United States Patent

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[54] **DOCUMENT VERIFIER USING PHOTOVOLTAIC CELL WITH LIGHT SENSITIVE BARS**
12 Claims, 14 Drawing Figs.

[52] U.S. Cl. **250/219,** 250/214; 356/71; 194/4
[51] Int. Cl. **G01n 21/32**
[50] Field of Search 250/219 (I), 219 (NG), 219 (F,DOC), 220 (SP), 206, 214, 211 (J); 356/71; 340/149, 149 (A); 356/209—211; 209/(PMSD); 194/4

[56] **References Cited**

UNITED STATES PATENTS

3,031,076	4/1962	DeClaris et al.	356/71X
3,158,748	11/1964	Laycak et al.	250/219
3,188,475	6/1965	Miller	250/211
3,206,606	9/1965	Burgo et al.	250/209X
3,370,986	2/1968	Amsterdam et al.	250/211X

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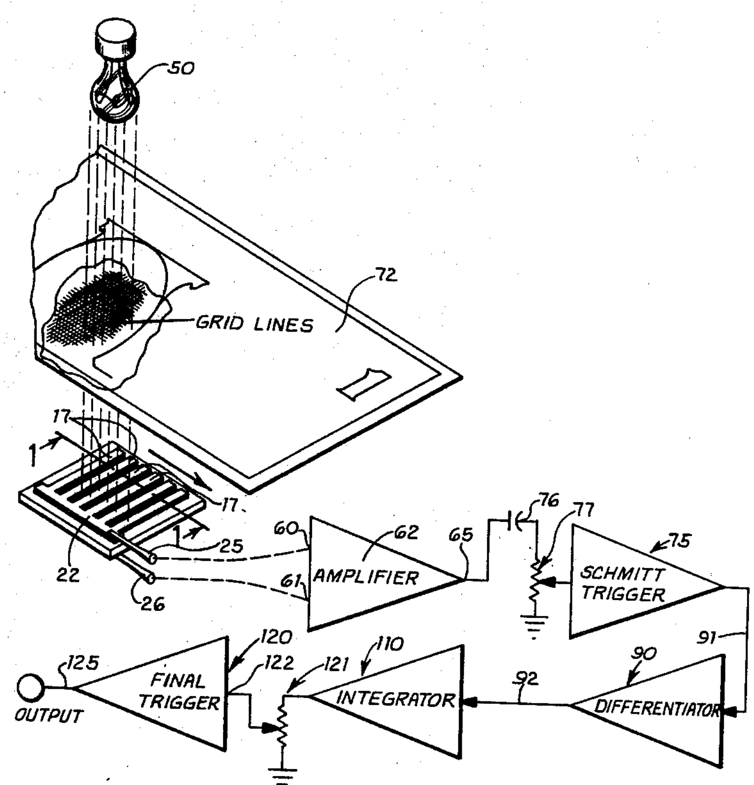
ABSTRACT: A dollar bill verifier including a photovoltaic cell having light sensitive bars approximately the same width as the black grid lines on the bill. An amplifier receives the output of the cell and couples it through a potentiometer to a Schmitt trigger. The Schmitt trigger is coupled through a differentiator, integrator and potentiometer to a switch.



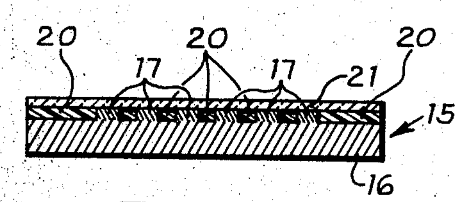


Fig.1

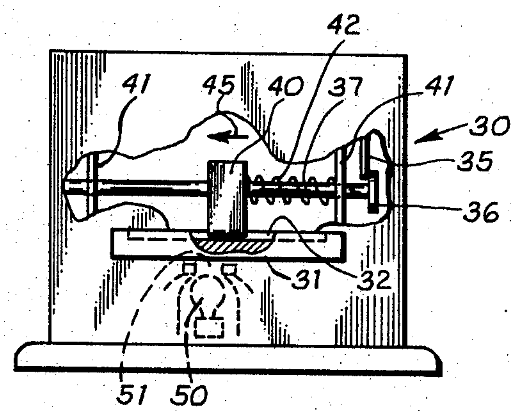


Fig.2

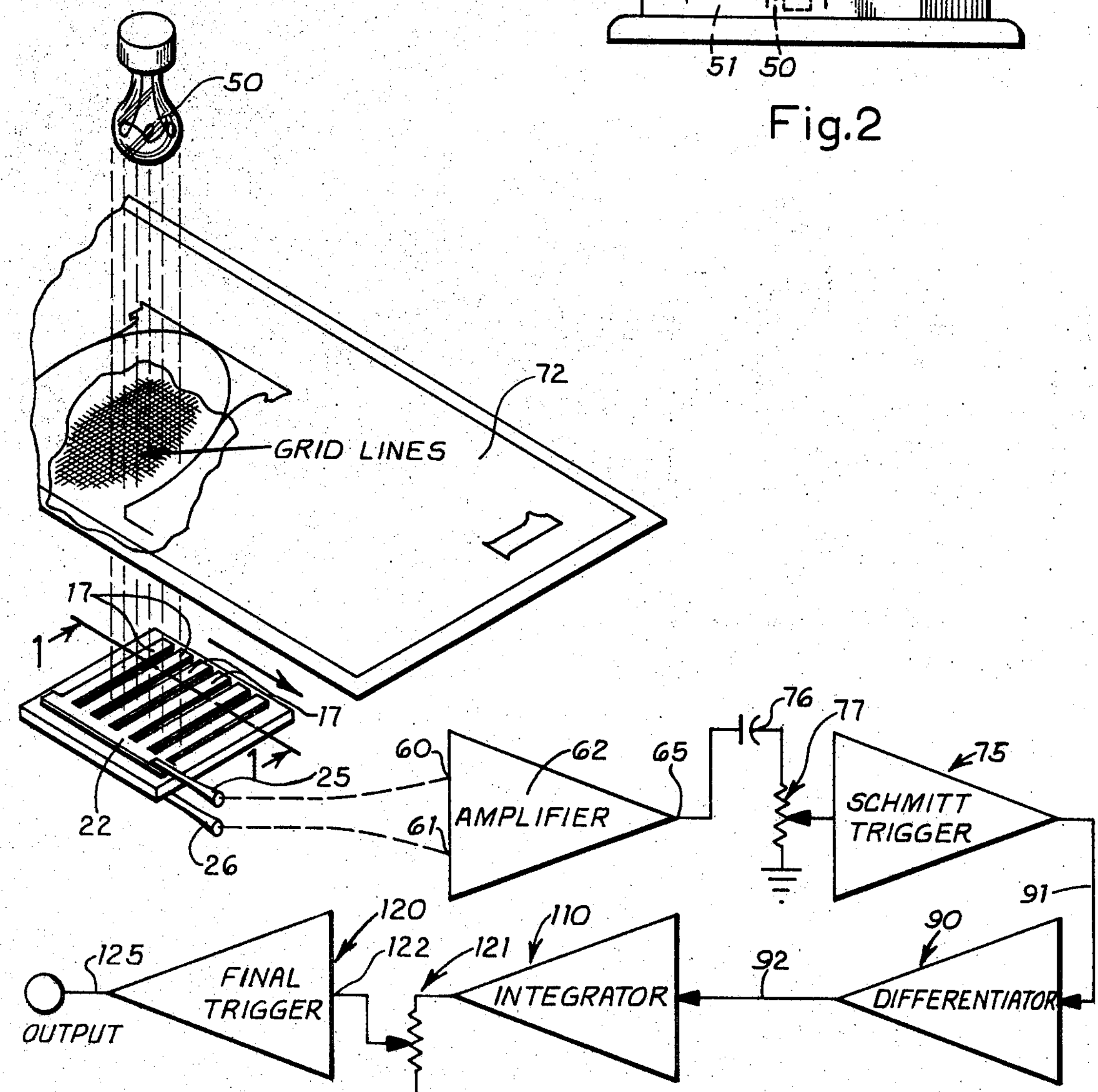


Fig.3

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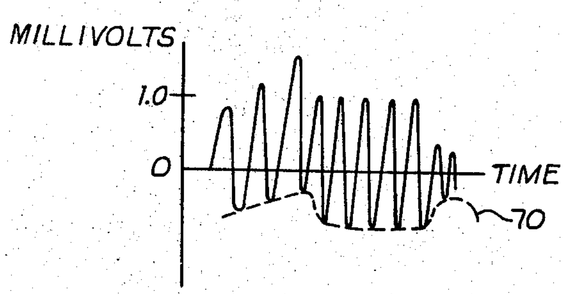

Fig.4

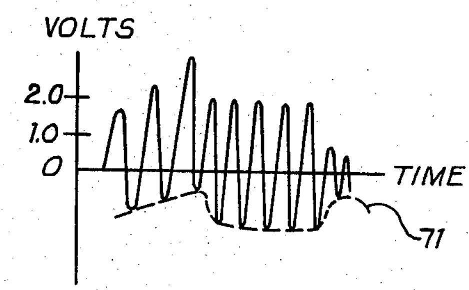

Fig.5

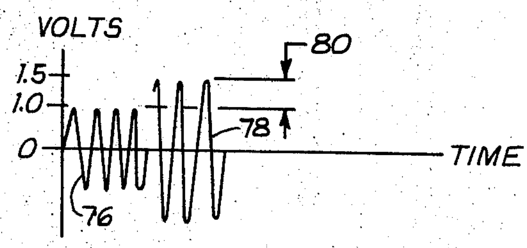

Fig.6

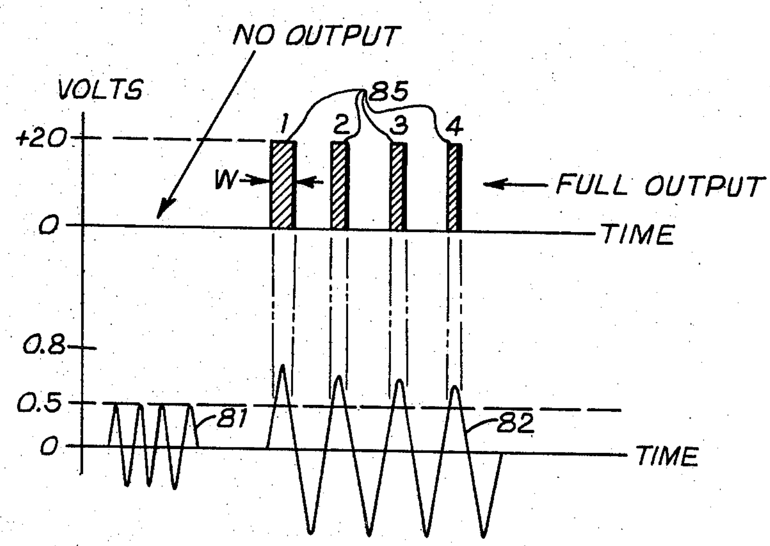

Fig.7

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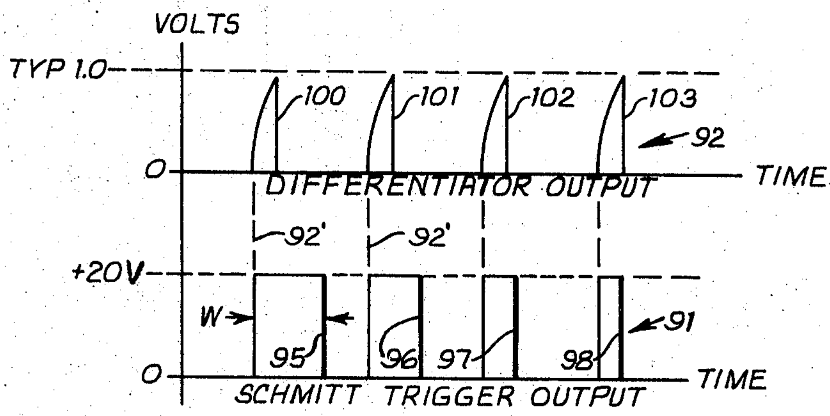

Fig.9

Fig.8

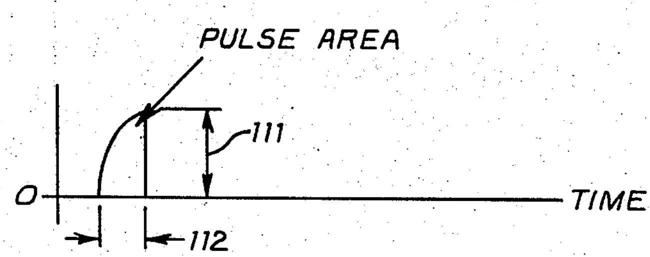

Fig.10

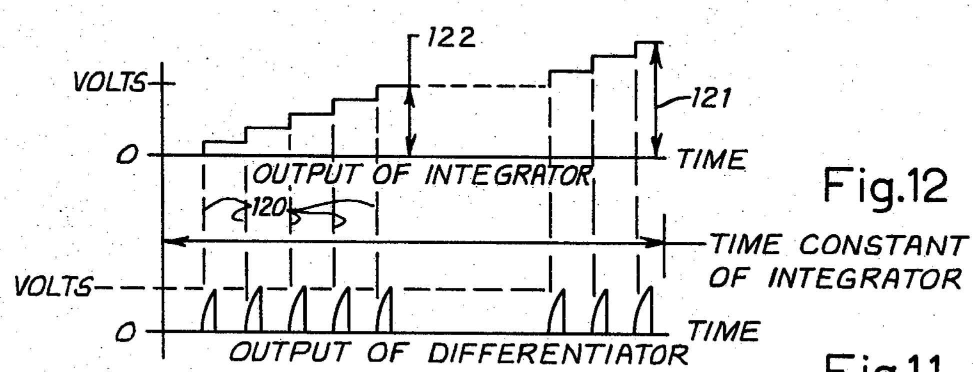

Fig.12

Fig.11

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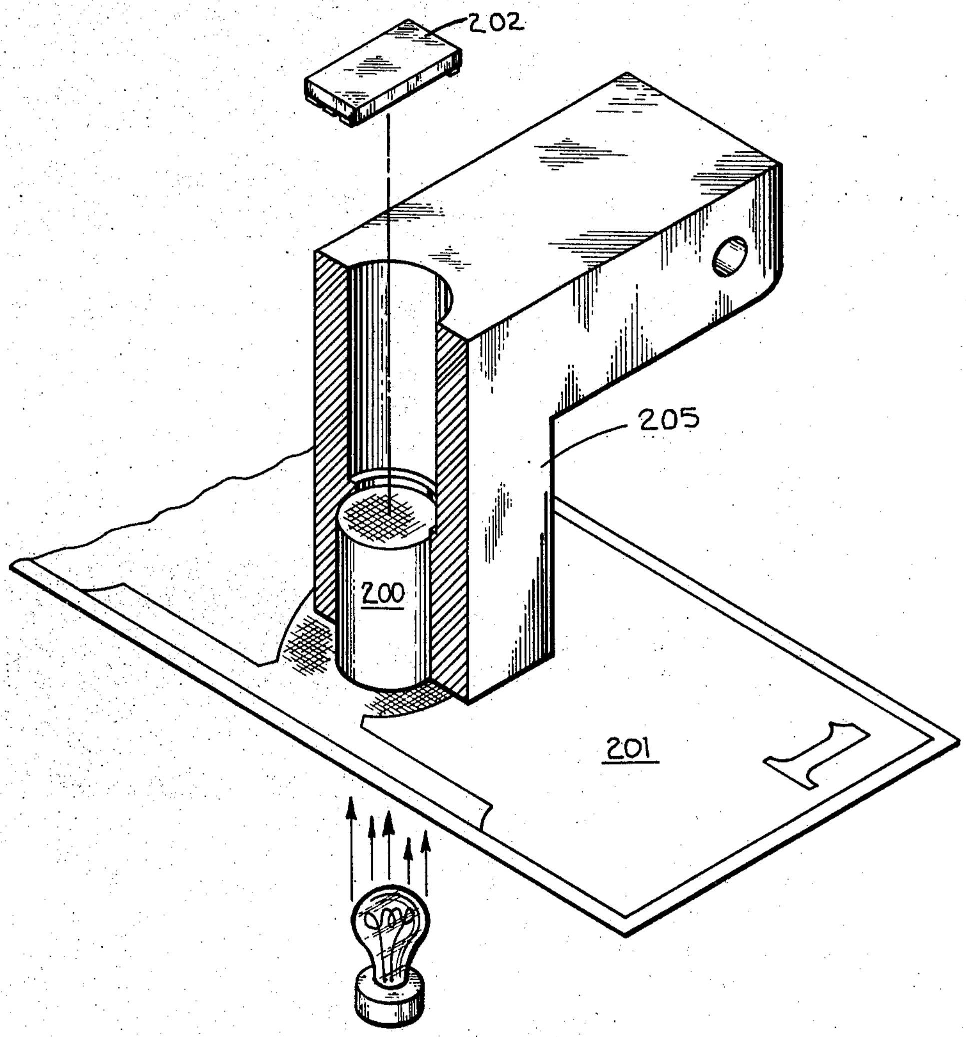

Fig. 13

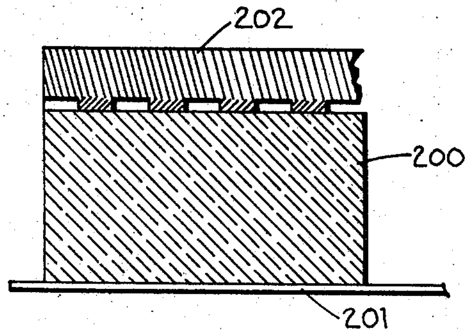

Fig. 14

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DOCUMENT VERIFIER USING PHOTOVOLTAIC CELL WITH LIGHT SENSITIVE BARS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to apparatus for examining paper money and like documents for genuineness.

2. Description of the Prior Art

It is known in the art to optically scan a predetermined area of a dollar bill to determine whether the parallel lines in the predetermined area are sufficiently sharp and clear for the dollar bill to be valid. This scanning has been performed by moving a transparent mask and a piece of money to be examined with respect to each other and in a linear direction while maintaining the money and the mask close to one another or in engagement with one another. The mask has thereon a predetermined pattern of parallel spaces and lines which correspond to the spaces and lines on the money. The patterns as they move into and out of coincidence produce light flashes the frequency and intensity of which is examined. If the lines are improperly spaced or have rough edges, the light from the two patterns will not wink on and off with the proper frequency and intensity and the apparatus will refuse to recognize the money.

Such prior art devices are relatively complicated and therefore expensive and subject to frequent repair. Also the electronic circuits of such prior art devices are not as selective as might be desired.

SUMMARY OF THE INVENTION

One embodiment of this invention might include a document verification system comprising a light source, a photovoltaic cell formed in approximately the same pattern as the document to be verified, and means for causing relative movement between the document, the cell and the light source.

One object of this invention is to provide an improved document verifier apparatus.

A further object of this invention is to provide a document verifier apparatus which is relatively simple and uncomplicated.

Another object of the invention is to provide a document verifier apparatus which is capable of great selectivity.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a section taken along the line 1–1 of FIG. 3 in the direction of the arrows.

FIG. 2 is a somewhat schematic front elevation of a document verifier apparatus embodying the present invention.

FIG. 3 is a partially schematic partially exploded perspective view showing the electrical circuit and portions of the mechanical components of the present invention.

FIG. 4, 5, 6, 7, 8, 9, 10, 11, and 12 are graphical plots of the wave forms of the various signals at various points throughout the present apparatus and show in serial form the manner in which the signal is operated upon by the various elements of the present apparatus.

FIG. 13 is a partially exploded perspective view of a further embodiment of the present invention; and

FIG. 14 is a side elevation of a portion of the structure illustrated in FIG. 13.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now more particularly to the drawings, there is illustrated a photovoltaic cell or photocell **15**. The cell **15** is made from a flat chip of silicon which has been cut from a grown single crystal of silicon. During the growing process, the silicon is doped with suitable impurities so that the resulting crystal is a semiconductor of the P type. The crystal is then sliced into flat chips such as for example about one centimeter in area and a few thousandths centimeters thickness. The resulting chip is of course P-type semiconductor.

In order to make the surface of the silicon chip photosensitive, N-type impurities are diffused into the P-type chip by a gaseous diffusion process. The final result of this procedure is

to form an NP semiconductor junction on one surface of the silicon chip which extends approximately **10** angstroms into the surface of the silicon chip. The entire surface of the chip is now photosensitive. The next step in the process is the etching of alternating areas of the NP junction. This etching dissolves alternate spaces on the silicon surface below the level of the NP region. The resulting raised portions of the silicon surface are still NP regions and are still each separately photosensitive. Thus, in FIG. **1** the photovoltaic cell **15** includes the main portion thereof **16** which is approximately one centimeter in area and a few thousandths thick and which is doped with P-type impurity. The portions **17** of the photovoltaic cell are NP semiconductor junctions where the P-type silicon has been further doped with N-type impurity. Between and outboard of the raised portions **17** there are located etched out portions **20** which are not light sensitive. In order to protect the portions **17** and the pattern made up by the light-sensitive portions **17**, a transparent cover glass **21** of perhaps 0.003 centimeters thickness is secured to the chip by epoxy or the like.

Referring to FIG. **3**, the raised portions **17** are shown as having the configuration of straight parallel bars or lines all of which are connected together by another raised portion **22**. The raised portion **22** is a plated conductor which may also be covered and protected by the glass cover **21** not shown in FIG. **3**. Wire leads **25** and **26** are connected to the conductor **22** and the P-type region **16** of the chip respectively.

Referring now to FIG. **2**, there is illustrated a bill verifier **30** which, except for the modifications effected by the present invention, may be identical to the bill verifier sold by Standard Change-Makers, Inc. of Indianapolis, Indiana, under Model No. 25 or 25A. This bill verifier incorporates a slidable tray **31** which moves toward and away from the viewer of FIG. **2**. The user of the bill verifier places the dollar bill in the recess **32** and pushes the tray **31** onto the bill verifier. When the tray has moved a certain distance into the bill verifier, a cam, indicated schematically at **35**, is moved out of the way of a limit stop element **36** which is fixed to a rod **37** in turn fixed to a cart **40**. The rod **37** is slidably mounted for movement leftwardly and rightwardly as viewed in FIG. **2** on the frame elements **41**. Acting between the cart **40** and the frame element **41** is a coiled compression spring **42**. When the member **35** moves out of the path of the limit stop **36**, the shaft **37** is free to move leftwardly until the limit stop **36** engages the frame **41** which also acts as a limit stop. Thus, the cart **40** is caused to move a distance leftwardly in the direction of the arrow **45** a predetermined distance.

The tray **31** is transparent. Mounted on the frame beneath the tray **31** is a light source **50** which shines upwardly through the aperture **51** thence through the transparent tray **31** and through the bill carried by the tray into the cart **40**. The cart **40** has mounted thereon at its lower end the photovoltaic cell **15**. The cell is spaced fairly closely to the tray **31** and the dollar bill in the tray, this spacing being approximately 0.001 inches in a typical installation such as the one herein described and preferably as close as possible to the bill surface.

When the tray **31** is returned to its initial position toward the viewer of FIG. **2**, the cart is also returned to the illustrated rightward position with the limit stop **36** being held by the member **35** in readiness for a further cycle as above described. Thus, each time the tray **31** is pushed into the bill verifier and when it reaches a certain point in its travel into the bill verifier, the cart is tripped so that the spring **42** can move it through a predetermined distance leftwardly and the cell moves across the bill in the direction of the arrow.

The light-sensitive bars or strips **17** on the photovoltaic cell are of the same size and relative spacing as the grid lines printed on the money being examined, although the bars **17** may be somewhat thinner than the grid lines on the money. As the light passes through the printed grid lines on the bill, it forms a shadow pattern on the surface of the photocell adjacent to the bill. With the proper relative positioning of the bill and the photocell, the dark shadow areas will completely mask all of the light-sensitive strips of the photocell. At this point, the electrical output will be of low voltage. When the relative position of the bill and photocell is adjusted so that the dark or shadowed portions of the transmitted light pattern fall between the photosensitive strips of the photocell, the photosensitive strips will be illuminated at greater intensity and the voltage output of the photocell will be high. The relative linear motion produced by the cart **40** across the bill causes alternate illumination and shadowing of the photocell resulting in an alternating voltage output being produced by the photocell. An example of such an alternating voltage output is shown in FIG. 4.

Since the photocell is a direct light to energy converter, no power supply or external source of voltage is required by the photocell to generate the alternating output voltage. Typical cell outputs can range from 0.5 to 1.5 millivolts peak to peak measured with a voltmeter having 6,000 ohms internal resistance. Typical frequencies of alternating voltages generated by the photocell measure from 800 to 1,500 cycles per second on the above described representative type of mechanical transport system. The frequency of photocell output, however, could vary widely from one type of mechanical transport system to another.

The output of the photocell is connected by means of the wires **25** and **26** to amplifier input terminals **60** and **61** of the amplifier **62**. The amplifier **62** is of the integrated circuit operational type and has a differential input. The function of the amplifier is to amplify the typically 1.0 millivolt signal from the photocell to a value of 1 to 1.8 volts (typical) at the amplifier output **65**. An example of a suitable amplifier **62** might be RCA type CA3033.

Thus, the total voltage amplification provided at this point in the system is approximately 1,200 to 2,000 times. In FIG. **5** the wave form of the amplifier output is illustrated. The amplifier wave form output is a faithful reproduction of the wave form shown in FIG. 4 but is much amplified in magnitude of voltage. The dotted line **70** in FIG. 4 and **71** in FIG. **5** illustrates a typical variation in illumination over the area of the lighted spot of the bill **72** in FIG. 3. As suggested, this causes a low frequency modulation of the wave form at the output of the photocell. Because this modulation is in the nature of interference, it contributes no information about bill characteristics. The amplifier is designed so that the maximum gain of the amplifier exists over a frequency range corresponding to the grid line frequencies of the photocell. In this manner, the interference signal may be attenuated with respect to the grid line signal. It is not possible or desirable, however, to totally remove this interference signal at the present point in the system. Consequently, the amplified signal from the photocell will contain both interference signals and the grid line signals at point **65** in FIG. 3.

After being amplified, the signal is coupled into the input of a schmitt trigger **75** by means of a capacitor **76** and a potentiometer **77** so that the amount of signal transmitted into the schmitt trigger can be adjusted in voltage level. The wave form of the signal at the input to the schmitt trigger is illustrated in FIG. **6** The wave form **76** shows the minimum input to the schmitt trigger and the wave form **78** shows the maximum input. In other words, the difference **80** is a typical range of adjustment by the potentiometer **77**.

The characteristic of the schmitt trigger circuit is that the output is constant in amplitude when present but is present or not present depending upon the voltage level of the input signal. FIG. 7 is a double graph which shows at the lower portion of the graph in the wave forms **81** and **82** typical inputs to the schmitt trigger. At the upper portion of the graph of FIG. **7** the corresponding typical outputs of the schmitt trigger are shown at **85**. Thus, it can be seen for the input **81** there is no output from the schmitt trigger. However, for the input **82** there is an output. It will be noted, however, that some of the various pulses **85** of the schmitt trigger are on for shorter periods of time than other pulses **85**. This is determined by the amount of time that the signal **82** is above the minimum "on" level for the schmitt trigger which in the illustrated example is 0.5 volts schmitt input. It can be seen that the cause of the reduction in width of the signal produced in the upper portion of FIG. **7** is because of the tilt or slope of the envelope of the signal input wave form **82**. A typical tilt of this type is caused by the superposition of interference signals of lower frequency on the bill signal wave form as suggested in connection with the envelope **70** and **71** in FIG. **4** and **5**. The net result is that, while the output of the schmitt trigger is extremely constant in amplitude, the interference signal components are still present through their modulation of the width or time period of the schmitt trigger output pulses.

In order to eliminate the variable width factor in the schmitt trigger output pulses, the output from the schmitt trigger is fed to a differentiator circuit **90**. FIGS. **8** and **9** show the effect of the differentiator circuit **90**. Thus, the signal **91** is the input to the differentiator while signal **92** is the output. The dotted lines **92'**, of course, indicate that the upper and lower wave forms are time synchronized. It will be noted that, even though the various schmitt trigger output wave forms **95**, **96**, **97**, and **98** have decreasing widths, still the outputs **100**, **101**, **102** and **103** are of equal amplitude similarly to the schmitt trigger output **91**.

To review, the bill signal has been applied to the amplifier containing both grid line and interference signals. The amplifier has increased the voltage magnitude of the bill signal and the interference signals and applied them to the schmitt trigger. The schmitt trigger a has made all of the voltage wave forms of the amplified bill signal of the same magnitude or height. It has therefore, removed part of the interference signal but a component still exists due to the variable width factor of the schmitt trigger output. The differentiator circuit then removes the variable width factor or interference from the amplified bill signal. Thus, the bill signal has now been "-cleaned up" or "scrubbed" and is ready to produce a grid line count or totalization at the integrator.

The output of the differentiator **90** is coupled into an integrator **110**. The integrator **110** is designed with a time constant. During the time of the time constant, the DC output voltage of the integrator circuit is proportional to the number and the area of voltage pulses at its input. FIG. **10** shows an enlarged view of the differentiator output and shows that each pulse has a certain area which is determined by the constant height or amplitude **111** of the pulse and by the width or time period of the pulse **112**. Thus, the output of the integrator DC voltage is approximately twice as high for 20 pulses of a constant area as it is for 10 pulses of the same area, provided, of course, that the natural time constant of the integrator is much longer than the span of time occupied by the 20 pulses. FIGS. **11** and **12** show the above described action of adding or totalizing pulses. The dotted lines **120** between the upper and lower time axes indicate time synchronization. Thus, in FIG. **12**, if the integrator output voltage level required for bill acceptance is the voltage indicated at **121** which corresponds to 8 pulses, then 8 pulses at the input to the integrator would cause acceptance while, for example, 5 pulses indicated at **122** would not.

The output of the integrator circuit **110** is connected to a final trigger or switch **120** through a potentiometer **121**. The final trigger **120** may consist of a silicon controlled switch or SCS. The input **122** to the final trigger is connected to the gate electrode of the SCS. When the gate electrode becomes positive by about 0.4 to 0.6 volts, the SCS component conducts giving a "go" or "accept" signal which is delivered to the output **125**. The potentiometer **121** connected between the integrator and the final trigger make possible adjustment of the voltage level at which the SCS or final trigger is fired.

While it has not been been previously stated, each grid line existing on the bill and scanned by the photocell produces one voltage pulse at the input to the amplifier. These amplified pulses are made of constant amplitude and constant width by action of the schmitt trigger and the differentiator circuits. The integrator sums these pulses, giving at least approximately equal weight to each pulse. The integrator output DC level is, therefore, an exact function of the number of grid line pulses scanned. Amplitude and frequency of the grid line pulses do not affect the count. Thus, by adjustment of the potentiometer **121**, the final trigger can be made to give an "accept" signal at any desired number of grid lines detected. For example, the potentiometer **121** may be adjusted to give an "accept" signal after **10** grid lines are added up by the integrator or, if desired, after **20** grid lines are detected by the integrator. Thus, the potentiometer **121** is a means of varying the selectivity of the entire grid line detection system.

The potentiometer **77** may be adjusted so that the schmitt trigger **75** is operating for the minimum grid line signal generated by a worn, old and wrinkled bill of genuine printing. As mentioned above, the schmitt trigger will not operate unless it receives a signal of a certain minimum value. The potentiometer **77** can be adjusted so that the schmitt trigger will not operate at all for a great amount of obviously bogus money such as play money, photostats, poor quality counterfeits and the like. Thus, no signal will be generated for such items and no signal will be passed on to the differentiator for such items.

Thus, the net result of the structure described above is to perform the following three checks for bill authenticity:

1. Is a grid line signal generated? This check is performed by the photocell and the spacing and width of the light-sensitive areas of the photocell.
2. If a grid line signal is generated, is it of enough amplitude to be typical of either an old or a new genuine bill? This is accomplished by the schmitt trigger and the threshold adjustment of the potentiometer **77**.
3. If the grid line signal is of sufficient amplitude so that it might be genuine, what is the total grid line count over the length of the scan? Is it of sufficient number so that it is typical of a genuine bill? This check is accomplished by the combination of the schmitt trigger, differentiator, integrator, the adjustment of the potentiometer **121** and the final trigger **120**.

Referring now to FIGS. **13** and **14**, there is illustrated an alternative embodiment of the invention which is identical to the apparatus described in FIGS. **1—12**, except as described below. In place of the cover glass **21**, a fiber optics tube or conduit **200** is used between the document or bill **201** and the photovoltaic cell **202**. The tube **200** may be, for example, Model No. 1C–b **200–6** image conduit manufactured by The American Optical Company of Southbridge, Massachusetts, although the tube is cut and polished to a shorter length than the usual 6 -inch length of this model number. As shown one end of the image conduit contacts the bill **201** while the other end is in contact with or closely spaced to the cell **202**. The end surfaces of the image conduit are optically flat and polished. The image conduit is made up of at least 70,000 separate fibers for each one-fourth inch of conduit diameter. Each fiber is separately clad to individually transmit a light spot through the conduit. The size of each light spot is very small (about 12 microns). The grid line image is thus transmitted up the conduit to the cell surface.

The advantages of replacing the cover glass **21** with the conduit **200** are that the cell **202** may be located within a protective housing **205** which is identical to or corresponds to the cart **40**. The housing **205** shields the cell from mechanical shock, vibration, moisture and other foreign matter which might be picked up from the bill surface. The housing also protects the cell from external electrical contact. Also the conduit **200** prevents substantial diffusion of light in the area between the cell and the document so that a sharp clear image is delivered to the cell.

It will be evident from the above description that the present invention provides an improved document verifier apparatus. It will also be evident that the document verifier apparatus of this invention is relatively simple and uncomplicated and is capable of great selectivity.

We claim:

1. A document verification system comprising a light source; a photovoltaic cell formed in approximately the same pattern as the document to be verified; and means for causing relative movement between the document, the cell and the light source, said document including a plurality of bars, said photovoltaic cell also including a plurality of similar bars of light-sensitive material of the same relative size and spacing as the bars of the documents, said bars being separated by non-light-sensitive material.

2. A document verification system as defined in claim **1** wherein said bars are parallel.

3. A document verification system as defined in claim **1** additionally comprising a fiber optics image conduit positioned between the light source and the cell and conducting an image of the document from the document to the cell.

4. A document verification system as defined in claim **2** wherein said cell includes a flat chip of silicon doped with P- and N-type impurities, said flat chip being doped with one of said types of impurities therethrough, said chip having a photosensitive surface thereon formed by the other of said types of impurities fused into the one type impurity chip, said chip being etched at selected portions of said surface to remove portions of said photosensitive surface providing said pattern of photosensitive material.

5. A document verification system as defined in claim **2** additionally comprising first means for receiving the output of said cell and for converting those portions thereof which are above a given amplitude into pulses of constant voltage of varying time duration which is determined by the time that said portions are above said amplitude, second means for differentiating the output of said first means to produce for each input pulse an output pulse that is constant in amplitude and time duration, integrating means for counting the output pulses of said differentiating means and producing an output directly proportional to the number of second means output pulses, and switch means receiving the output of said integrating means and arranged to be turned on by an output of given amplitude from said integrating means.

6. A document verification system as defined in claim **5** wherein said means for causing relative movement comprises a spring and a pair of limit stops and a cart, said cell being mounted on said cart, said limit stops being spaced apart a fixed distance, one of said limit stops normally acting to hold said cart at a first position, said one stop being movable to permit said cart to move from said first position to a second position under the action of the spring, said first and second positions being a given distance apart so that the travel of said cart between said positions is always the same distance.

7. A document verification system as defined in claim **6** additionally comprising a fiber optics image conduit mounted on said cart and positioned between the light source and the cell and conducting an image of the document from the document to the cell.

8. A document verification system as defined in claim **5** additionally comprising a potentiometer coupling the output of said cell to the input of said first means and making possible adjustment of said given amplitude of the first means so that said first means will respond to a signal of the amplitude produced by a worn old genuine document but will not respond to lesser amplitudes.

9. A document verification system as defined in claim **8** additionally comprising a potentiometer coupling said integrating means to said switch and making possible adjustment of the number of pulses from said integrating means required to turn on said switch.

10. A document verification system comprising a photovoltaic cell, a light source, said photovoltaic cell including means for comparing a pattern of the document with the document itself to provide a variation in light to said cell, first means for receiving the output of said cell and for converting those portions thereof which are above a given amplitude into pulses of constant voltage of varying time duration which is determined by the time that said portions are above said amplitude, second means for differentiating the output of said first means to produce for each input pulse an output pulse that is con-

stant in amplitude and time duration, integrating means for counting the output pulses of said differentiating means and producing an output directly proportional to the number of second means output pulses, and switch means receiving the output of said integrating means and arranged to be turned on by an output of given amplitude from said integrating means.

11. A document verification system as defined in claim **10** additionally comprising a potentiometer coupling the output of said cell to the input of said first means and making possible adjustment of said given amplitude of the first means so that said first means will respond to a signal of the amplitude produced by a worn old genuine document but will not respond to lesser amplitudes.

12. A document verification system as defined in claim **11** additionally comprising a potentiometer coupling said integrating means to said switch and making possible adjustment of the number of pulses from said integrating means required to turn on said switch.