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REPLY TO
ATTN OF: GP

11-24-70

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,532,894

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) : NA

NASA Patent Case No. : XGS-05715

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

Yes ☐ No ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

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Enclosure
Copy of Patent cited above

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(NASA CR OR TMX OR AD NUMBER)
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(CODE)
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(CATEGORY)
FACILITY FORM 602

Oct. 6, 1970 E. J. DEVINE 3,532,894

OPTICAL TRACKER HAVING OVERLAPPING RETICLES ON PARALLEL AXES

Filed Sept. 15, 1967 4 Sheets-Sheet 1

FIG. 2

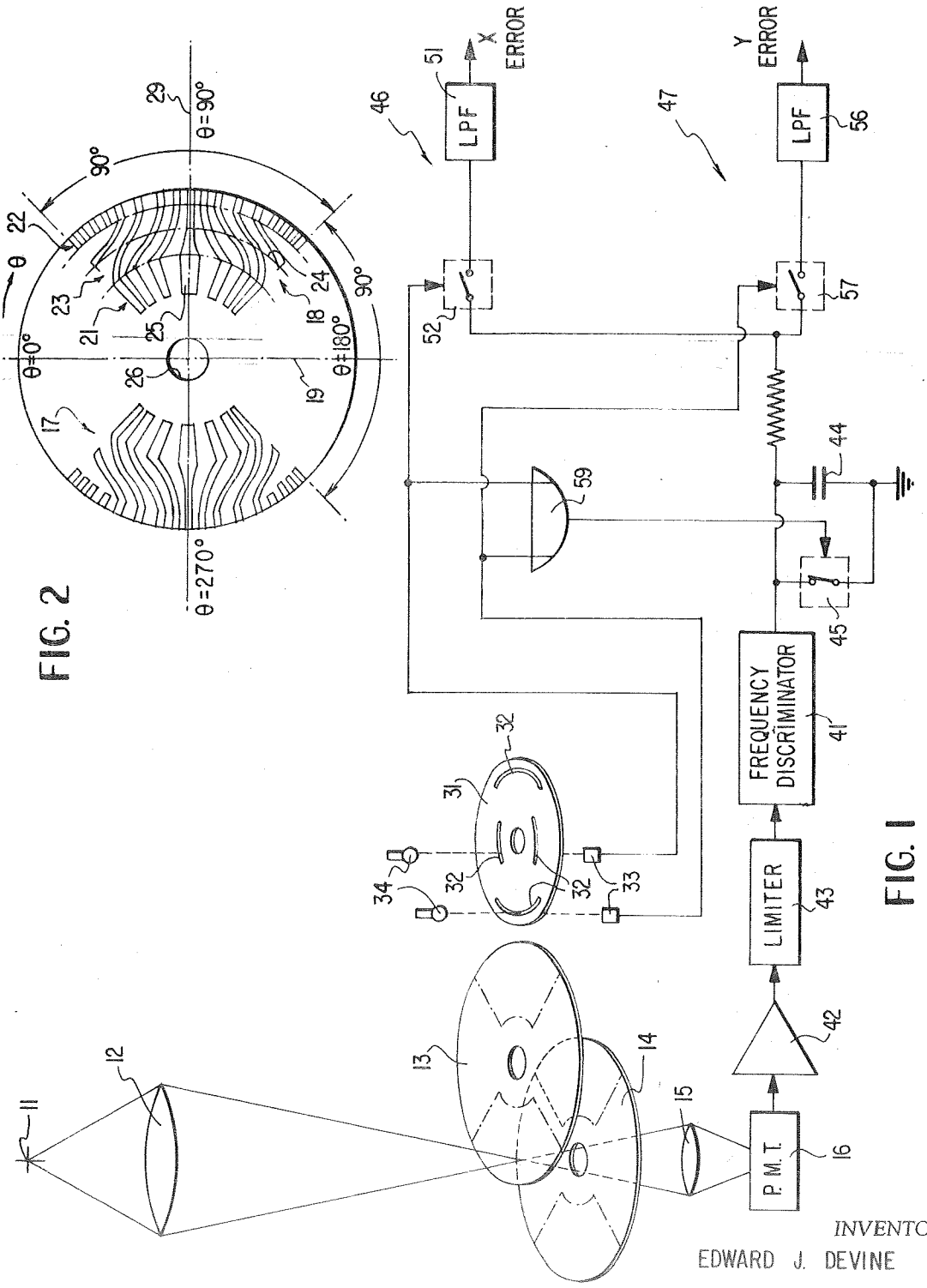

FIG. 1

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Oct. 6, 1970 E. J. DEVINE 3,532,894

OPTICAL TRACKER HAVING OVERLAPPING RETICLES ON PARALLEL AXES

Filed Sept. 15, 1967 4 Sheets-Sheet 2

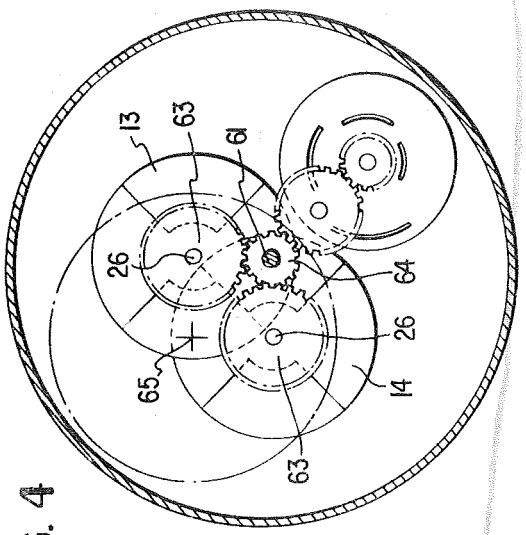

FIG. 4

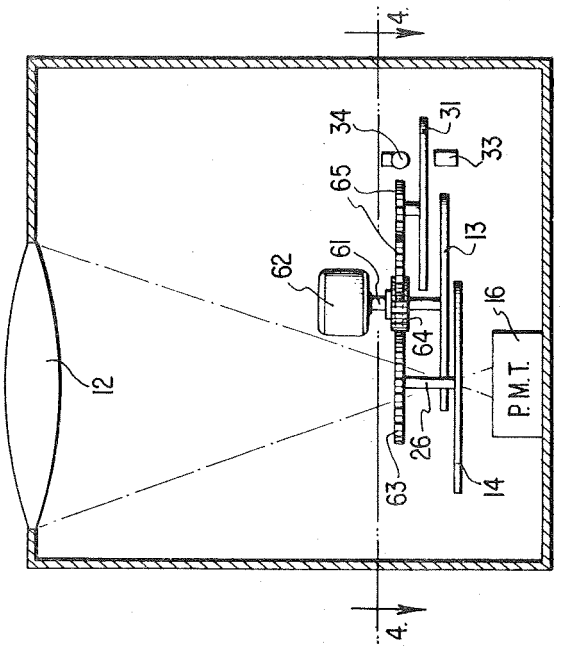

FIG. 5

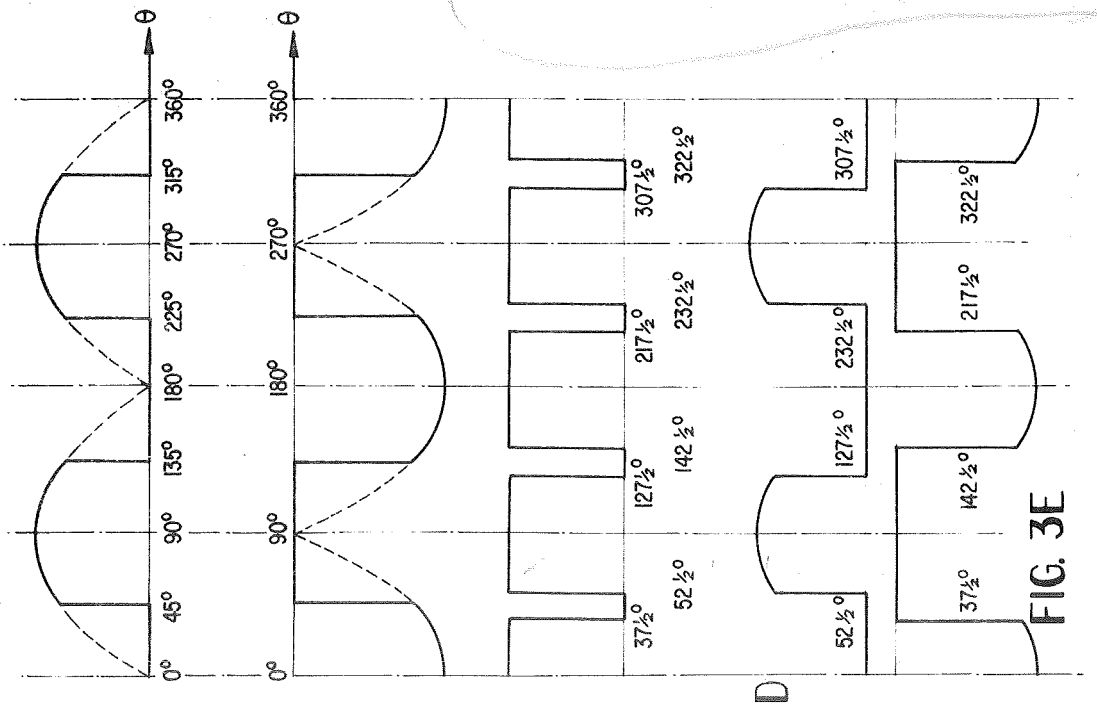

FIG. 3A

FIG. 3B

FIG. 3C

FIG. 3D

FIG. 3E

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Oct. 6, 1970 E. J. DEVINE 3,532,894

OPTICAL TRACKER HAVING OVERLAPPING RETICLES ON PARALLEL AXES

Filed Sept. 15, 1967 4 Sheets-Sheet 3

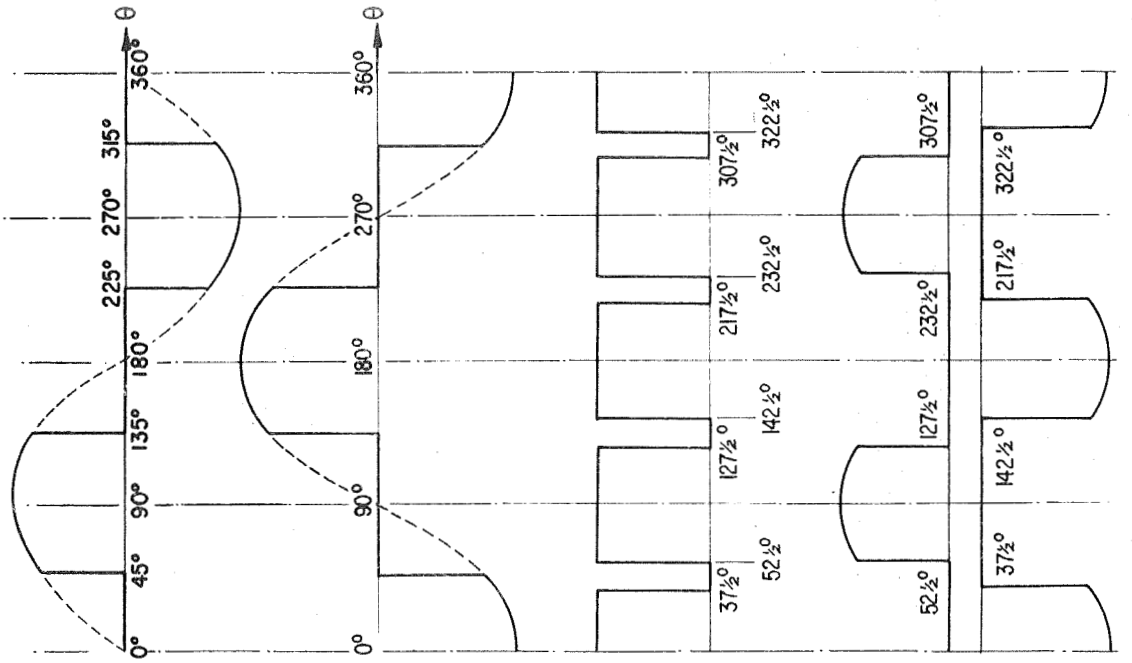

FIG. 8A fx FIG. 8B FIG. 8C FIG. 8D FIG. 8E

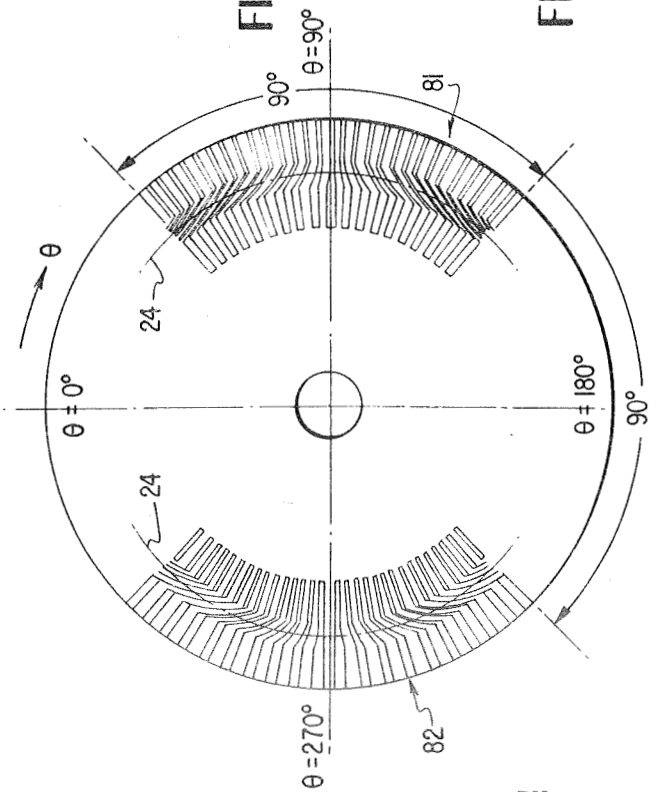

FIG. 6

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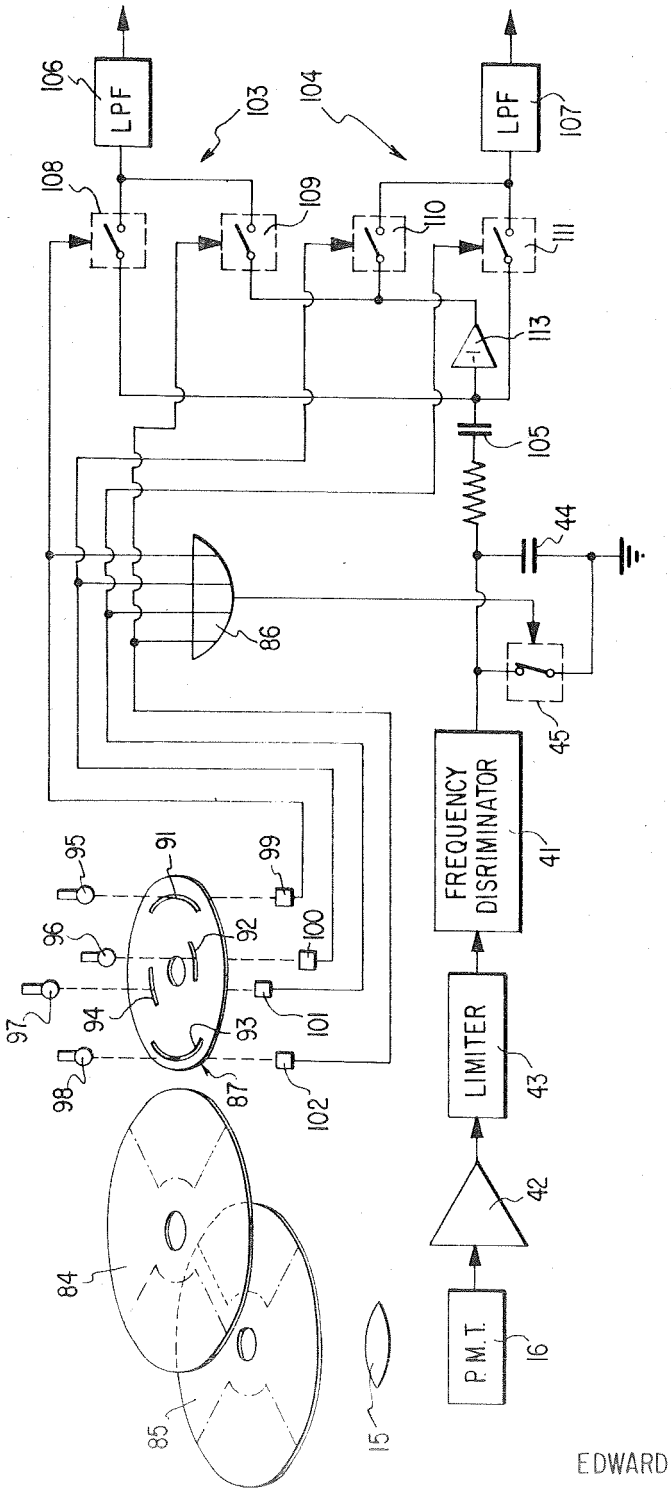
Oct. 6, 1970 E. J. DEVINE 3,532,894

OPTICAL TRACKER HAVING OVERLAPPING RETICLES ON PARALLEL AXES

Filed Sept. 15, 1967 4 Sheets-Sheet 4

FIG. 7



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United States Patent Office

3,532,894
Patented Oct. 6, 1970

3,532,894

OPTICAL TRACKER HAVING OVERLAPPING RETICLES ON PARALLEL AXES

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Filed Sept. 15, 1967, Ser. No. 668,257
Int. Cl. G01d 5/36; G01j 5/20
U.S. Cl. 250—233 8 Claims

ABSTRACT OF THE DISCLOSURE

An optical tracker comprises a pair of frequency modulation reticles, positioned on separate transparent overlapping carriers so that the two reticle patterns are spatially phase displaced by 90° relative to an image of a tracked object. A single photodetector responds to the image chopped by the two reticles to drive X and Y signal channels through an FM discriminator.

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates generally to optical trackers and more particularly to an optical tracker employing a pair of frequency modulation reticles phase displaced from each other spatially by 90° relative to an image of a tracked object.

Optical trackers for determining the position of point sources, such as stars, generally employe reticles having either amplitude modulation or frequency modulation characteristics. Reticles of the latter type are generally preferred because of greater signal-to-noise ratio with regard to fields of view having multiple sources. In particular, an optical tracker employing a frequency modulation reticle tracks the brightest image to the exclusion of all other images in a field of view. Systems employing amplitude modulation reticles generally, however, derive signals indicative of the average position of all light sources in the field of view. Thus, if a field of view includes two light sources, systems employing amplitude modulation reticles generally derive signals indicating the presence of a single apparent image at a position between the two actual sources. In contrast, an optical tracker employing a frequency modulation reticle derives an indication of the position of the source having the greatest intensity.

Frequency modulation reticles are generally classifiable into two different types; those in which the center of the image field is directed at the center of a reticle carrier disk and a second class wherein the center of the image field is directed at a point removed from the reticle carrier disk center. In the former type, the reticle disk includes a plurality of radially extending, alternately opaque and transparent sectors having a common point at the disk center. The differing sectors have varying degrees of arc, as a function of angular and radial position, whereby a photodetector responsive to light chopped by the reticle pattern derives a signal having maximum frequency swings proportional to the displacement of the image from the reticle and disk center and an instantaneous frequency commensurate with reticle angular position.

In the second type of FM reticle, the "center" of the reticle pattern is located at a radial position removed from the center of the carrier disk. An image focussed on the "center" of the reticle pattern causes a photodetector to derive a constant frequency output signal. The reticle pattern is variable as a function of radial position and angle. Thereby, images focussed on the reticle at regions removed from the reticle "center" modulate the instantaneous frequency of light chopped by the reticle, with the maximum frequency swing from the constant frequency being proportional to the displacement between the image and the reticle "center."

It has been found that reticles employing FM patterns wherein the reticle center is removed from the center of the carrier disk produce more accurate signals than trackers employing reticles having the center of the disk and the reticle pattern in coincidence. Poorer accuracy results with the latter type of system because resolution is inherently poorest at the common merging point of all the radially extending sectors. In contrast, reticles wherein a null is indicated by a constant, finite output frequency have excellent resolution at the center of the field of view because thereat the alternate opaque and transparent segments are diverging away from the edge of the carrier disk. Of course, it is desirable for resolution to be as great as possible at the center of the reticle pattern because optical trackers are generally employed in servo systems attempting to position a source at the center of the reticle pattern.

In the past, optical trackers employing frequency modulation reticles have generally employed two separate optical systems to derive signals indicative of the X and Y positions of a tracked image. The separate optical systems have generally each employed one reticle, one focussing telescope and one photomultiplier tube. In addition to requiring a relatively large amount of expensive equipment, such a system requires an excessive amount of volume, a condition that cannot be tolerated in outer space applications.

According to the present invention, the X and Y coordinate positions of an image are determined with an optical tracker by employing a pair of frequency modulation reticle patterns of the type wherein the pattern center is removed from the disk center. The reticles are spatially removed from each other by 90° with respect to the image and a single light detector.

The reticles are preferably mounted on separate, overlapping transparent disks, whereby the image is chopped by the reticle on the first disk and subsequently chopped by the reticle on the second disk. To provide for successive chopping of the image by the two reticles, the reticle on each disk includes two separate segments, each traversing an arc of approximately 90°. Thereby, when the reticle on one disk is chopping the image, the reticle on the second disk is removed from the image and only the transparent portion of the disk is in the path to the light detector.

In response to the image being chopped by the FM reticles, the photodetector derives a series of variable frequency waveforms, having frequency swings proportional to the X and Y positions of the optical image passing through the reticles. The variable frequency signals are detected by a frequency discriminator, the output of which includes a series of variable amplitude, half wave sinusoids. The half wave sinusoids alternate in maximum amplitude in response to the alternate chopping by the two reticles, whereby alternate peaks of the discriminator output indicate the X and Y positions of the image being tracked. The alternate peaks are coupled to separate channels to derive indications of the direction and amplitude of the image from the centers of the reticle patterns.

It has been found through experimentation that the output of the frequency discriminator has a tendency to generate large amplitude pulses in response to sudden changes in the FM signal applied thereto. The large amplitude signals or spikes are derived for a relatively short duration subsequent to switching between the X and Y reticle patterns. Such spikes, if allowed to be coupled to

the X and Y amplitude detecting channels, could introduce serious error in the positional information derived.

According to a further aspect of the present invention, the derivation of signal spikes is avoided by gating the output of the frequency discriminator to the position detecting channels for a time period slightly less than the time required for the 90° arc of each reticle to be positioned before the light detector and in synchronism with rotation of the reticle carrier disks.

It is, accordingly, an object of the present invention to provide a new and improved frequency modulation optical tracker.

It is another object of the present invention to provide a frequency modulation optical tracker wherein only a single optical system is required.

It is another object of the present invention to provide an optical tracker employing frequency modulation reticles having sudden transitions therein which have a tendency to cause an FM discriminator to derive relatively large amplitude, spurious outputs, and wherein means are provided for eliminating such spurious outputs.

It is another object of the present invention to provide a new and improved optical tracker employing a pair of frequency modulation reticles displaced in phase 90° relative to each other for chopping an optical image onto a single photodetector.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic diagram of the optical and electronic systems employed in a preferred embodiment of the present invention;

FIG. 2 is a plan view of a single frequency modulation reticle of the type employed in the system of FIG. 1;

FIGS. 3A–3E are waveforms indicating the manner in which the system of FIG. 1 functions;

FIG. 4 is a plan view of the reticles and the drives therefor in a preferred embodiment of the present invention;

FIG. 5 is a side view of the preferred embodiment illustrated by FIG. 4;

FIG. 6 is a plan view of a frequency modulation reticle employed in a second embodiment of the invention;

FIG. 7 is a schematic diagram of the optical and electronic systems employed in an embodiment of the invention utilizing a pair of reticle disks of the type illustrated by FIG. 6; and

FIGS. 8A–8E are waveforms indicating the manner in which the system of FIG. 7 functions.

Reference is now made to FIG. 1 of the drawings, wherein there is illustrated in schematic form a system for determining the X, Y coordinate positions of point source **11** of optical energy. The image of source **11** is focussed by lens **12** at a point approximately midway between spatially overlapping, transparent reticle carrying disks **13** and **14**. Disks **13** and **14** are positioned in parallel planes and are relatively close to each other, whereby the image of source **11** is substantially focussed on each of the reticle carrying disks. Light chopped by disks **13** and **14** is focussed by lens **15** on a light detector, photomultiplier tube **16**.

Light chopping reticles **13** and **14** are identically constructed in the manner indicated by FIG. 2. The disk illustrated by FIG. 2 is generally transparent and includes a pair of identical frequency modulation patterns **17** and **18** which comprise the reticle. Each of patterns **17** and **18** extends for an arc of 90° on opposite sides of centerline **19**. The edges of reticle patterns **17** and **18** are separated from each other by 90°, whereby perfect symmetry of the different reticle patterns is achieved. Since the two reticle patterns **17** and **18** are identical, being mirror images of each other relative to centerline **19**, a description of pattern **18** suffices for both.

Reticle pattern **18** includes three separate segments, namely inner and outer constant frequency modulation amplitude segments **21** and **22** and center variable frequency modulation amplitude segment **23**. Variable frequency modulation amplitude segment **23** includes a plurality of alternate opaque and transparent, radially extending fingers having variable sectors as a function of angle and radius. The fingers are positioned so that with constant disk rotation velocity the instantaneous chopping frequency of a light image focussed on a circle defined by radius **24** is constant as a function of disk rotation angle. As the fingers progress outwardly from and inwardly of radius **24**, the maximum and minimum chopping frequencies increase and decrease, respectively, as a function of rotation angle, assuming constant disk rotation velocity.

To achieve these variations in chopping frequency, symmetrical opaque section **25** is positioned along line **29**, at an angle 90° displaced from centerline **19**. Opaque section **25** has a relatively wide base at its point nearest the center **26** of the disk and sides that taper inwardly with increasing radius. The transparent sections adjacent opaque section **25** are both unsymmetrical and have a greater length along radii less than radius **24** than those portions of the transparent segments are radii greater than radius **24**. In a similar manner, a plurality of successive, alternate opaque and transparent sections alternately are provided to 45° on either side of line **29**. Asuming constant rotation velocity of the disk, the pattern of alternate opaque and transparent sections in reticle pattern **18** causes light to be chopped in conformance with:

$$f=f_o+A(r-r_o)\sin\theta \tag{1}$$

where:

f is the instantaneous frequency of light chopped by the disk;
f_o is the frequency of light chopped by the disk if the image is focussed on the circle defined by radius **24**;
A is a constant:
r is the radial position of the light image in sector **23**;
r_o is the length of radius **24**; and
θ is the angular position of the disk relative to line **19**.

Equation 1 applies only for light chopped by reticle pattern **23**, i.e., Equation 1 applies only when the light image falls within the boundaries defined by $45°\leq\theta\leq 135°$ and for $r_{min}\leq r_{max}$, where r_{max} and r_{min} are the radii of the pattern sector **23** farthest from and closest to disk center **26**, respectively.

To limit the frequency excursion derived from photomultiplier **16**, and yet provide a finite frequency output from the pohtomultiplier in response to optical images focussed at radii outside the limits of sector **23**, as defined by r_{min} and r_{max}, patterns **21** and **22** are provided. Each of patterns **21** and **22** includes a plurality of radially extending, alternate opaque and transparent fingers. Each of the fingers in patterns **21** and **22** covers the same degree of arc as the end of each finger to which it is connected in pattern **23**. Since the fingers of patterns **21** and **22** cover the same arc length as the ends of the fingers of pattern **23** to which they are connected, the fingers of patterns **21** and **22** are of a constant frequency nature and limit the maximum and minimum frequency excursions derived from photomultiplier tube **16**.

While the reticle patterns **17** and **18** are identical, the mathematical relationship for pattern **17** differs slightly from that of pattern **18**. The difference in the mathematical relationship of the two patterns occurs because they are on opposite sides of centerline **19**, whereby photomultplier tube **16** derives frequencies having similar polarities relative to f_o for both reticle patterns **17** and **18**.

Hence, reticle pattern **17** causes photomultiplier tube **16** to derive an output signal in accordance with:

$$f=f-A(r-r_o)\sin\theta \qquad (2)$$

for $225°\leq\theta\leq315°$ and $r_{min}\leq r\leq_{max}$.

Returning now to the schematic diagram of FIG.1, disks **13** and **14** are mounted so that their reticle patterns are spatially displaced from each other by 90° relative to the focussed image and detector **16**, whereby the reticle pattern of disk **13** chops the optical image of source **11** while the transparent segment of disk **14** is in the path of the chopped optical energy. Similarly, but in an opposite manner, the transparent portion of disk **13** is intercepting the image of source **11** while the reticle pattern of disk **14** is chopping the image. Because of the 90° spatial separation of the reticles of disks **13** and **14**, the FM signals derived from photodetector **16** alternately represent the X and Y coordinate positions of source **11** relative to a common point between disks **13** and **14**. As seen infra, the 90° phase displacement of the signals chopped by disks **13** and **14** is achieved by displacing the disks equally from a common drive point, about which they are spatially displaced by 90°. The disks are connected to the common drive point, so that they are rotated in opposite directions at constant velocity.

To establish reference phases for separating the alternate frequency modulation waves derived from photomultiplier **16**, opaque phase reference disk **31**, driven synchronously with and at the same velocity as reticle disks **13** and **14**, is provided. Phase reference disk **31** includes four transparent arcuate sections **32**, each subtending an angle of 75°. Oppositely disposed transparent, arcuate sections **32** are at the same radius from the center of disk **31**, with adjacent ones of sections **32** at different radii. The four sections **32** are displaced from each other angularly by 90°. Positioned at the two radii of sections **32** from the center of disk **31** is a separate low intensity photodetector **33** and lamp **34** combination. Thereby, each of the two photodetectors **33** derives a finite, binary one output only while the two transparent sections **32** is aligned therewith to enable an optical path to be formed between it and the corresponding lamp **34**. The two photodetectors **33** thereby derive four reference phase rectangular waves, each having a duration commensurate with 75° of arc of reticle disks **13** and **14**, and being in 90° relative phase relationship.

The four reference phase signals dervied from photodetectors **33** and the FM signal generated by photomultiplier **16** are applied to the electronics unit of the present invention. The elctronics unit includes frequency discriminator **41** responsive to the variable frequency output of photomultiplier **16**, after suitable amplification by amplifier **42** and amplitude limiting by limiter **43**. Discriminator **41** includes circuitry for deriving a variable ampltude signal indicative of the departure of the frequency chopped by disks **13** and **14** from the reference chopping frequency associated with radius **24**. In particular, discriminator **41** derives a zero amplitude signal in response to the reference frequency being applied thereto, while positive and negative voltages are generated thereby in response to frequencies greater and less than the reference frequency. Across the output circuit of frequency discriminator **41** is connected capacitor **44**, shunted by the normally closed contacts of switch **45**.

The varying amplitude signal derived by frequency discriminator **41** across the plates of capacitor **44** is applied in parallel to phase detecting channels **46** and **47**, that derive signals proportional to the X and Y coordinate locations of the optical image of source **11**, relative to radii **24** of reticle disks **13** and **14**. Channel **46** includes normally open switch **52** series connected between the output of frequency discriminator **41** and the input of low pass filter **51** and responds to the reference phase signals generated by one of photodetectors **33**. Similarly, channel **47** comprises normally open switch **57**, connected in series between the output of discriminator **41** and the input of low pass filter **56**, but is responsive to reference phase signals 90° displaced from the reference phases supplied to channel **46**.

Switches **52** and **57** are connected to a different one of each of the photodetectors **33**, with switch **52** being closed in response to oppositely located transparent sections **32** passing in front of their associated photodetector **33**, and switch **57** being closed in response to transparent segments **32** passing light from lamp **34** to the other one of photodetectors **33**. Thereby, for each revolution of disk **31** each of switches **52** and **57** is closed twice, each time for slightly less than one-quarter of a revolution of reticle disks **13** and **14**, and the switches are closed at different times, displaced by 90°. On the other hand, normally closed switch **45** is controlled in response to the output of both of the photodetectors **33** so that the switch **45** is open from the 75° of arc covered by each of the opaque sections **32**. To this end, OR gate **59** is connected to be responsive to both of the photodetectors **33** and supplies a voltage waveform to open contacts **45** during the four 75° arc lengths.

To provide a better and more complete understanding of the present invention, reference is now made to the waveforms of FIGS. 3A–3E. In discussing the waveforms of FIGS. 3A–3E, it is assumed that reticle disk **13** is positioned to derive information indicative of the X coordinate position of source **11**, while disk **14** chops light from source **11** in accordance with the Y position thereof. In addition, it is assumed that source **11** is located at a position to cause the image thereof to be focussed at a point beyond radius **24** of disk **13**, while the image focussed on disk **14** is at a position interior of the disk relative to radius **24**.

The variation of frequency relative to f_o, as a function of rotation angle, θ, of disk **13**, derived from photomultiplier tube **16** in the X coordinate direction is indicated as the ordinate in FIG. 3A and comprises, for each cycle of rotation of reticle **13**, a pair of half wave sinusoids having frequency variations represented by Equations 1 and 2, supra. The frequency variations resulting from chopping of the image by reticle disk **13** occur only in the intervals $45°\leq\theta\leq135°$ and $225°\leq\theta\leq315°$. The amplitude of the frequency variation is positive relative to f_o, the reference frequency along radius **24**. As reticle disk **13** rotates, the chopping frequency increases from a minimum at $\theta=45°$ to a maximum at $\theta=90°$ and drops back to the minimum value at $\theta=135°$. The chopped light impinging on photomultiplier **16** as a result of disk **13** goes from a zero frequency to a finite frequency with a step jump and, theoretically, such a step should be derived from frequency discriminator **41**.

In response to the assumed conditions of the position of the optical image relative to reticle disk **14**, the frequency of light impinging on photomultiplier **16** occurs as indicated by the waveform of FIG. 3B. It is noted from FIG. 3B that frequency variations occur only in the region $0°\leq\theta\leq45°$, $135°\leq\theta\leq225°$ and $315°\leq\theta\leq360°$. In the other regions, $45°\leq\theta\leq135°$ and $225°\leq\theta\leq315°$, there is no output of photomultiplier **16** due to chopping by reticle wheel **14**. This is the result that is to be expected since reticle wheels **13** and **14** have patterns displaced from each other by 90° and include alternate chopping and transparent patterns.

A further observation from FIG. 3B is that the frequency variations are in the negative direction relative to f_o and the variations of FIG. 3A. This is to be expected as the image of source **11** is assumed to be at an interior point of the pattern of reticle disk **14** relative to radius **24**. It is also noted that the amplitude of the maximum swing of the waveform of FIG. 3B is greater than the frequency swing of FIG. 3A. Such a swing occurs because the optical image in the Y direction is assumed to be positioned farther from reference radius **24** than the optical image in the X direction.

Hence, the maximum frequency excursions derived from photomultiplier **16** for the alternate segments of reticle disks **13** and **14** result in materially different frequency variations from the photomultiplier. The frequency variations derived from photomultiplier **16** are applied to frequency discriminator **41**, including circuitry whereby a zero output voltage is derived in response to an input frequency equal to the frequency associated with radii **24** of reticle disks **13** and **14**. Hence, if one or the other of reticle disks **13** and **14** has its pattern aligned with the lines associated with X=0 or Y=0, frequency discriminator **41** derives a zero output for that particular interval. The discriminator theoretically derives during all other intervals, waveforms of the types illustrated by FIGS. 3A and 3B.

It has been found, however, that the theoretical waveforms of FIGS. 3A and 3B are not actually derived from frequency discriminator **41** unless switch **45** is included. Sudden variations occurring as a result of transitions in the reticle pattern cause large amplitude pulses to be derived by frequency discriminator **41** at the edge of the reticle patterns, e.g., when $\theta=135°$ in the waveforms of FIGS. 3A and 3B. To prevent such spikes from being coupled to detector channels **46** and **47**, OR gate **59** responds to photodetectors **33** to feed the waveform of FIG. 3C to switch **45**. Thereby, switch **45** is closed during the transition period, and for 7.5° of arc rotation of reticles **13** and **14** to either side of the transition period.

Hence, frequency discriminator **41**, in combination with switch **45** and capacitor **44**, feeds a series of varying amplitude and polarity spaced pulses to detector channels **46** and **47** during each rotation cycle of reticle disks **13** and **14**. During the first 37.5° of each cycle of rotation, switch **57** in channel **47** is closed while switch **52** in channel **46** is maintained open in response to signals from photodetectors **33**. The output of frequency discriminator **41** is negative during the 37.5° interval being considered, whereby the negative D.C. signal indicated in FIG. 3E in the interval $0°\leq\theta\leq37.5°$ is applied to low pass filter **56**. During the next 15°, the output of frequency discriminator **41** is shunted to ground by switch **45**.

In the interval $52.5°\leq\theta\leq127.5°$, photodetectors **33** feed signals to channels **46** and **47**, whereby switch **52** is closed while switch **57** is open. In said interval, the output of frequency discriminator **41** is positive, as indicated by FIG. 3A. The positive output of frequency discriminator **41** occurring during the interval $52.5°\leq\theta\leq127.5°$ is passed through switch **52** to low pass filter **51** as indicated by FIG. 3D, which averages the positive signal applied thereto to derive a positive D.C. signal. The positive D.C. signal derived by low pass filter **51** is proportional to the amplitude and direction of the image of source **11** relative to radius **24** of reticle disk **13** to provide an indication of the image displacement in the X direction.

During the next interval when one of photodetectors **33** is activated, $142.5°\leq\theta\leq217.5°$, switch **57** is again closed to the exclusion of switch **52**, whereby the negative output of frequency discriminator **41** is coupled to low pass filter **56**, as indicated by FIG. 3E. Low pass filter **56** responds to negative output of frequency discriminator **41** to derive a negative voltage proportional to the displacement of image **11** relative to reference radius **24** of reticle disk **14** and the image position in the Y direction.

During the following interval when one of the photodetectors **33** is activated, $232.5°\leq\theta\leq307.5°$, switch **52** is again closed while the switch in channel **47** is open and the positive output of discriminator **41** is coupled to low pass filter **51**. In the manner described, the output signals of discriminator **41** are alternately fed to channels **46** and **47** that derive D.C. signals indicative of the X and Y positions of the optical source.

It is thus seen that each of low pass filters **51** and **56** is connected to the output of frequency discriminator **41** for approximately one-half of each cycle of rotation of reticle disks **13** and **14**, as indicated by FIGS. 3D and 3E. The low pass filters smooth the pulsating voltages applied thereto to derive D.C. signals indicative of the amplitude and position of the optical image relative to the reference radii **24** of reticle disks **13** and **14**. These D.C. signals may be utilized to control servo mechanisms for controlling the position of image **11** on the two reticle disks in a manner well known to those skilled in the art.

Reference is now made to FIGS. 4 and 5 of the drawings wherein details of the mechanical construction of the optical tracker of the present invention are illustrated in plan and side views, respectively. From FIG. 4, reticle disks **13** and **14** are positioned so that their reticle patterns lie in substantially parallel relationship. The 90° spatial relationship between the reticle patterns and the optical image is obtained by positioning the centers of disks **13** and **14** equally from the center of drive shaft **61** of motor **62**. Centers **26** of reticle disks **13** and **14** are located along lines orthogonal to each other and intersecting the center of drive shaft **61**. To drive reticle disks **13** and **14** at a constant velocity and in opposite directions, the disks carry gears **63**, concentric with their centers and engaging gear **64** driven by shaft **61**.

The positional relationship of reticle disks **13** and **14** reltaively to shaft **61** establishes an $X=0$, $Y=0$ position for the image of source **11** at point **65**, equally spaced from the centers of reticle wheels **13** and **14**. Thus, the centers of reticle wheels **13** and **14** and shaft **61**, as well as point **65**, define the corners of a square with the two reticle centers at opposite apexes of the square and the center of shaft **64** and point **65** at the other apexes of the square. Positioned immediately below point **65** is photomultiplier tube **16**, whereby the photomultiplier tube generates outputs commensurate with the reference frequency in response to the star image impinging on reference radii **24** of reticle wheels **13** and **14**.

To provide the phase reference signals and prevent light from lamps **34** from interfering with light from source **11**, disk **31** is driven by motor **62** via gears **64** and **65**. Gear **65** extends in a direction 180° displaced from the diagonal between shaft **61** and point **65** to minimize light interference between lamps **34** and photodetector **16**.

While the system described in conjunction with FIGS. 1–3 is noted for its simplicity, it has the disadvantage of requiring D.C. coupling between frequency discriminator **41** and demodulation channels **46** and **47**, whereby drift in the discriminator output causes errors to be derived in the indications of the X and Y positions of radiation source **11**. D.C. coupling between discrminator **41** and channels **46** and **47** is necessary because of the full wave reticle pattern of the disk illustrated by FIG. 2, that results in a D.C. output of freqeuncy discriminator **41** for any particular information channel, as noted by the waveforms of FIGS. 3A–3E.

To avoid the problems associated with D.C. coupling between the output of frequency discriminator **41** and demodulator channels **46** and **47**, the reticle disk of FIG. 6 is utilized instead of the disk of FIG. 2. The reticle disk of FIG. 6 is similar to the disk of FIG. 2 in that a pair of FM reticle patterns **81** and **82** is provided and these patterns are separated by transparent sections having an arc length of approximately 90°. The reticle patterns of the FIG. 6 disk, however, are not mirror images of each other, but can be represented as a true sinusoid, such as defined by Equation 1, within the boundaries defined by $45°\leq\theta\leq135°$; $225°\leq\theta\leq315°$, for $r_{min}\leq r\leq r_{max}$. Hence, in the region $45°\leq\theta\leq135°$, reticle pattern **81** is identical with reticle pattern **18** of FIG. 2, and the fingers comprising the pattern converge as a function of increasing radius. In the region $225°\leq\theta\leq315°$, however, reticle pattern **82** is arranged so that there is a greater number of lines intercepting light from a source interiorly of centerline **24** than at radii greater than the centerline, whereby

the pattern fingers diverge as a function of increasing radius. Thereby, the frequency variation as a function of angular rotation of an image focussed on the reticle disk of FIG. 6, at any point removed from centerline **24**, is defined as a sinusoid as a function of angle in the regions $45° \leq \theta \leq 135°$; $225° \leq \theta \leq 315°$.

Because of the true sinusoidal pattern of the frequency modulation on the disk of FIG. 6, an optical tracker employig such disks includes circuitry modified relative to the circuitry of FIG. 1. The modified circuitry is illustrated by the schematic diagram of FIG. 7, wherein reticle disks **84** and **85** of the type shown by FIG. 6 are positioned in precisely the same manner as indicated supra in conjunction with FIGS. 4 and 5 for disks **13** and **14**. Reticle disks **84** and **85** intercept optical energy from a suitable variable position source whereby a chopped F.M. image impinges on photomultiplier tube **16**, the output of which is fed to frequency discriminator **41** via amplifier **42** and limiter **43**.

As in the system of FIG. 1, the output of frequency discriminator **41** is normally short-circuited by normally closed switch **45**, approximately at the same that a sudden transition occurs in the reticle pattern of disks **84** and **85** during four 15° periods of each revolution of reticle disks **84** and **85**. Switch **45** is opened in response to a finite output voltage of OR gate **86**. OR gate **86** is responsive to phase reference signals derived from disk **87**, that is rotated synchronously with and at the same velocity as reticle disks **84** and **85**. Phase reference disk **87** is generally similar to phase reference disk **31**, FIG. 1, but the former disk includes four transparent segments **91–94**, each lying along a diffeernt radius from the disk center and covering an arc of approximately **75°**. Each of transparent segments **91–94** cooperates with a separate lamp and photodetector pair, the lamps being denominated by reference numerals **95–98** and the photodetectors by reference **99–102**. The reference phase signals generated by photodetectors **99–102** are coupled to OR gate **86**, to open switch **45** during the intervals:

$0° \leq \theta \leq 37.5°$; $52.5° \leq \theta \leq 127.5°$;
$142.5° \leq \theta \leq 217.5°$; $232.5° \leq \theta \leq 307.5°$; and
$322.5° \leq \theta \leq 360°$.

The reference phase singals generated by photodetectors **99–102** are also coupled to phase detecting channels **103** and **104**, also responsive to the output of frequency discriminator **41** via the A.C. coupling path established by capacitor **105**. Channels **103** and **104** respond to the phase reference signals and the discriminator **41** output to derive D.C. signals propotrional to the X and Y locations of the image focussed on sinusoidal reticle disks **84** and **85**.

Demodulating channels **103** and **104** respectively include low pass filters **106** and **107**, selectively connected to the A.C. output of frequency discriminator **41** via normally open switches **108–111**. are directly connected to the inputs of filters **106** and **107** from frequency discriminator **41**, while switches **109** and **110** are connected to the filters via polarity reversing amplifier **113**, having a gain of minus one. Switches **108–111** are connected with photodetectors **99–102** so that the switches are closed during each revolution of reticle disks **84** and **85** in accordance with:

Switch closed:	θ
108	52.5°–127.5°
109	232.5°–307.5°
110	142.5°–217.5°
111	0°–37.5°; 322.5°–360°

To provide a more complete understanding of the manner in which the system of FIG. 7, incorporating a pair of reticle disks of the type shown by FIG. 6, functions, reference is made to the waveforms of FIGS. 8A–8E. FIGS. 8A and 8B are waveforms respectively illustrating the frequency variations in the output of photomultiplier tube **16** in response to chopping of an optical image by reticle disks **84** and **85** along the X and Y coordinate directions. The image chopped by reticle disk **84** is presumed to lie beyond the radius **24** thereof, whereby the frequency variation is positive above a reference level in the interval of $45° \leq \theta \leq 135°$ and negative in the interval $225° \leq \theta \leq 315°$. The frequency swing indicative of image position in the Y coordinate direction, resulting from chopping of the optical image by reticle disk **85**, is negative in the intervals of $0° \leq \theta \leq 45°$; $315° \leq \theta \leq 360°$, while the variation is positive for values of $135° \leq \theta \leq 225°$, since the Y position of the image is less than radius **24** of disk **85**. The frequency variations derived from photomultiplier tube **16** are converted into amplitude variations by frequency discriminator **41**, the output of which is positively shifted to a zero level during the intervals when none of the arcuate, transparent segments **91–95** on reference phase disk **87** allows light to impinge on photodetectors **99–102**, as indicated by the waveform of FIG. 8C.

The two opposite polarity sinusoidal like, pulse waveforms of FIG. 8A are converted into a pair of positive going sinusoidal like waveforms, having the shape indicated by FIG. 8D, by the circuitry including switches **108** and **109**. This relationship is seen by noting that in the interval of $52.5° \leq \theta \leq 127.5°$, switch **108** is closed, whereby most of the information in the positive going portion of the waveform of FIG. 8A is coupled directly to low pass filter **106**. During the interval of

$$232.5° \leq \theta \leq 307.5°$$

the negative portion of the waveform of FIG. 8 is coupled, in polarity inverted form, to low pass filter **106**, because switch **109** is closed during the stated interval and the discriminator **41** output is connected to the filter via phase inverting amplifier **106**.

In a similar manner, low pass filter **107** responds to the waveform of FIG. 8B, to derive the negative going pulsating waveform of FIG. 8E. This is seen by noting that in the intervals of $0° \leq \theta \leq 37.5°$, and

$$322.5° \leq \theta \leq 360°$$

switch **111** is closed, whereby the negative going portion of the frequency discriminator **41** output is coupled to low pass filter **107**. In the interval of $142.5° \leq \theta \leq 217.5°$, switch **110** is closed, whereby the positive output of frequency discriminator **41** is inverted to a negative going waveform that is coupled to the input of low pass filter **107**. Filters **106** and **107** respond to the half-wave rectified inputs thereof to derive positive and negative voltages respectively indicative of the position of an optical image focussed on reticle disks **84** and **85**.

While I have described and illustrated several specific embodiments of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims.

I claim:

1. A tracker for a source of optical energy comprising first and second reticles, each of said reticles positioned on respective parallel displaced axes of rotation in a spatially overlapping relationship, each of said reticles having alternate frequency modulation patterns and transparent sectors, means for rotating said reticles in synchronism about said axes such that said patterns alternately frequency modulate the optical energy, said patterns chopping light at a constant reference frequency along an arc of constant radius, optical detector means responsive to optical energy propagating through said patterns, means for substantially focussing an image of said source on both of said reticles and for directing the image chopped by said patterns on said detector means, a frequency discriminator coupled with said detector means, said discriminator deriving a predetermined, constant amplitude output signal in response to the detector

deriving a signal equal in frequency to said reference frequency, means for generating a first series of reference pulses, each of said first pulses occurring in coincidence with the chopping of light by said patterns on said first reticle, means for generating a second series of reference pulses, each of said second pulses occurring in coincidence with the chopping of light by said patterns on said second reticle, and first and second gating means coupled to the output of said discriminator, said first gating means, further, being coupled to said first generating means and rendered conductive by each of said first pulses in coincidence with the chopping of light by said first reticle, and said second gating means, further, being coupled to said second generating means and rendered conductive by each of said second pulses in coincidence with the chopping of light by said second reticle for deriving indications of the coordinate positions of the image substantially focussed on said reticles.

2. The tracker of claim 1 wherein said means for rotating comprises a constantly rotating shaft, a drive for each of said reticles at the center of each reticle, said drives being driven by said shaft, said centers being equally spaced from said shaft along lines extending at right angles to each other.

3. The tracker of claim 1 wherein said patterns produce sudden frequency transitions in an output of said detector means, and means for decoupling signals from said gating means during said transitions.

4. The tracker of claim 3 wherein said means for decoupling signals includes an OR gate actuated by said reference pulses and a switch interposed between said discriminator and said gating means and responsive to said OR gate to decouple said discriminator from said gating means during said transitions.

5. The tracker of claim 1 wherein each of said frequency modulation patterns have at least one segment having radially extending fingers and covering an arc length of substantially 90°, said fingers having the same separation at all other radii, and a transparent segment at all angles other than those traversed by said at least one finger including segment and at the radii of said at least one finger including segment.

6. The tracker of claim 5 wherein each pattern includes a pair of said finger including segments, said transparent segment separating said finger including segments by arc lengths of approximately 90°, one of said finger including segments having the fingers thereof diverging as a function of increasing radius, the other of said finger including segments having the fingers thereof converging as a function of increasing radius, and only A.C. coupling means connecting said discriminator to said outputs.

7. The tracker of claim 6 wherein said patterns produce sudden frequency transitions in an output of said detector means, and means for decoupling signals from said gating means during said transitions.

8. The tracker of claim 7 wherein said means for decoupling signals includes an OR gate actuated by said reference pulses and a switch interposed between said discriminator and said gating means and responsive to said OR gate to decouple said discriminator from said gating means during said transitions.

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U.S. Cl. X.R.

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