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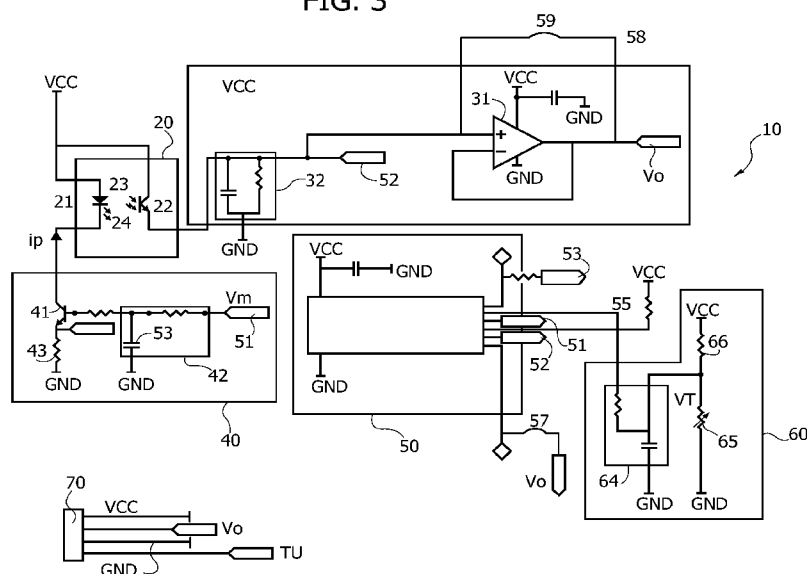
**Declarations under Rule 4.17:**

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(54) **Title:** TURBIDITY SENSOR USING A MICROCONTROLLER

**FIG. 3**

(57) **Abstract:** Controlled optical sensor device (10) including an optical emitter (21) generating an optical radiation (23), in particular in the visible or infrared field, and an optical receiver (22) to detect said optical radiation (23) upon interaction with a medium to be measured (24), a driving current ( $I_p$ ) of said optical emitter (21) setting the intensity of said radiation (23) being controlled by driving means (50, 40) included in said optical sensor (10). According to the invention, said driving means (50, 40) include a microcontroller (50) configured to access calibration and/or compensation parameters and to adjust said driving current ( $I_p$ ) as a function of said calibration and/or compensation parameters.

**DESCRIPTION** of the industrial invention entitled:

TURBIDITY SENSOR USING A MICROCONTROLLER

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**DESCRIPTION**

Field of the invention

The present invention relates to a controlled optical sensor device including an optical emitter generating an optical radiation, in particular in the visible or infrared field, and an optical receiver to detect said optical radiation upon interaction with a medium to be measured, a driving current of said optical emitter setting the intensity of said radiation being controlled by driving means included in said optical sensor device.

Background of the invention

Optical sensors adapted to detect the turbidity of a fluid used in a washing machine or in a dishwasher are well known. These sensors typically include an optical emitter, which emits light radiation through a medium, such as the washing liquid, and an optical receiver, which receives the optical radiation emitted by the emitter after the radiation has passed through said medium, that is the washing liquid. By comparing the measurements of the optical radiation emitted by the emitter and the optical radiation received by the receiver, it is possible to determine the level of turbidity of the washing liquid. The geometry of the sensor defines whether the radiation is reflected, refracted or attenuated by the medium to be measured. In addition to applications such as as a sensor

for detecting turbidity, this type of sensor can be used for sensors for detecting the level of the liquid, sensors for detecting a distance and sensors for detecting the presence of liquid. As mentioned, different types of sensor can be analyzed by changing the relative position of the emitter and of the receiver, for example opposite one another frontally or laterally to work in reflection, and the types of lenses which can be used in conjunction with said emitter and receiver.

One of the main problems encountered with this type of sensor is the large signal difference resulting from the tolerance margins from component to component. This is also the case if use is made of emitters and receivers which originate from the same batch, or rather from the same production batch. With reference to the graph shown in figure 1, which illustrates an output voltage  $V_o$  of an optical sensor, in particular of a phototransistor of said sensor, as a function of the turbidity, indicated in NTU (Nephelometric Turbidity Unit), a typical turbidity sensor for household electrical appliances has an optical emitter, for example an LED (Light Emitting Diode), which emits an optical signal in a straight line toward a receiver, for example a phototransistor, while the suspended particles of the liquid, which is the medium placed between the LED and the phototransistor, attenuate the signal, absorbing, reflecting and diffusing the emitted radiation. The emitter and the receiver are present within transparent plastic housings so as to prevent contact with the water. It is known to vary the value of the current which flows in the emitter to set a reference level to the receiver in the presence of fresh water, that is water assumed to be clean, and to thus monitor the decrease in the output of the

receiver with an increase in turbidity. The graph shown in figure 1 shows an example of an output voltage  $V_o$  of a typical turbidity sensor after adjustment to a given output voltage of 4 V in clean water, the different curves representing the variation from component to component. The degree of the variation in the output values at a certain level of turbidity is influenced by a multiplicity of factors, including the distance between the emitter and the receiver, the size of the cone of radiation emitted by the emitter, the size of the cone of the receiver and the transparency of the plastic housings. Another variation of a large magnitude can be verified because of the temperature dependence of the behavior of these emitters and receivers.

#### Object and summary of the invention

It is an object of the present invention to provide an optical sensor device, in particular a turbidity sensor, which is able to compensate the differences in tolerance and behavior of the components.

According to the present invention, this object is achieved by an optical sensor device having the features described in claim 1.

The claims form an integral part of the teaching provided in relation to the invention.

#### Brief description of the drawings

The present invention will now be described in detail with reference to the attached drawings, provided purely by way of non-limiting example, in which:

- figure 1 is a graph which is representative of the output characteristic of known optical sensors;
- figure 2 is a perspective view of an optical sensor device according to the present invention,

- figure 3 is a circuit diagram of the optical sensor device according to the present invention.

Detailed description of embodiments of the invention

With reference to figure 2, said figure shows a schematic view of an optical sensor device 10, which includes a printed circuit board 81 bearing an optical emitter 21 and an optical receiver 22. The printed circuit board 81 also bears the components 80 of an electronic control circuit associated with the emitter 21 and with the receiver 22. As can be seen in greater detail in figure 3, these components 80 include a microcontroller 50, a current generator 40, a circuit for conditioning the output signal 30 and a temperature compensation circuit module 60. The printed circuit board 81 also bears an electrical connector 70 for electrically connecting the optical sensor device 10 to an external circuit.

As the emitter 21, it is possible to use an LED, for example, while a phototransistor, a photodiode or a solar cell can be used as the receiver 22. With reference in particular to figure 2, the emitter 21 and the receiver 22 are fixed to the printed circuit board 81 by respective metallic terminals 88, which are inserted and fixed in respective holes in the printed circuit board 81. The printed circuit board 81 has two branches 86 spaced apart from one another, such that one end of the board 81 is substantially U-shaped. The emitter 21 and the receiver 22 are fixed to the ends of the respective branches 86. The board 81 and the branches 86 are inserted, for example, into a transparent plastic casing (not shown in figure 1), and the branches in particular are inserted into plastic arms having a corresponding shape, between which it is possible for a medium to be measured 24, for example

washing water, to be interposed. In figure 2, the emitting surfaces of the emitter 21 and the receiving surfaces of the receiver 22 face one another, so that a radiation 23 is transmitted directly, with the interposition of the medium 24, in particular the washing water, the turbidity of which is to be measured. In various embodiments, the positioning of the emitter 21 and of the receiver 22 could, however, provide for the radiation to propagate from the emitter 21 to the receiver 22 by reflection on the medium 24, for example having a cone of radiation emitted by the emitter and a cone of the receiver which are not aligned in the same direction.

With reference to figure 3, what is shown is a circuit diagram of the optical sensor device 10. Reference numeral 20 denotes an emitter-receiver circuit module including the LED emitter 21, which emits the light radiation 23 through the medium 24, for example the washing water. This light radiation 23 is received by a receiver 22, represented for example by a phototransistor.

The emitter-receiver module 20 is controlled by a current generator 40, the operation of which is controlled by a microcontroller 50. This microcontroller 50, through a signal output 51 thereof, supplies a PWM (Pulse Width Modulation) modulated signal  $V_m$ , which is filtered by a filter 42 in the current generator 40 in order to obtain a continuously adjustable voltage, depending on the value of the duty cycle of the PWM modulated signal  $V_m$  across the output 51, which is used to adjust the base current of a transistor 41. This transistor 41 has a resistor 43 on the emitter electrode thereof, which converts the emitter current into a voltage which is read by means of a signal input 53 by the microcontroller 50, so as to form closed

loop regulation, the duty cycle of the PWM signal  $V_m$  from the output 51 being adjusted to obtain the desired current value in the emitter of the transistor 41. The transistor 41 is then connected through the collector electrode to the optical emitter 21, so as to adjust the driving current  $I_p$ , that is the collector current is the driving current  $I_p$  which flows in the LED. Located downstream of the emitter-receiver module 20, in particular in series with the collector of the phototransistor, which acts as optical receiver 22, there is a circuit module for conditioning the output signal 30.

This circuit module for conditioning the output signal 30 operates in the following manner: the radiation detected by the optical receiver 22, in the form of a phototransistor, is converted into a voltage and is filtered by an RC circuit 32 connected to the collector of the phototransistor. This voltage across the collector of the phototransistor is also read by the microcontroller 50 by means of a signal input 52 thereof, which is connected to the input of an operational amplifier 31, the output signal  $V_o$  of which, in particular an output voltage, is led to one of the output pins of the output connector 70. The output connector 70 also has pins for receiving the supply voltage VCC and the ground reference GND from the outside, and for supplying these to the circuits of the optical sensor device 10 and to the microcontroller 50 thereof, and also includes a further, digital signal input pin for a calibration signal TU.

The operational amplifier 31 can amplify the signal or operate as a unitary-gain buffer. In an alternative configuration, the output buffer is not required if the microcontroller 50 digitally communicates the signal, after

acquiring it, as a signal 52 to the optical receiver. In this case, the microcontroller 50 provides at a digital output thereof, optionally with the insertion of a jumper 57, the output signal Vo, which is returned externally to the circuit by means of the corresponding pin of the connector 70. Figure 3 also shows a short-circuit branch 58, which carries the signal 52 directly to the output Vo, when an appropriate jumper 59 is connected to this branch 58. This jumper 59 and this branch 58 are needed if the amplifier 31 is not installed and there is nevertheless a desire for a voltage output without a buffer.

In short, even if all the components are shown in figure 3, the circuit may adopt the following configurations:

- Analog output with a buffer, preferably for example in areas of increased electrical noise, for example very long wiring: amplifier 31 installed, jumpers 57 and 59 not installed.
- Analog output without a buffer: jumper 59 installed, amplifier 31 and jumper 57 not installed.
- Digital output: jumper 57 installed, 31 and 59 not installed.

According to a main aspect of the solution described here, the optical sensor device 10 also includes a temperature compensation circuit module 60, which includes a negative temperature coefficient element 65, for example an NTC (Negative Temperature Coefficient) thermistor constitutes a particularly economical solution, even if other similar thermistors can be used. This negative temperature coefficient element 65 forms, with a resistor 64, a divider for the supply voltage VCC, which provides a divider voltage which is variable as a function of the

temperature and corresponds to the voltage  $V_T$  which is representative of a temperature information. This divider voltage, variable as a function of the temperature, or voltage  $V_T$ , is supplied through a filter 64 to an input 55 of the microcontroller 50, which is for example the input for a reference voltage with which the microcontrollers are conventionally supplied, in particular the input of an analog-digital converter of the microcontroller 50.

The temperature compensation circuit module 60 thus supplies the microcontroller 50 with voltage values which are representative of a temperature information measured by the negative temperature coefficient device 65. This temperature information is used by the microcontroller 50 to vary the driving current  $I_p$  sent by the generator 40 to the emitter 21, to compensate temperature effects increasing or decreasing the intensity of the emitted radiation.

The strategies for temperature compensation may provide, for example, for the application of a predefined transfer function, in particular according to the features reported by the datasheets of the optical components. Otherwise, provision may be made to carry out the calibration of every individual device further to measurement of the output signal  $V_o$  at at least two different temperatures. In these compensation strategies, use is preferably made of a look-up table which, according to the temperature read, applies a correction factor to the current in the emitter 21. An alternative to the look-up table may be represented by a polynomial approximation function or linear interpolation between values from a table.

In general, the microcontroller 50 is configured to

also provide for the calibrations which are required for the emitter-receiver 20, as explained in detail hereinbelow.

The functions of the microcontroller 50 thus include:

- Calibration of the emitter-receiver module 20 to supply the same output signal in the same operating conditions, using the reading of the output signal 52 and values of this signal in reference conditions, for example in clean water at a given temperature, stored in the memory of the microcontroller. With an appropriate command signal being supplied to the microcontroller 50, the latter provides for the regulation of the current to obtain the prefixed reference value at the output, for example 4 V, and then the current value required to obtain this prefixed reference value is saved in the memory of the microcontroller 50. For this purpose, figure 3 shows in the connector a digital input pin TU, which starts the calibration process.

- Temperature compensation using the circuit 60 to detect the internal temperature of the sensor.

- Compensation of variations from component to component resulting from mechanical assembly tolerances and thickness tolerances of plastic parts, storing correction values during factory calibration.

- Compensation with respect to the aging of the components. This can be carried out by re-calibrating the sensor in clean water and compensates the aging of the emitter and of the receiver, as well as the reduction in the transparency of the plastic casings of the optical module.

- Storing in a memory thereof all the calibration and compensation parameters of the sensor in order to allow for

easier replacement thereof.

Therefore, the present invention, by means of an optical sensor device which associates a microcontroller with an optical emitter-receiver module, advantageously makes it possible to compensate differences in the parameters and in the tolerances of components even originating from the same production batch, allowing both the compensation and the calibration of the sensor, and in particular the compensation of temperature effects.

The arrangement in a single unit integrated on a single board comprising the emitter-receiver module, the temperature sensor circuit and the microcontroller allows the device to autonomously regulate its output with respect to the variations in temperature. In addition, the microcontroller advantageously makes it possible to store the calibration and compensation parameters.

Clearly, provided that the principle of the invention is retained, the details of construction and the embodiments may vary considerably from what has been described and illustrated, without thereby departing from the scope of the invention as defined by the following claims.

The optical sensor device according to the invention, described here with reference in particular to a turbidity sensor for washing machines, can also be used in applications such as sensors for detecting the level of the liquid, sensors for detecting a distance and sensors for detecting the presence of liquid.

**CLAIMS**

1. Controlled optical sensor device (10) including an optical emitter (21) generating an optical radiation (23), in particular in the visible or infrared field, and an optical receiver (22) to detect said optical radiation (23) upon interaction with a medium to be measured (24), a driving current ( $I_p$ ) of said optical emitter (21) setting the intensity of said radiation (23) being controlled by driving means (50, 40) included in said optical sensor (10), characterized in that said driving means (50, 40) include a microcontroller (50) configured to access calibration and/or compensation parameters and to adjust said driving current ( $I_p$ ) as a function of said calibration and/or compensation parameters.

2. Sensor device according to claim 1 characterized in that includes a temperature compensation circuit module (60) adapted to detect an operating temperature of said emitter (21) and receiver (22) and in that said microcontroller (50) is configured to adjust the driving current ( $I_p$ ) of said optical emitter (21) as a function of a temperature information ( $V_T$ ) supplied by said temperature compensation circuit module (60).

3. Sensor device according to claim 2 characterized in that said microcontroller (50) is configured to vary the driving current ( $I_p$ ) of said optical emitter (21) to compensate temperature effects increasing or decreasing the intensity of the emitted radiation (23).

4. Sensor device according to any of the preceding claims characterized in that said microcontroller (50) is configured to perform the adjustment of said current in said optical emitter (21) supplying a pulse width modulated signal ( $V_m$ ) determining as a function of a value of its

duty cycle the value of said driving current ( $I_p$ ) of the optical emitter (21), the value of said duty cycle being controlled by a closed loop regulation as a function of a signal (53) which is taken proportionally to said driving current ( $I_p$ ).

5. Sensor device according to claim 4 characterized in that includes a filter (42) to convert said pulse width modulated signal ( $V_m$ ) in a continue voltage signal supplied to the control input of a transistor (41) operating as current generator, said signal (53) which is taken proportionally to said driving current ( $I_p$ ) being taken on an emitter electrode (43) of said transistor (41), said optical emitter (21) being electrically connected to a collector of said transistor (41) to receive said driving current ( $I_p$ ).

6. Sensor device according to any of the preceding claims characterized in that said optical sensor (10) is configured to operate as turbidity sensor, in particular for use in washing machines.

7. Sensor device according to any of the preceding claims characterized in that includes a circuit for conditioning the output signal (30) supplied by the optical receiver (22).

8. Sensor device according to one of the preceding claims from 2 to 7 characterized in that said temperature compensation circuit module (60) includes a resistive divider (65, 66) including a negative temperature coefficient element (65), the output voltage ( $V_T$ ) of said divider (65, 66) being used as temperature information.

9. Sensor device according to claim 8 characterized in that said output voltage ( $V_T$ ) of said divider (65, 66) used as temperature information is supplied as reference voltage

to said microcontroller (50).

**10.** Sensor device according to one of the preceding claims from 2 to 9 characterized in that said emitter (21) and receiver (22), said microcontroller (50) and said temperature compensation circuit module (60) are arranged on a same printed circuit board (81).

**11.** Sensor device according to any of the preceding claims characterized in that said microcontroller (50) is also configured to take, upon receiving a calibration command (TU), an output signal (52) of the optical receiver (22) to perform a calibration of the optical emitter (21) and of the receiver (22) regulating said driving current ( $I_p$ ) to supply a same output signal value ( $V_o$ ) in the same operating conditions.

**12.** Sensor device according to any of the preceding claims characterized in that an output signal (52) of the optical receiver (22) is supplied as output signal ( $V_o$ ) of the device through an amplifier (31), which is in particular configured to operate as a buffer.

**13.** Sensor device according to any of the preceding claims characterized in that said microcontroller (50) is configured to supply at a digital output thereof the output signal ( $V_o$ ) after having acquired the output signal (52) of the optical receiver (22) and includes means (57) to selectively connect said digital output to an output connector (70).

**14.** Sensor device according to any of the preceding claims characterized in that said microcontroller (50) includes memory means to store said calibration and/or temperature compensation parameters of the sensor (10).

FIG. 1

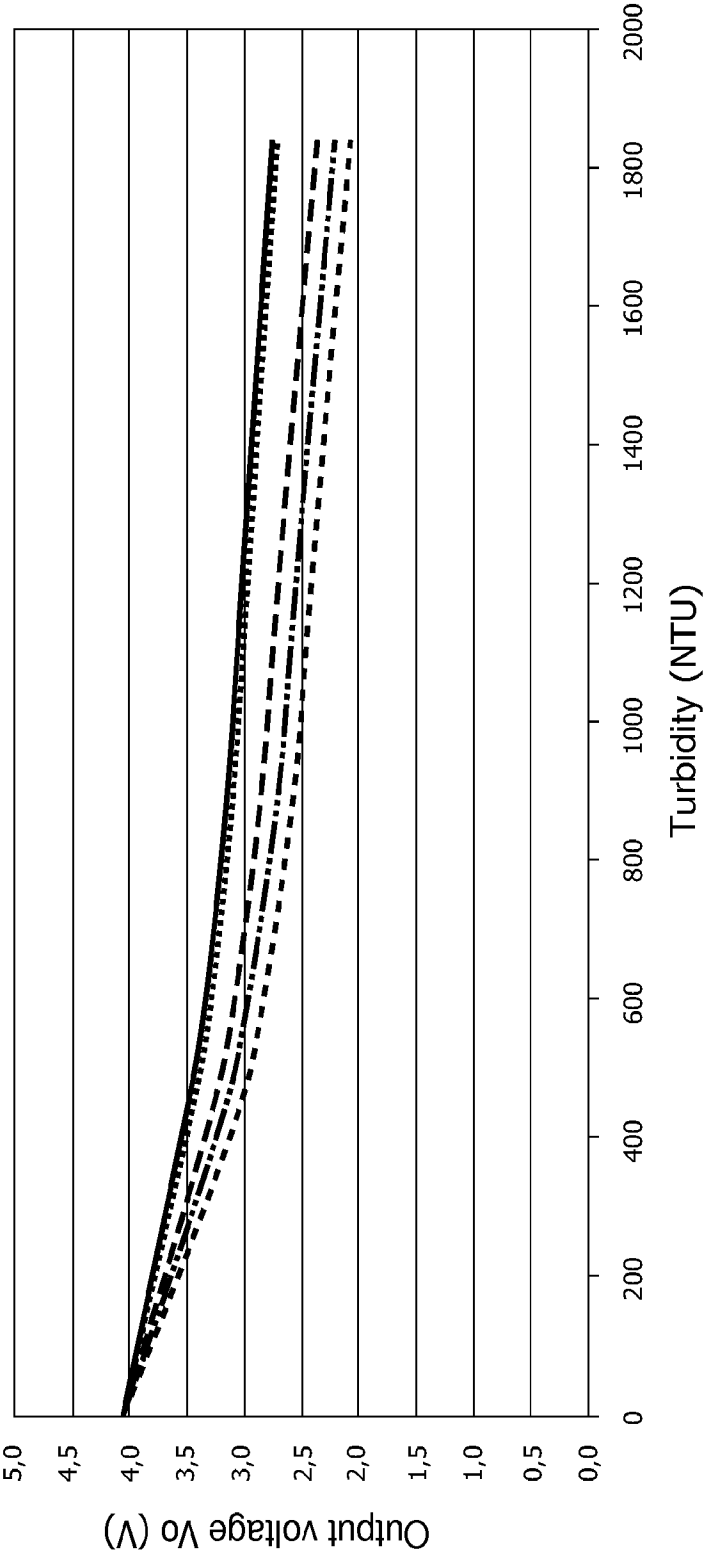


FIG. 2

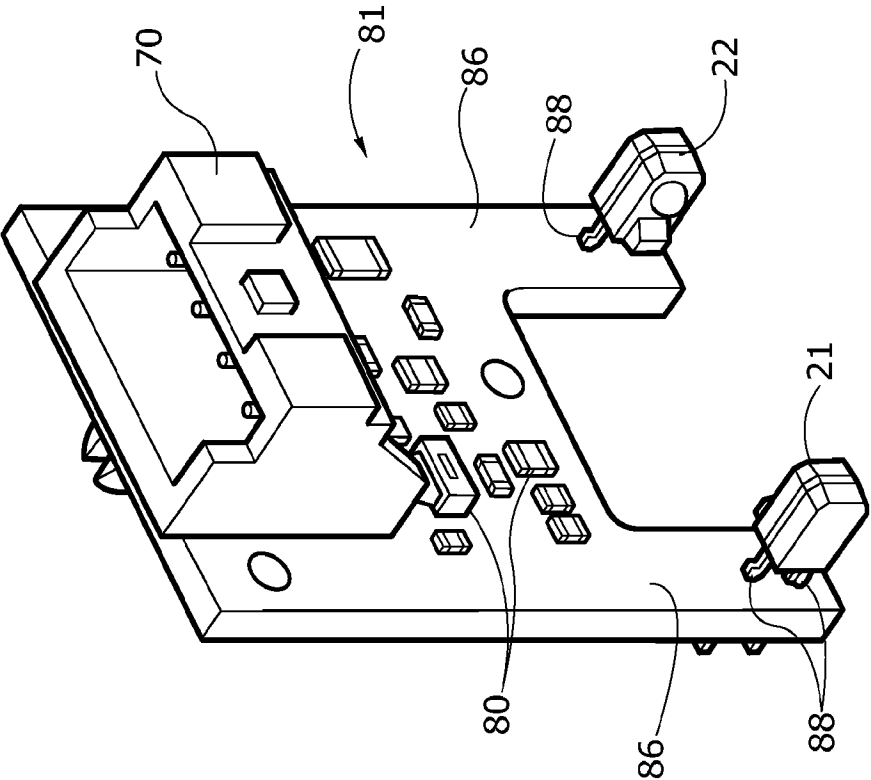
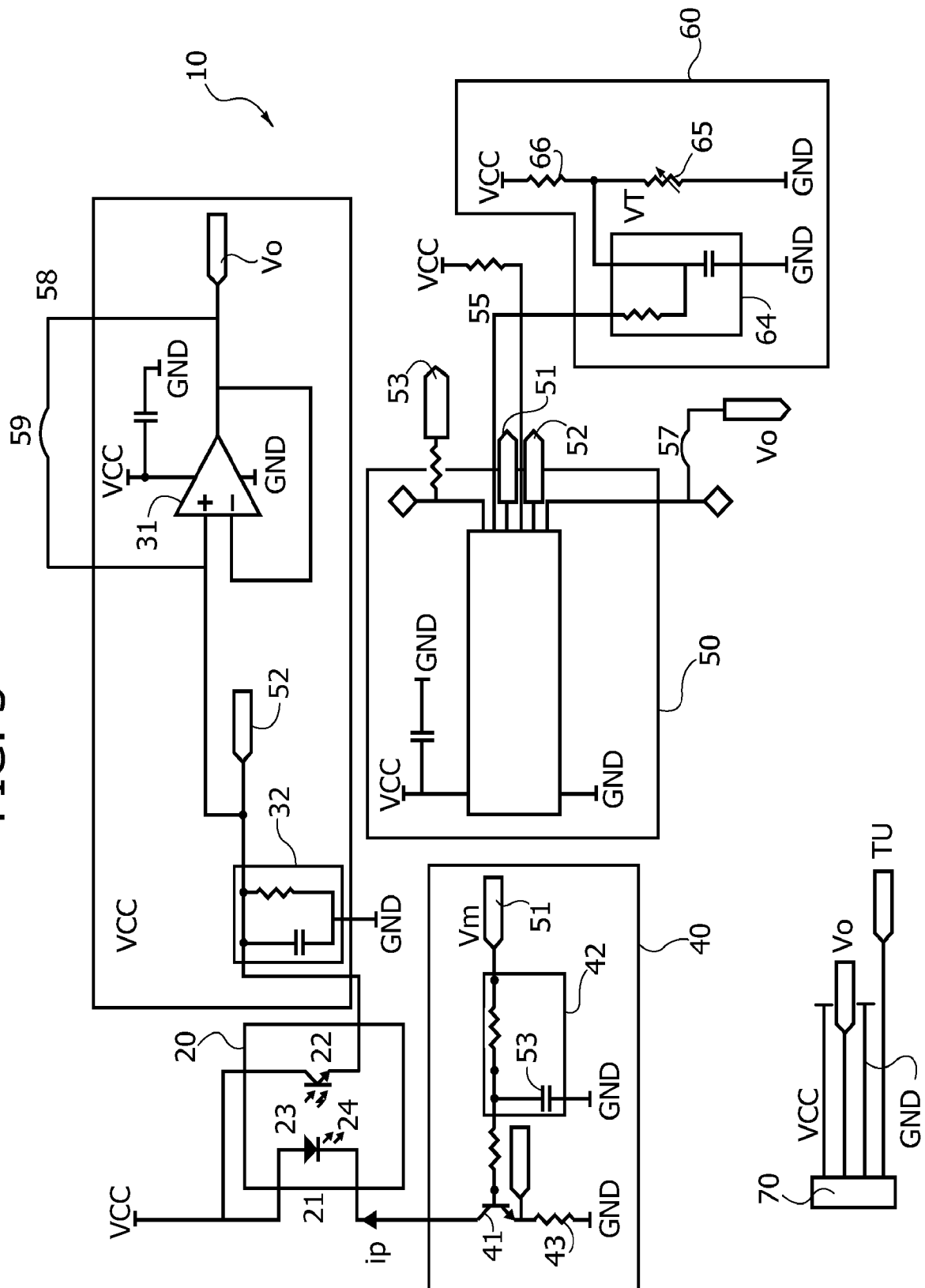


FIG. 3



# INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/036946

## A. CLASSIFICATION OF SUBJECT MATTER

INV. G01N21/53 D06F39/00  
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01N D06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

5 June 2012

Date of mailing of the international search report

13/06/2012

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/036946

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                            | Relevant to claim No. |
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/036946

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