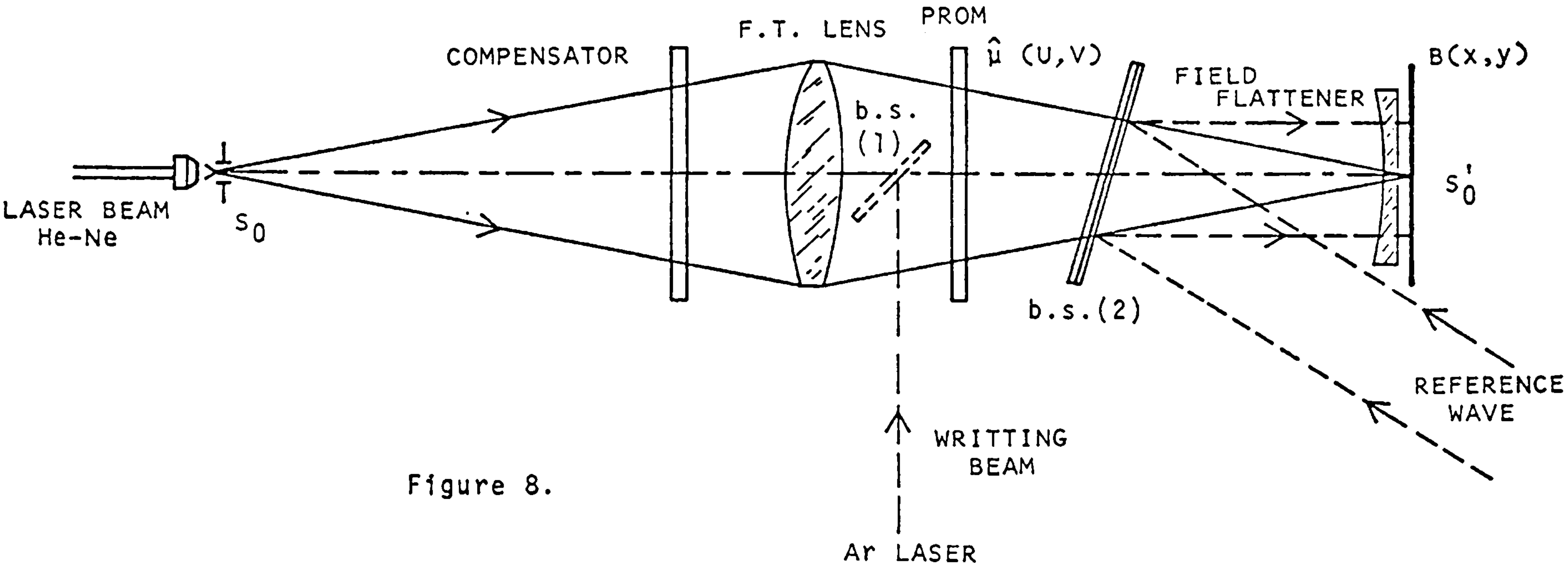
COMPENSATOR
F.T. LENS
PROM
$\hat{\mu}$ (U,V)
B(x,y)
FIELD FLATTENER
b.s. (1)
LASER BEAM He-Ne
S_0
S_0'
b.s.(2)
REFERENCE WAVE
WRITTING BEAM
Ar LASER

Figure 8.

AV3) Different transducers can be used in the exit pupil.

AV4) The diverging reference beam obtained by means of a thin little mirror cemented on the transducer cancels the curvature of the wavefront in the output plane.

AV5) The additional lens, lens (1) Figure 7b, is a very simple lens and can be very well corrected.

Disadvantages DV1) The spherical phase term must be corrected with a field flattener or with the reference beam whose curvature is matched to the spherical phase in the output plane.

CONFIGURATION	I	II	III	IV	V
Transducers	Photo. Mat. PROM	CLV	Photo. Mat. PROM CLV	Photo. Mat. PROM CLV	Photo. Mat. PROM
Modulation	Amplitude or Phase	Phase	Amplitude or Phase	No carrier frequency	Amplitude or Phase
Collimator	1	1	1	2	0
Add. Lens	1	0	1	0 but grating	0 or 1
Beam Splitter Inside the Setup	0	1	1	0	1 or mirror
Reference Wave	Plane (P)	(P)	Spherical (S)	(P) or (S)	(P) or (S)
Aberrations	Collimator Transducer F. T. lens	Collimator Transducer Beam Splitter F. T. lens	Collimator Transducer Beam Splitter	Collimator Transducer F. T. lens Grating	Transducer Beam Splitter
Phase Plate Corrector	No	Yes (beam splitter)	Yes (1.s.)	No	Yes or No
Phase Control	Yes (PROM)	Yes (Oil film)	Yes	No (not required)	Yes (PROM)

TABLE IV

VI. Conclusion

After this brief introduction to five different processors (summarized in Table 4), the question is: How to define the coherent optical processor most liekly to reach the precision asked in this specific application?

To reach the required level of aberration in the Fourier plane ($\lambda/62.8$ in r.m.s. value for an intensity distribution), it is necessary to make a choice between two different approaches.

(i) to work with a minimum number of very well corrected optical components.

(ii) to work with a sophisticated system in which each optical component is associated with a corrector or a compensator.

The extremes of approaches are illustrated for processor V in the Figure 7b (Case 1) and in the Figure 8 (Case 2).

The answer to our question can be obtained if we consider the aberrations in the output plane resulting from the superposition of aberrations due to all components. If we assume that all the components have the same rms aberrations it is easy to show that as the number of components increases the degree of correction must also increase for each component.

Let us consider two and three components: With two components (F. T. lens and Transducer) the accuracy of 1% in the output plane corresponds to $W_{rms} \leq \lambda/62.8$. That is to say to W_{rms} for each component $\leq \lambda/88.8$

$$W_{FT\ Lens} = W_{Transducer} \leq \lambda/88.8 \text{ rms}$$

<u>With three components</u> (F. T. lens + transducer + collimator)

if $W_{\text{Coll}} = W_{\text{F.T. Lens}} = W_{\text{Transducer}} \leq \lambda/108.76$ rms

The precision becomes very quickly too high to be manufacturable and the cost also increases quickly. It seems more realistic to work with a limited number of components.

The signal to noise ratio (scattered light & ghost images) varies in the same way. The scattered light increases with the number of elements. Each surface air-glass is the source of scattered light and internal reflection.

The classification of these different coherent optical computers can be done from these points of view.

All the setups work in the back focal plane of the F. T. lens except the setups V. The setups number I and II are similar, the third setup used a lot of spherical reference waves instead of a plane wave, it is more complex and it is not sure that the advantages brought by this way compensate the disadvantages due to the complexity of this setup. The fourth device is attractive but the relative position of R(u,v) and I(u,v) in the input plane must be very precise to keep the relationship of phase between the real and imaginary parts of $\hat{\mu}(u,v)$.

Therefore, if any technical difficulty comes out against the different configurations, their classification would be:

No. 1 setup V in its most simple version, figure 7b.

No. 2 setups I and II. The choice is connected with
the choice of the transducer.

No. 3 setup III.

No. 4 setup IV.

It appears that the choice between each different setup is not obvious as long as several tests are not carried out. These experimental tests must be done for the F. T. lens, for the transducers and for the different complete coherent optical processors. It is the association of all the optical components which must be tested to evaluate actual performances for various configurations and to determine the best configuration. The performance must be specified by mathematics and experiences for a perfect system (strehl ratio ≃ 0.99) and for a diffraction limited system with large isoplanetic fields. An error analysis and model must be made to quantitatively specify the expected performances of optics and linearization. $(|B(x,y)+jB(x,y)\otimes \hat{\Phi}_w+R|^2)$. As far as transducers are concerned, the best one must be selected before the optical configuration selection. Actually the photosensible materials (photographic emulsion or dichromated gelatin) have the highest space bandwidth product. The coherent light valve and the Pockel's readout optical modulator can be written and erased in real time. It is also possible to use with them an aberration or error correction. The selection cannot be made before knowing their actual performances. It is clear, to my knowledge, that the optical device wished for the VLA has not yet been built, but it is reasonable to think that it will later be built step by step. That is to say, after a first coherent optical processor whose accuracy will be less than a few percent, it will be possible to change either the transducer or the F. T. lens, ~~in~~ taking into account the improvements of the optical or electro-optical technology in the next five or six years, to obtain 2% then 1% and so forth. In my opinion the gain brought by the optical device, and its low cost compared to the whole expense accepted for the VLA, merit that its manufacturing is undertaken. In the worst hypothesis this optical device can be used (i) to have very quickly a good image of the radio brightness of the sky and then (ii) to determine if the information obtained from the radiotelescope is good enough to spend much time with a digital computer to process it.

It seems after this first step, that the continuation of this preliminary work must be done by someone who will be able to make many experiments and tests. The necessary materials (laser, optical bench, collimator, photomultipliers, etc.) will be used in the future by the people who will work in the optical laboratory which will be indispensable to the maintenance of the optical components and for the different processes (optical filtering, deconvolution, etc.) of the output signals or the input signals before their optical process in the coherent optical computer.