

Feb. 11, 1969

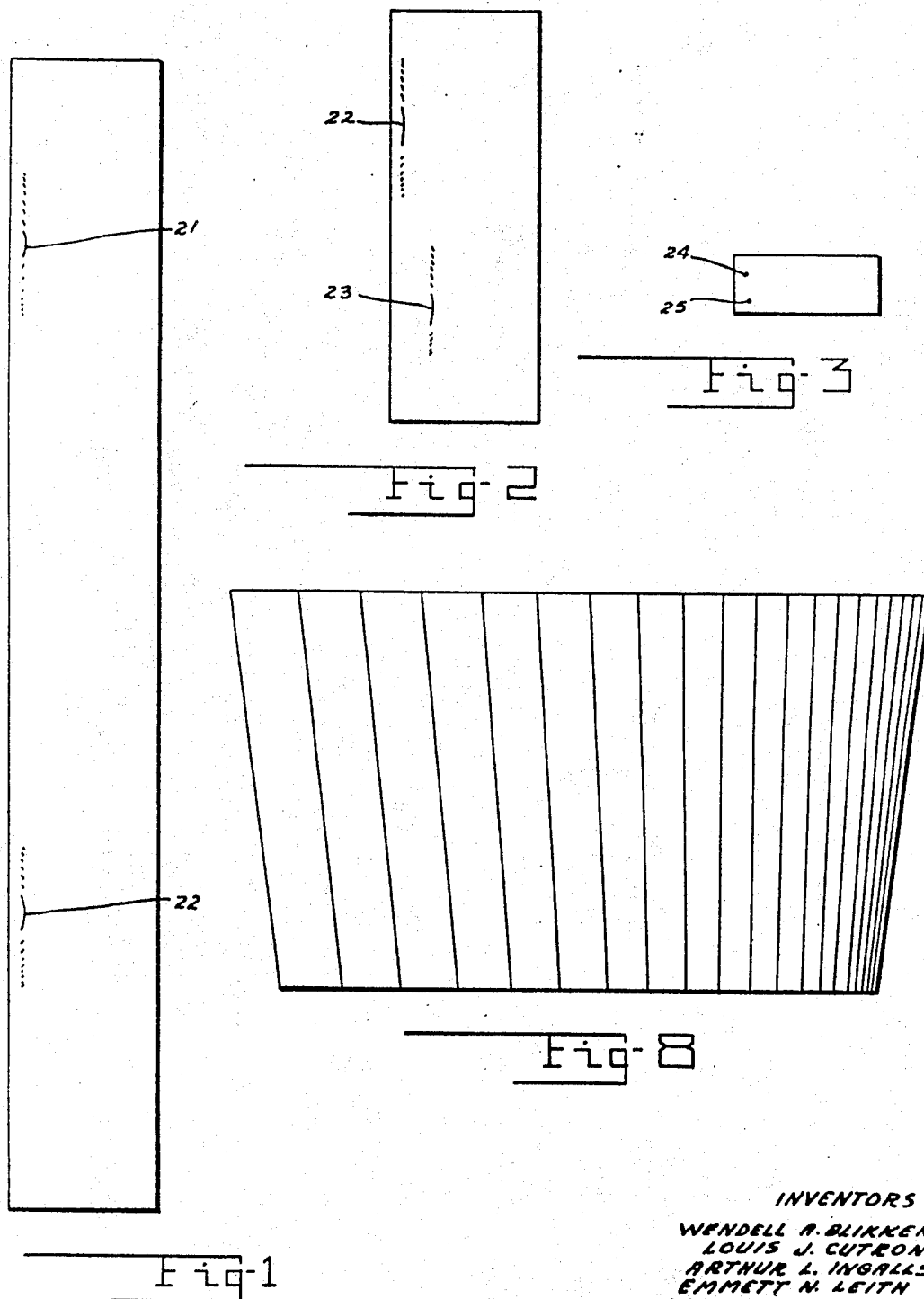
W. A. BLIKKEN ETAL

3,427,104

OPTICAL PLURAL CHANNEL SIGNAL DATA PROCESSOR

Filed May 4, 1960

Sheet 1 of 4



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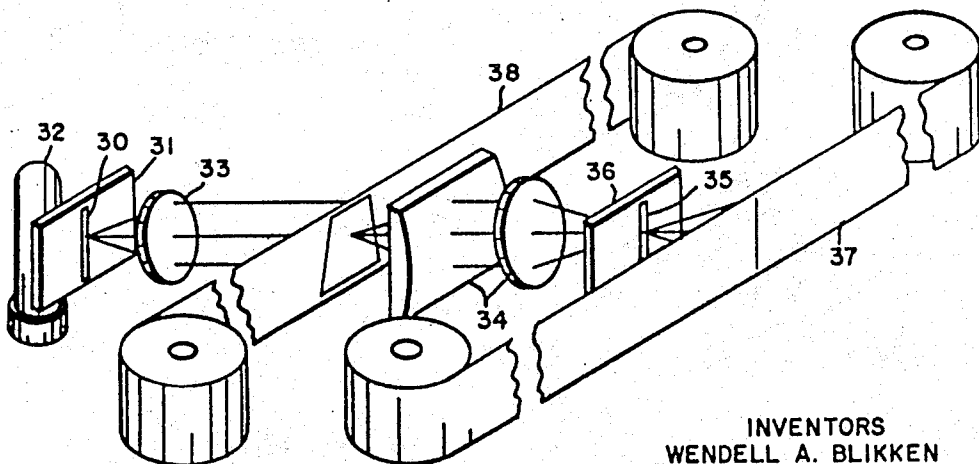
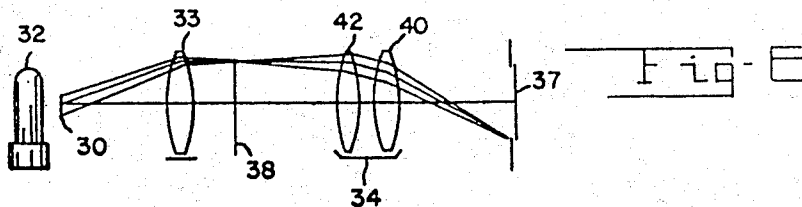
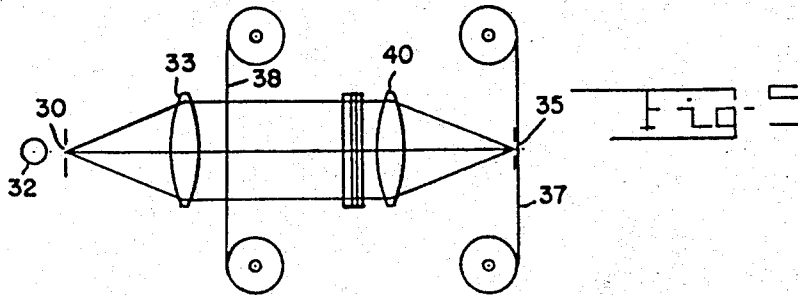


Fig-4

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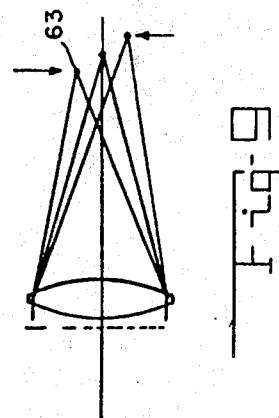
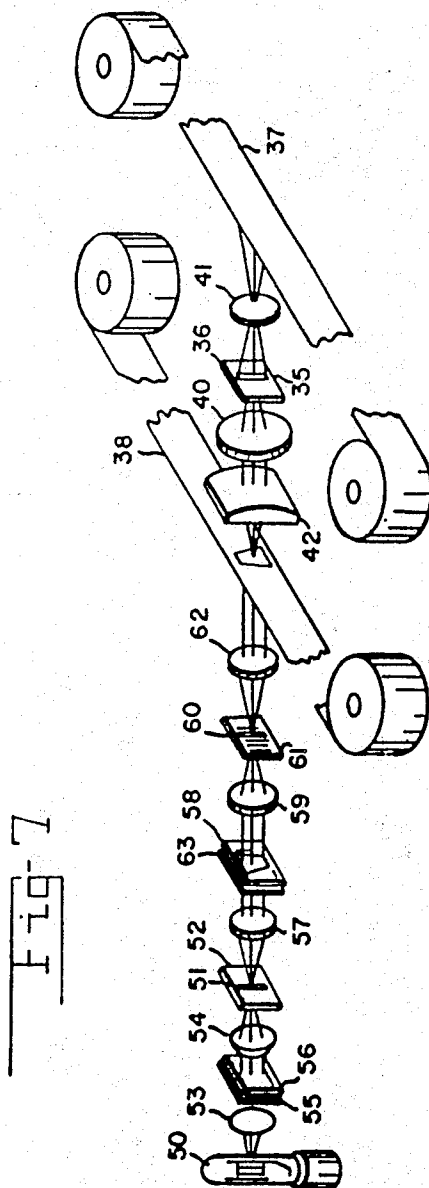
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Sheet 3 of 4



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OPTICAL PLURAL CHANNEL SIGNAL DATA PROCESSOR

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Fig-10

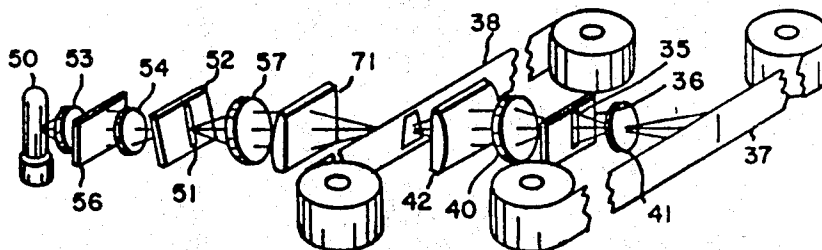
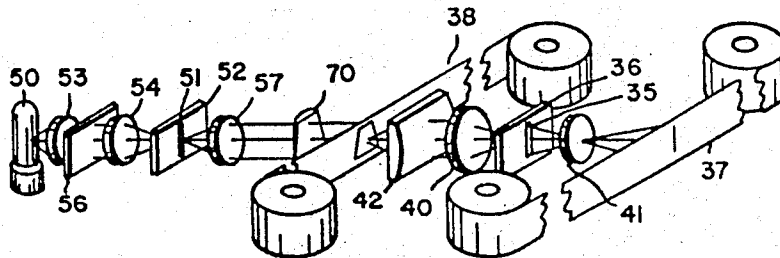


Fig-11

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3,427,104 OPTICAL PLURAL CHANNEL SIGNAL DATA PROCESSOR

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This invention relates to a device for simultaneously processing wave trains in a great number of channels; wherein the wave trains in the various channels need not all be the same.

One object of the invention is to provide a device which processes Doppler frequency target information for all ranges simultaneously from information obtained from an air-borne coherent side-looking radar.

Another object is to provide a device to produce desired compressed signals simultaneously in a great many channels from signals greatly dispersed in time or space by the use of optical techniques with noise and undesired signals greatly reduced.

These and other objects will be more fully understood from the following detailed description taken with the drawing, wherein:

FIG. 1 is a diagrammatic illustration of radar target information with targets separated in azimuth such as would appear on a film obtained from the recording unit of an air-borne coherent side-looking radar;

FIG. 2 is another diagrammatic illustration of radar target information with targets separated both in azimuth and range;

FIG. 3 shows the target information of FIG. 1 as it will appear on a film strip after processing in the device of the invention;

FIG. 4 shows a three-dimensional view for a basic optical processor according to the invention;

FIG. 5 shows the optical system for the device of FIG. 4 for resolving target information in the azimuth direction;

FIG. 6 shows the optical system for the device of FIG. 4 for resolving information in the range direction;

FIG. 7 shows a modification of the device of FIG. 4 for providing compensation for changes of focus with range;

FIG. 8 is a schematic showing of the reference mask used in the device of FIG. 7;

FIG. 9 shows the relative motion of the first order images as the film is moved;

FIG. 10 shows a modification of the device of FIG. 7 which provides another method for providing range compensation;

FIG. 11 shows another modification for providing range compensation.

The radar used to obtain the information as represented in FIGS. 1 and 2 is a coherent radar, that is, it provides phase as well as amplitude information on all received radar signals by comparison with a stable reference oscillator. As the radar is carried along by the aircraft, a radar pulse is transmitted and the amplitude and phase of the returning signals from all targets are stored by recording on film. A short distance later another pulse is transmitted and the return signals are again recorded on the film. Continuing in this fashion the radar phase and amplitude history for each radar illuminated target is obtained over an extended distance of travel of the aircraft. All of the phase information for each target adds up to produce the Doppler history for each target from the time it enters the radar beam until it leaves the radar beam.

This information can be used to give an improved resolution in azimuth.

The processing program in azimuth, however, is a function of range so that one needs a large number of computing channels, each having the required computer program for each particular range. The various range increments may then be assigned to the appropriate computer channels. To avoid the construction of many channels, a single channel may be provided to scan all of the required programs sequentially in synchronism with the corresponding data for the different ranges. This system requires a large bandwidth, a scanning system and a data storage system. Either of these systems constructed on an electronic basis will involve a great amount of equipment and therefore a great cost. According to this invention, an optical data processing system is used which processes the Doppler frequency target information for all ranges simultaneously.

The operation of the system (for a given range) can be described as a cross-correlation of the signal with reference function which is a replica of the expected return from that range, the expected return having a form determined by the geometry of the radar antenna-target relation. Alternatively, the operation of the system can be described in terms of optical properties of the recorded signals. A recorded signal from a radar target is a substantially linearly frequency modulated record, which resembles a diffraction grating with grating spacing varying substantially linearly along its length, of a slice taken through a zone plate. Such structures have focal properties similar to those of a lens, as likewise does the recorded signal. When the signal history brings the impinging light to focus, the resulting image is the high resolution image which is sought. The signals have focal length which is a function of range to the target. The reference function described above is, from this viewpoint, a variable focal length lens which has a different focal length for each channel and compensates for the range variation of the signal focal length.

These two viewpoints are equivalent. However, some configurations are best described from one viewpoint, some from the other.

The simplest form of the invention consists essentially of a light source, a slit for providing coherent illumination, a collimator, a signal film, a cylindrical lens, a photographic lens, an analyzer slit and a recording film. This simple form of the invention can be used only for a very limited range interval due to the change in focus with range. For a more extended range interval, means must be provided to correct for the change in focus.

Referring more particularly to FIGS. 1 and 2 of the drawing, which show a graphical representation of the Doppler histories of targets as they would appear on a strip of film from the recording unit of an air-borne coherent side-looking radar. Reference numbers 21 and 22 in FIG. 1 show a graphical representation of the Doppler histories of two targets separated in azimuth. Reference numbers 22 and 23 in FIG. 2 show a graphical representation of the Doppler histories of two targets separated in range and azimuth. FIG. 3 shows at 24 and 25 a graphical representation of the processed data for the targets 21 and 22 of FIG. 1.

The basic optical processor shown in FIG. 4 has a slit 30 in mask 31 illuminated by a monochromatic light source 32 to obtain coherent illumination in the azimuth direction. This light is passed through the optical systems 33 and 34 through the final slit 35 in mask 36 and onto the recording film 37. The signal function appears on the film 38, which passes between optical systems 33 and 34. Since the optical systems are different for range and azimuth; these systems will be described separately with reference to FIGS. 5 and 6.

In the azimuth direction, shown in FIG. 5, the light from the narrow slit 30 is made parallel by collimator lens 33. This light is then brought to a distant focus by a signal on film 38. The distant image is then brought to focus on the final slit 35 by a camera lens 40. The recording film 37 may be placed very near the final slit 35 to receive the image. It is preferable, however, to provide a relay lens 41 to image the slit 35 on the film, as shown in FIG. 7.

In the range direction, the light from the line source proceeds through lens 33 in the manner shown in FIG. 6 to illuminate the signal film. The illustration of the light path in FIG. 6 is for only one range. A cylindrical lens 42 works together with the camera lens 40 to image the range elements from the signal film onto the final slit. In the range direction, the light source and first slit simply determine the amount of light allowed through the system and thereby determine the brightness of the image on the recording film. The astigmatic lens system 34 thus acts to integrate the signal in the azimuth direction while preserving the range information in the range direction.

The speed of recording film with respect to the speed of the signal film is determined by the ratio of range reduction to azimuth reduction existing on the signal film. If 10,000 yards is shown as 35 mm. in the range direction, this same ratio should exist in the azimuth dimension so that the resulting image will be in proper proportion. However, the two ratios are not necessarily equal on the signal film, where, for example, 10,000 feet in azimuth might be represented as 700 mm., while 10,000 ft. in range might be represented as 35 mm. The equalization of the ratios is made by adjusting the speed ratio between signal film and recording film. For the example stated, the recording film should move $\frac{1}{20}$ the speed of the signal film in order to bring the image to proper portions.

The system thus far described can be used over a limited range interval only as the image goes out of focus due to a change in focus with a change in range.

FIG. 7 shows one system, which may be used to compensate for changes of focus with range which is inherent in the signal recording.

In the system of FIG. 7 reference numeral 50 refers to a light source which may be any type of light source, for example; a mercury vapor lamp. The light from light source 50 is imaged upon a slit 51 in mask 52 by means of a pair of lenses 53 and 54. The width of slit 51 is determined by a compromise between image sharpness and total light intensity and, for the devices used, it has been between 20 microns and 250 microns. The length of the slit is not critical.

Between the lenses 53 and 54 are provided a heat reflecting filter 55, to prevent heat from passing to the signal film and thereby damaging it, and an optical filter 56 to provide a monochromatic light for the data processor which, for the system built, was an optical green filter.

A lens 57 is provided to cause parallel light in the azimuth direction to impinge on the reference function mask 58, which will be explained in greater detail in connection with FIG. 8. Due to the diffraction effect of the reference function, the distribution of light in the focal plane of lens 59 is a spectrum analysis of the spatial frequencies of the reference function. A slit 60 in mask 61 is placed in the appropriate position in the focal plane of the lens so that only the desired signals can proceed further along the system, as will be explained later. A lens 62 acts together with lens 59 to image the reference function upon the signal film 38. A weighting function filter 63, which consists of a variable density filter which gradually decreases light transmission toward the edges of the reference mask, is provided for the same reason that antennas are tapered toward their ends which is to reduce side lobe effects, as described at the bottom of page 452 and the top of page 453 of vol. 12 of the MIT Radiation Laboratory Series. The remainder of the system is the same as FIG. 4.

The reference function on mask 58 the general configuration of which is shown in FIG. 8 consists essentially of the ideal Doppler signal histories for targets at all ranges of the radar and thus can be considered to have a like number of functions thereon corresponding to the functions on the signal film for all ranges of the radar. The spacings between the lines in the actual mask used are much less than as shown in FIG. 8. Since the time that a target appears in the radar beam will increase with range, the reference mask is wedge shaped.

The reference mask can be made in various ways. Two methods have been used. First, the mask is drawn by hand and then reduced to size and placed on a transparency by photographic means. Alternatively, a device used for ruling diffraction gratings has been used for producing the mask. In either case, the mask is only an approximation to the required function, since the former is a two-valued function, being either transparent or opaque, while the latter is a continuous tone or shaded transparency. Specifically, the required reference function is of the form $(+\cos \phi(x, y))$, and the actual mask has the form

$$+\frac{\cos \phi(x, y)}{|\cos \phi(x, y)|}$$

The lack of continuous tone merely generates higher diffracted orders and these are removed by the mask 61 of FIG. 7. The reference mask contains the frequency terms only on one side of zero frequency.

As the signal history on the film 38 moves through the data processor, the image also moves. FIG. 9 illustrates the effect of signal motion on the zero and two first diffracted order images. The first order images move in opposite directions, as shown in FIG. 9, while the zero order image does not move. If signal frequencies exist on only one side of the zero frequency, the first order images do not cross the zero order position, but fade out instead. The first order image that focuses short of the zero order image is called the first order positive image, since, with respect to this image, the signal history exhibits a positive focal length. The other first order image focuses beyond the zero order and this is called the negative first order image, since, with respect to this image, the signal history exhibits a negative focal length. Either the first order positive image or the first order negative image can be used for focusing on the output slit. Use can be made of the motion of the image to increase the exposure of the output film, by widening the output slit and choosing the proper camera lens to cause the motion of the first order image to correspond to the motion of the film.

Whichever first order image of the signal is used, the other first order image of the reference function is used. The negative first order image of the reference function compensates the positive first order image of the signal film, and the positive first order image of the reference function compensates the negative first order image of the signal film. The slit 60 is located in the proper position to select the required reference function image. The reference mask thus behaves as a lens with focal length equal to that of the signal film focal length, but of opposite sign. Hence, targets from all ranges are imaged at infinity by the reference function signal-film combination. The lens 40 brings this image in from infinity to the focal plane of the lens.

Other means for compensating for range requiring less equipment than shown in FIG. 7 is possible. FIG. 10 shows a system wherein a conical lens 70 is substituted for the reference function. With this system, the primary slit 51 is located off of the axis in the position of slit 60 of FIG. 7. The remainder of the system is the same as FIG. 7.

Another method of compensating for the change of focus with range is shown in FIG. 11. The recording film and output slit could be slanted to compensate for the change of focus with range, however, a simpler method

is to slant the mask containing the slit 51 as shown in FIG. 11. An additional cylindrical lens 71, and also a longer slit and light source, are needed when slit 51 is slanted.

Still another system which could be used to compensate for focus would be to provide an optical system to vary the wave length of the light used with range thereby producing a constant focus and perfect tracking at all ranges.

The data processor was developed primarily to solve a specific problem in fine resolution radar. However, during the course of the investigation, a number of other applications were conceived. With the device of FIG. 7, the positions of the images on the mask 36 consist of a one-dimensional Fourier analysis of the spatial frequencies of the signal film 38. Thus, this portion of the system is a multi-channel spectrum analyzer.

The operation involved with the device of FIG. 7 is given by the following equation:

$$h(y, t) = \int_{a(t)}^{b(t)} g(x, y, t) f(x, y) dx \quad (1)$$

In the special case described $f(x, y)$ represents the reference function, $g(x, y, t)$ represents the signal history and $h(y, t)$, the output of the optical processor, represents the processed radar data.

Integrals of the form of Equation 1 occur for a number of cases, such as, high resolution radar, Fourier analysis, antenna pattern computation, cross-correlation, auto correlation, signal detection, biological correlation, signature analysis, analog computation and many others.

While the operation of the system has been described with parallel, or collimated, light impinging on certain elements, such as the reference function and conical lens, it is obvious that the device does not require collimated light for its operation, although the description, as well as the design, are facilitated by having collimated light at such positions. Likewise, the position of the signal film and reference function, or signal film and conical lens, can be interchanged. Numerous such variants are possible.

Other functions, which the device of the invention is capable of performing by positioning of the slit in mask 61, are amplitude modulation detection, spectral analysis and filtering and frequency translation. It is obvious that there may be many other operations which can be performed with the apparatus of this invention.

The lens unit made up of lenses 40 and 42 produces a one dimensional Fourier transformation between the plane of the film 38 and the plane of the mask 36, while preserving the other dimension for plural channel operation. A number of such lens units can be placed in tandem to produce successive transformations with respect to one variable, while always preserving the variable of the other direction, namely, the vertical direction as the figures are drawn. At the successive planes wherein the successive transformations occur, additional transparencies representing functions can be placed. Therefore, complicated system transfer functions can be generated. Let the functions at successive planes be labeled $f, a, b, c, \dots$ etc., where f is regarded as the input signal and $a, b, c, \dots$ produce an overall system transfer function. Let $T(p)$ be the one dimensional Fourier transform of p . Then, the light distribution at successive planes, after the light is transmitted by the transparencies of the plane, is

$$\begin{aligned} &f(x, y) \\ &a(\omega x, y)Tf(x, y) \\ &b(x, y)Ta(\omega x, y) + f(x, y) \end{aligned}$$

etc., where ωx is the spatial frequency along the x -direction and is the variable generated by the Fourier transformation.

While certain arrangements of the elements have been shown, it is to be understood that other arrangements might be used. For example, filters 55 and 56 need not

be in the position shown, but may be located wherever there is parallel light in the azimuth direction; however, filter 55 must be located between the light source and the signal film. Lens 42 may be located behind slit 35 adjacent relay lens 41, but its axis must be rotated 90 degrees with respect to its position as shown in FIG. 4.

There is thus provided a device for simultaneously processing wave trains in a great number of channels simultaneously.

We claim:

1. A device for obtaining the integrated product of two functions in a plurality of channels simultaneously, comprising: a first transparency having thereon a plurality of spatial frequency functions with the functions extending in a first direction and the separate channels extending in a second direction perpendicular to said first direction, means for illuminating said first transparency with monochromatic coherent light which is collimated in said first direction, a second transparency having a plurality of functions extending in said first direction with the separate channels extending in said second direction, a pair of lenses for imaging said first transparency upon said second transparency, a first mask in the focal plane of the first lens of said pair of lenses, said mask having a slit in the position of at least one of the first diffracted order images of said first transparency, a second mask, output means adjacent said mask, means for integrating the output of said second transparency in said first direction and for focusing said output on said mask, said mask having an output slit therein in the position of one of the first diffracted order images of said second transparency and means including said last named means for imaging the information in the separate channels in said second direction on said slit.

2. A device for obtaining the integrated product of two functions in a plurality of channels simultaneously, comprising: a first transparency having thereon a plurality of spatial frequency functions with the functions extending in a first direction and the separate channels extending in a second direction perpendicular to said first direction, means for illuminating said first transparency with monochromatic coherent light which is collimated in said first direction, a second transparency having a plurality of functions extending in said first direction with the separate channels extending in said second direction, a pair of lenses for imaging said first transparency upon said second transparency, a first mask in the focal plane of the first lens of said pair of lenses, said mask having a slit in the position of the first positive diffracted order image of said first transparency, a second mask, output means adjacent said mask, means for integrating the output of said second transparency in said first direction and for focusing said output on said mask, said mask having an output slit therein in the position of the first negative diffracted order image of said second transparency, and means including said last named means for imaging the information in the separate channels in said second direction on said slit.

3. An apparatus for processing a signal film, from an airborne coherent side-looking radar, having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, means for producing a beam of monochromatic light, means for moving said film through said light in the azimuth direction, a first mask having a slit therein located between said beam producing means and said film, said slit being narrow in the azimuth direction and elongated in the range direction, means located between said mask and said film for collimating the light in the azimuth direction, a second mask having an output slit therein, output means adjacent said output slit, a first lens for integrating the light information from said signal film in the azimuth direction and for focusing it on said slit, a second lens which together with said first

lens images the range information from said signal film on said output slit.

4. An apparatus for processing a signal film from an airborne coherent side-looking radar, having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, a first mask having a narrow elongated slit therein, means for illuminating said mask to thereby produce a thin line light source, means for moving said film through said light in the azimuth direction with the range direction being parallel to the line of light, a reference transparency between said light source and said film, said reference transparency having thereon a signal for all ranges representing the ideal Doppler frequency history for targets at all ranges of said radar, means located between said first mask and said reference transparency for collimating the light in the azimuth direction, a heat reflecting filter and a monochromatic filter between said light source and said signal film, means for collimating the light passing through said heat reflecting filter and said monochromatic filter, a pair of lenses for imaging said reference transparency on said signal film, a second mask in the focal plane of the first of said pair of lenses, said second mask having a slit in the position of at least one of the first diffracted order images of said reference transparency, a third mask having an output slit in the position of one of the first diffracted order images of said signal film, output means adjacent said output slit, means located between said signal film and said third mask for integrating the light information from said signal film in the azimuth direction and for focusing it on said slit, and means for imaging the range information from said signal film on said output slit.

5. An apparatus for processing a signal film from an airborne coherent side-looking radar, having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, a first mask having a narrow elongated slit therein, means for illuminating said mask to thereby produce a thin line light source, means for moving said film through said light in the azimuth direction with the range direction being parallel to the line of light, a reference transparency between said light source and said film, said reference transparency having thereon a signal for all ranges representing the ideal Doppler frequency history for targets at all ranges of said radar, means located between said first mask and said reference transparency for collimating the light in the azimuth direction, a heat reflecting filter and a monochromatic filter between said light source and said signal film, means for collimating the light passing through said heat reflecting filter and said monochromatic filter, a pair of lenses for imaging said reference transparency on said signal film, a second mask in the focal plane of the first of said pair of lenses, said second mask having a slit in the position of at least one of the first diffracted order images of said reference transparency, a third mask having an output slit therein, a recording film, means for moving said recording film past said output slit, means located between said signal film and said recording film for integrating the light information from said signal film in the azimuth direction and for focusing it on said slit, said slit being in the position of one of the first diffracted order images of said signal film and means for imaging the range information from said signal film on said output slit.

6. An apparatus for processing a signal film from an airborne coherent side-looking radar, having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, a first mask having a narrow elongated slit therein, means for illuminating said mask to thereby produce a thin line light source, means for moving said film through said light in the azimuth direction with the range direction being parallel to the line of

light, a reference transparency between said light source and said film, said reference transparency having thereon a signal for all ranges representing the ideal Doppler frequency history for targets at all ranges of said radar, means located between said first mask and said reference transparency for collimating the light in the azimuth direction, a heat reflecting filter and a monochromatic filter between said light source and said signal film, a pair of lenses for imaging said reference transparency on said signal film, a second mask in the focal plane of the first of said pair of lenses, said second mask having a slit in the position of the first positive diffracted order image of said reference transparency, a third mask having an output slit therein, a recording film, means for moving said recording film past said output slit, an astigmatic lens system located between said signal film and said recording film, said lens system having a first lens therein for integrating the light information from said signal film in the azimuth direction and for focusing it on said slit, said slit being in the position of the first negative diffracted order image of said signal film, said lens system having a second lens which together with said first lens images the range information of said signal film on said output slit.

7. An apparatus for processing a signal film from an airborne coherent side-looking radar, having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, a first mask having a narrow elongated slit therein, means for illuminating said mask to thereby produce a thin line light source, means for moving said film through said light in the azimuth direction with the range direction being parallel to the line of light, a reference transparency between said light source and said film, said reference transparency having thereon a signal for all ranges representing the ideal Doppler frequency history for targets at all ranges of said radar, means located between said first mask and said reference transparency for collimating the light in the azimuth direction, a heat reflecting filter and a monochromatic filter between said light source and said signal film, a pair of lenses for imaging said reference transparency on said signal film, a second mask in the focal plane of the first of said pair of lenses, said second mask having a slit in the position of the first negative diffracted order image of said reference transparency, a third mask having an output slit therein, a recording film, means for moving said recording film past said output slit, an astigmatic lens system located between said signal film and said recording film, said lens system having a first lens therein for integrating the light information from said signal film in the azimuth direction and for focusing it on said slit, said slit being in the position of the first positive diffracted order image of said signal film, said lens system having a second lens which together with said first lens images the range information of said signal film on said output slit.

8. An apparatus for processing a signal film from an airborne coherent side-looking radar, with the film having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, means for producing a beam of monochromatic light, means for moving said film through said light in the azimuth direction, a first mask having a slit therein located between said light beam producing means and said film, said slit being narrow in the azimuth direction and elongated in the range direction, a reference transparency with a signal thereon corresponding to the ideal Doppler frequency for all ranges, located between said first mask and said signal film, means located between said first mask and said reference transparency for collimating the light in the azimuth direction, a pair of lens for imaging the reference function upon said signal film, a second mask located in the focal plane of the first of said pair of lenses, said second mask having a slit in the position of at least one

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of the first diffracted order images of said reference transparency, a recording film, a third mask adjacent said film, means for moving said recording film past said third mask, a first lens for integrating the light information from said signal film in the azimuth direction and for focusing it on said third mask, said third mask having a slit therein in the position of one of the first diffracted order images of said signal film, a second lens which together with said first lens images the range information from said signal film on said output slit.

9. An apparatus for processing a signal film from an airborne coherent side-looking radar, having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, a first mask having a narrow elongated slit therein, means for illuminating said mask to thereby produce a thin line light source, means for moving said film through said light in the azimuth direction, a heat reflecting filter and a monochromatic filter between said light source and said signal film, a conical lens located between said collimating means and said signal film to compensate for changes of focus with range on said signal film, means located between said mask and said conical lens for collimating the light in the azimuth direction, a recording film, a second mask adjacent said film, said second mask having an output slit therein, a first lens located between said signal film and said recording film for integrating the light information from said signal film in the azimuth direction and for focusing it on said slit, a second lens which together with said first lens images the range information from said signal film on said output slit.

10. An apparatus for processing a signal film from an airborne coherent side-looking radar, having thereon Doppler frequency azimuth target information along the length of the film and range information across the film, comprising: a signal film, means for producing a beam

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of monochromatic light, means for moving said film through said light in the azimuth direction, a first mask having a slit therein located between said beam producing means and said film to permit light to pass along a path through said film, said slit being narrow in the azimuth direction and elongated in the range direction, said mask being tilted with respect to said beam path in the longer dimension of said slit, means located between said mask and said film for collimating the light in the azimuth direction, a cylindrical lens with its axis perpendicular to greater dimension of said slit located between said collimating means and said signal film, a recording film, a second mask adjacent said film, said second mask having an output slit therein, an astigmatic lens system located between said signal film and said recording film, said lens system having a first lens therein for integrating the light information from said signal film in the azimuth direction and for focusing it on said slit, said lens system having a second lens which together with said first lens images the range information from said signal film on said output slit.

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2,943,315	6/1960	Rosenthal	343—7.7

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