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INTERNATIONAL STANDARD

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Semiconductor devices –
Part 14-11: Semiconductor sensors – Test method of surface acoustic wave-based integrated sensors for measuring ultraviolet, illumination and temperature

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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International Standard IEC 60747-14-11 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices.

The text of this International Standard is based on the following documents:

CDV	Report on voting
47E/674/CDV	47E/709/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60747 series, published under the general title *Semiconductor devices*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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SEMICONDUCTOR DEVICES –

Part 14-11: Semiconductor sensors – Test method of surface acoustic wave-based integrated sensors for measuring ultraviolet, illumination and temperature

1 Scope

This part of IEC 60747 defines the terms, definitions, configuration, and test methods can be used to evaluate and determine the performance characteristics of surface acoustic wave-based semiconductor sensors integrated with ultraviolet, illuminance, and temperature sensors. The measurement methods are for DC characteristics and RF characteristics, and the measurement method for RF characteristics includes a direct mode and differential amplifier mode based on feedback oscillation. This document excludes devices dealt with by TC 49: piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 63041-1, *Piezoelectric sensors – Part 1: Generic specifications*

IEC 63041-2, *Piezoelectric sensors – Part 2: Chemical and biochemical sensors*

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

Units, letter symbols and terminology shall, wherever possible, be taken from IEC 63041-1 and IEC 63041-2.

3.1 General terms

3.1.1
surface acoustic wave
SAW
acoustic wave, propagating along the surface of an elastic substrate, the amplitude of which decays exponentially with substrate depth

Note 1 to entry: This entry was numbered 561-06-01 in IEC 60050-561:1991, Amendment 1:1995.

[SOURCE: IEC 60050-561:2014, 561-01-86]

3.1.2
interdigital transducer
IDT
SAW transducer made of a comb-like conductive structure that is deposited on a piezoelectric substrate and consists of interleaved metal electrodes (fingers) whose function is to transform electrical energy into acoustic energy or vice versa by means of the piezoelectric effect

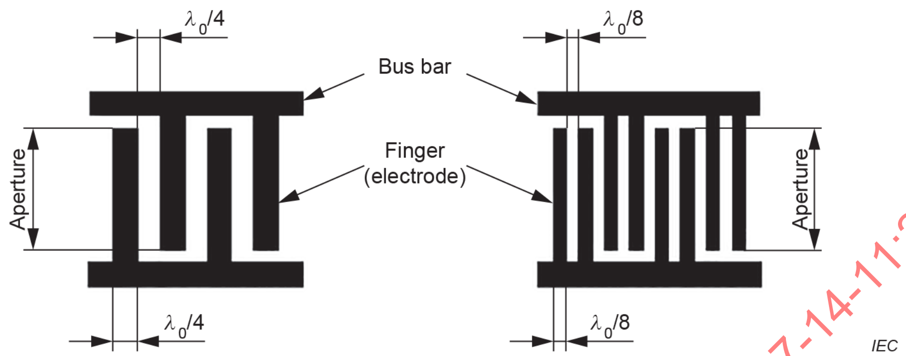


Figure 1 – Configuration of an interdigital transducer (IDT)

Note 1 to entry: This entry was numbered 561-06-09 in IEC 60050-561:1991, Amendment 1:1995.

[SOURCE: IEC 60050-561:2014, 561-01-41]

3.2 SAW-based integrated light sensors

3.2.1
ultraviolet sensor element
ultraviolet sensor component with a sensitive layer that detects the frequency, phase, delay, electrical charge, etc.

Note 1 to entry: Semiconductor materials, such as ZnO and ZnS, are used to detect ultraviolet.

3.2.2
visible-light sensor element
visible-light sensor component with a sensitive layer that detects the frequency, phase, delay, electrical charge, etc.

Note 1 to entry: Semiconductor materials, such as CdS and PbS, are used to detect visible light.

3.2.3
reference sensor element
device component used as a reference to minimize the effect of temperature variations in experimental environments

3.2.4
integrated multi-light sensor
sensor that can detect ultraviolet and visible light together with an array of two different light sensor components on one substrate

Note 1 to entry: Ultraviolet is electromagnetic radiation with wavelengths approximately in the 100 nm to 400 nm range, and visible light is defined as electromagnetic radiation with wavelengths of 400 nm to 700 nm. The integrated multi-light sensor measures both ultraviolet and visible light.

3.3 Characteristics parameters

3.3.1
centre frequency
arithmetic mean of two frequencies at which the attenuation relative to the minimum insertion attenuation reaches a specified value

Note 1 to entry: This entry was numbered 561-07-01 in IEC 60050-561:1991, Amendment 2:1997.

[SOURCE: IEC 60050-561:2014, 561-01-07]

3.3.2
phase shift
in angle modulation by a discretely timed signal, the difference between the phases of two signal elements of the modulated signal, assuming steady-state conditions

[SOURCE: IEC 60050-702:1992, 702-06-39]

3.3.3
frequency shift
intentional frequency change produced by modulation, or an unintentional change due to a natural phenomenon

[SOURCE: IEC 60050-702:1992, 702-01-12]

3.3.4
resonance frequency
frequency at which resonance exists

[SOURCE: IEC 60050-801:1994, 801-24-06]

3.3.5
insertion loss
resulting from the insertion of a network into a transmission system, the ratio of the power delivered to that part of the system following the network, before insertion of the network, to the power delivered to that same part after insertion of the network

Note 1 to entry: The insertion loss is generally expressed in decibels.

[SOURCE: IEC 60050-726:1982, 726-06-07, modified – The term and the definition have been modified so that only the concept of insertion loss is defined (the concept of insertion gain is no longer included in the entry).]

4 Device structure and characteristics

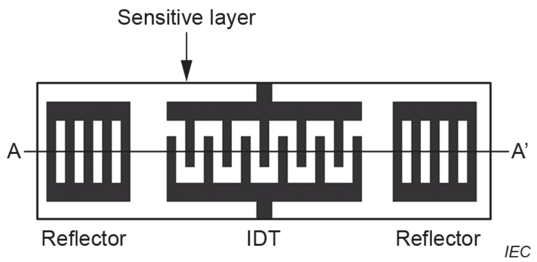
4.1 General

The SAW light sensor is used as a sensor in a smart device to measure the UV and visible light intensity, using semiconductor materials such as ZnO and CdS as the sensitive layer. The device's structure and the characteristics of SAW light detection sensors are shown in detail in 4.2 to 4.4.

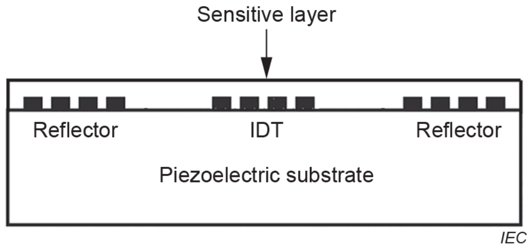
4.2 Device structure

4.2.1 SAW based resonator type light-sensor elements

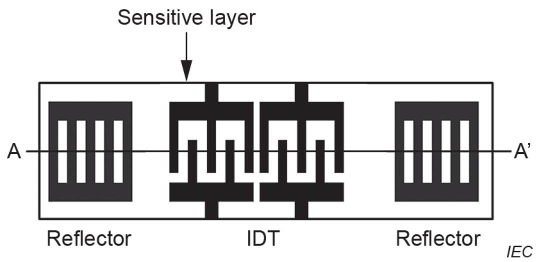
Figure 2 shows the practical conceptual diagram for a surface acoustic wave (SAW) based resonator type integrated light-sensor element. In the figure, mounting stages and enclosures are omitted.



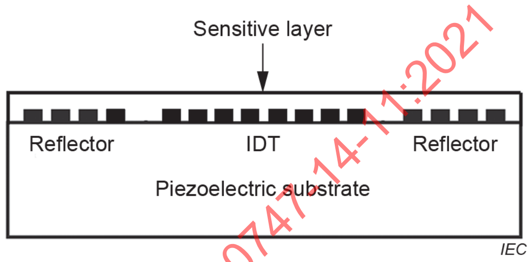
a) **Top view of one-port resonator type**



b) **Side view (cross-section of the A-A' line) of one-port resonator type**



c) **Top view of two-port resonator type**

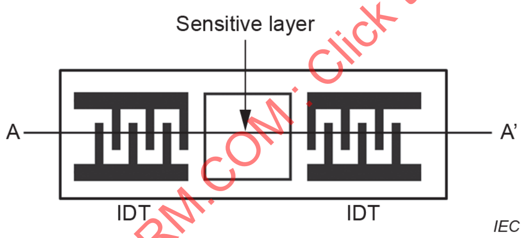


d) **Side view (cross-section of the A-A' line) of two-port resonator type**

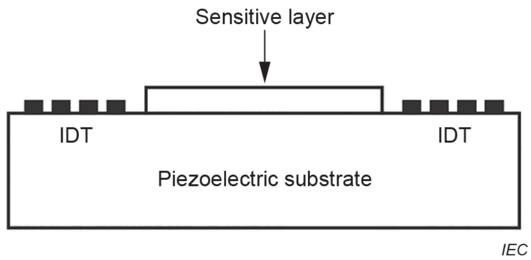
Figure 2 – Conceptual diagram for SAW-based resonator type light-sensor elements

4.2.2 SAW-based delay line type light sensor elements

Figure 3 shows the practical conceptual diagram for a surface acoustic wave (SAW) based delay line type integrated light sensor element. In the figure, mounting stages and enclosures are omitted.



a) **Top view of two-port delay line type**

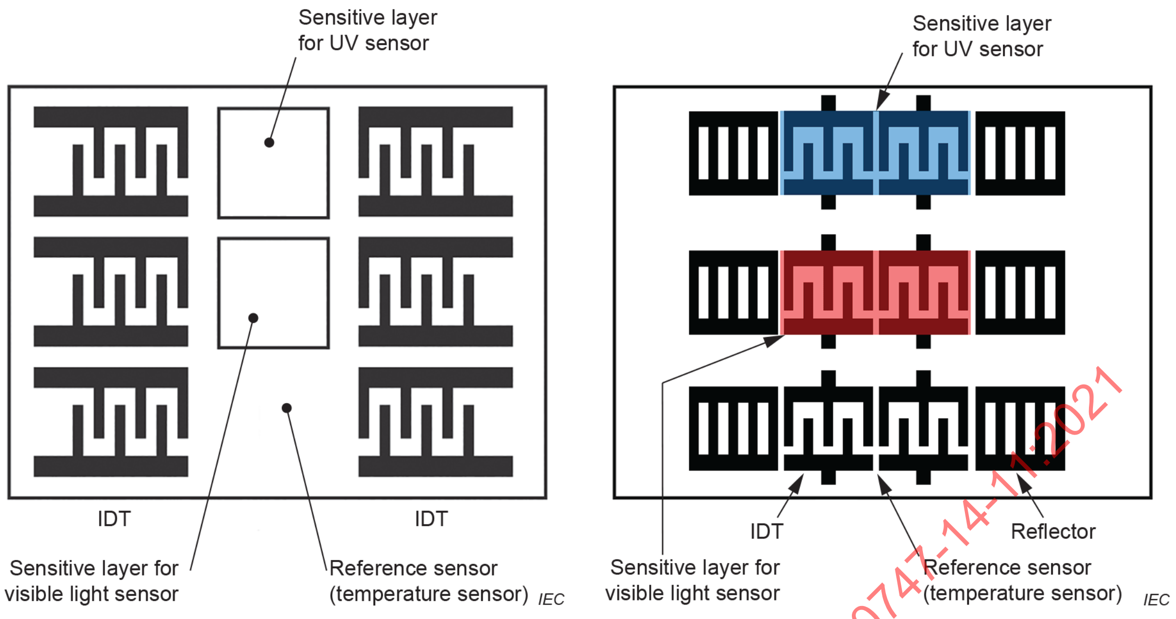


b) **Side view (cross-section of the A-A' line) of two-port delay line type**

Figure 3 – Conceptual diagram for SAW-based delay line type light sensor elements

4.3 Characteristics of integrated UV and visible-light sensors

Figure 4 shows a conceptual diagram of the integrated multi-light sensor elements. The sensors are composed of three different layers, and each layer is a sensitive layer for a UV sensor, a visible-light sensor, and a reference sensor element, which serves to compensate changes in temperature of the SAW sensor.



a) Integrated multi UV and visible light sensors for delay line type

b) Integrated multi UV and visible light sensors for two-port resonator type

Figure 4 – Conceptual diagram for integrated multi UV and visible-light sensors

4.4 Key points of integrated UV and visible-light sensors

4.4.1 UV sensitive layer

The UV sensitive layer employed in an ultraviolet sensor element should be selected for ultraviolet light. Some semiconductor materials such as ZnO, ZnS, GaN, SiC can be used for the sensitive layer for UV. See Annex A and Annex B for the principles and characteristics of photosensitive layers.

4.4.2 Visible-light sensitive layer

A sensitive layer for visible light employed in light sensor applications should be selected for only visible light. Some semiconductor materials such as CdS, CdSe, PbS and PbO can be used for sensitive layer for visible light. See Annex A and Annex B for the principles and characteristics of photosensitive layers.

5 Test conditions

5.1 Test environmental conditions

Measurements shall be carried out under standard environmental conditions:

a) Temperature: 25 °C ± 3 °C

b) Relative humidity: 25 % RH to 85 % RH

c) Atmospheric pressure: 86 kPa to 106 kPa

When using different environmental conditions, they shall be noted in the measurement report.

5.2 Darkroom condition

The illuminance from the darkroom illumination through the test environment shall be less than 1 lux and the UV intensity shall be less than 0,01 μW/cm^2. If this condition is not satisfied, then it shall be noted in the report.

5.3 Setup conditions

5.3.1 Starting conditions of test

Measurements shall be started after the UV/visible-light lamps achieve stability. When lamps are turned on, they take time to go from the standard darkroom condition to maximum illumination; therefore, warm-up time has to be allowed for the device to reach an illumination stability level of less than ±5 % over the entire measurement period.

5.3.2 Conditions of UV and visible light measurement equipment

The following equipment have been introduced for reliable experimentation.

a) Three types of UV lamps are used. The UVA at 315 nm to 400 nm, UVB at 280 nm to 315 nm and UVC at 100 nm to 280 nm lamps are used.
b) The green LED (495 nm to 570 nm) in the visible light area is used.
c) The lamp height controller controls the intensity of the UV/visible light by adjusting the lamp's height.
d) The UV meter measures the UV intensity.
e) The visible light meter measures the visible light's intensity.

6 Test methods

6.1 General

Basically, general test procedures for semiconductor light sensors are performed as shown in Figure 5. After the semiconductor light sensor has been mounted on a test chamber, the DC characterization and RF characterization are measured. The test of RF characteristic conducts the direct mode (option A) or differential amplifier mode (option B).

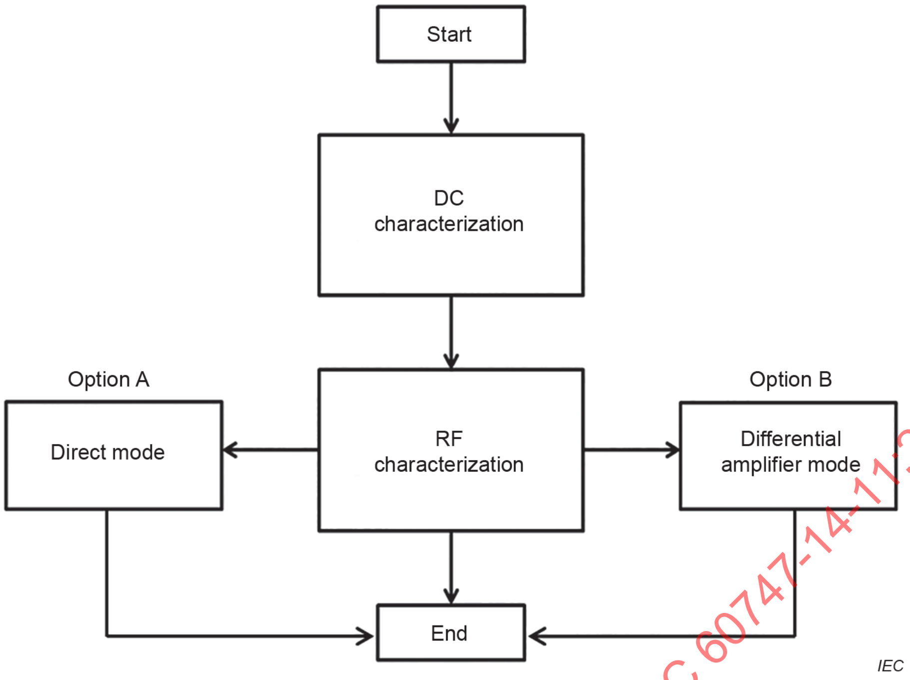


Figure 5 – Measurement procedure for the semiconductor light sensor

6.2 Test methods of DC-characteristics for the light sensor element

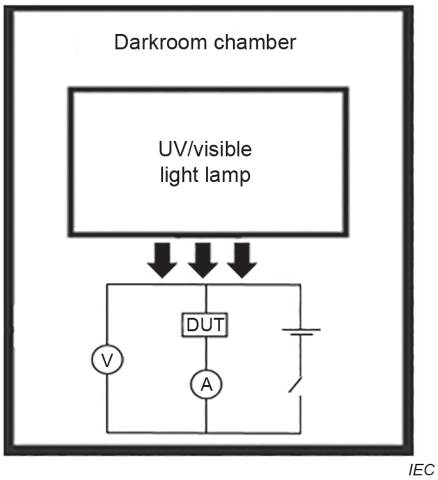
Figure 6 and Figure 7 show the test setup for measuring the current–voltage (I–V) characteristics of the light sensor element and example I-V characteristics, respectively. I–V characteristics of the light sensor element are measured in the following sequence.

a) Prepare a DC measurement instrument to obtain transient responses under UV/ visible light on/off light conditions and to get the current-voltage (I–V) characteristics as a function of the UV intensity and visible light.

b) Place a semiconductor light sensor in a dark room chamber, and fix the sensor at the light's centre.

c) Set the voltage range of the circuit.

d) Turn on the UV/visible light lamp and measure electric current by voltage.



Key

DUT device under test (SAW-based integrated light sensors)

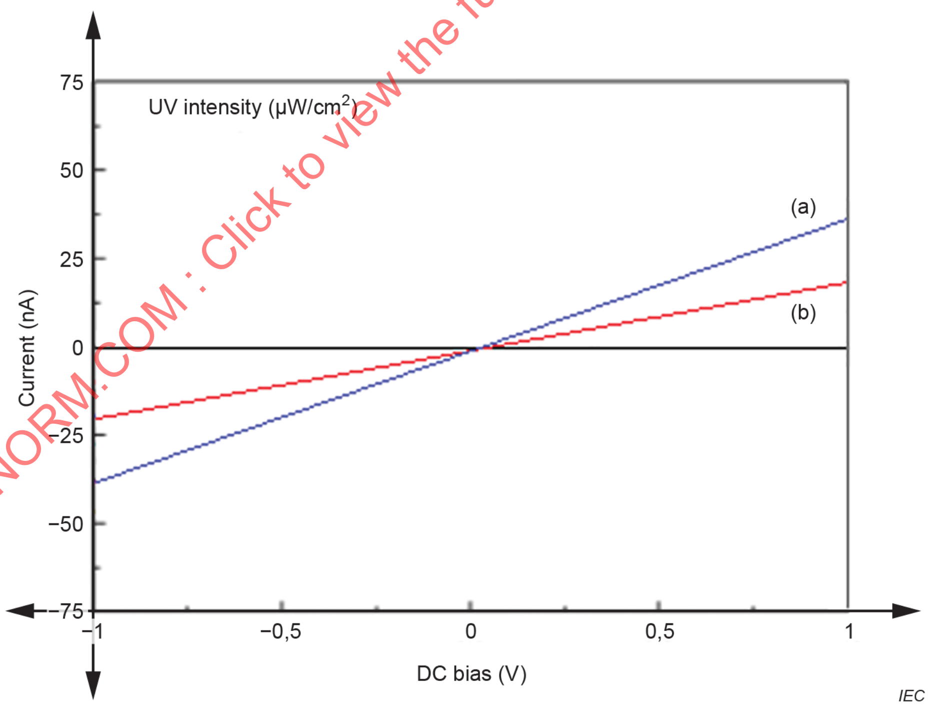
UV/visible light lamp light source of UV/visible light

Voltage meter (V) to detect a voltage across the external load

Ampere meter (A) to detect a current through the external load

NOTE The voltage source type is direct current (DC). Use a DC current meter.

Figure 6 – Test setup to measure the I-V characteristics of semiconductor light sensor



NOTE When the UV intensity is 0, the slope of the I-V curve is 0. (a) has a larger slope than (b) because (a) has a larger intensity than (b).

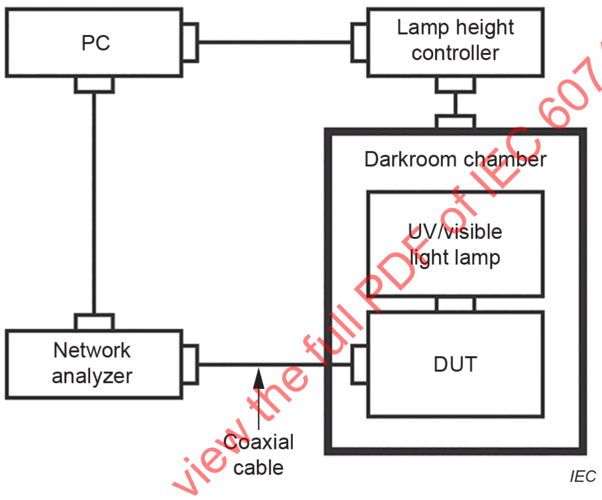
Figure 7 – Example of I-V characteristics of a UV sensor element as a function of UV intensity

6.3 Test methods of RF characteristics for integrated light sensors

6.3.1 Direct mode

This method measures the frequency and phase shift or insertion loss (IL) variation in integrated light sensors. Figure 8 shows the test set up for measuring the frequency, phase or IL variation in the light-sensor element without UV and visible light.

a) Measure the frequency, phase, or IL variation of the light sensor's element according to the UV and visible light intensity, by preparing measurement equipment as described in 5.3.
b) Locate the light sensor in a dark room chamber and fix the sensor under the light's centre.
c) Connect a coaxial cable from the network analyser to the sensor.
d) Measure the intensity of light according to height change with the UV/visible-light meter.
e) Meanwhile, measure the centre frequency, phase or IL variation corresponding to the light's intensity.



Key

DUT: device under test — SAW based integrated light sensors

Lamp height controller — to control light lamp's height

PC to select input parameters and gets data

UV/visible light lamp — light source of UV/visible light

Network analyser — detect frequency, phase or IL variation of integrated light sensors

Figure 8 – Test setup to measure the frequency shift of semiconductor light sensor

6.3.2 Differential amplifier mode

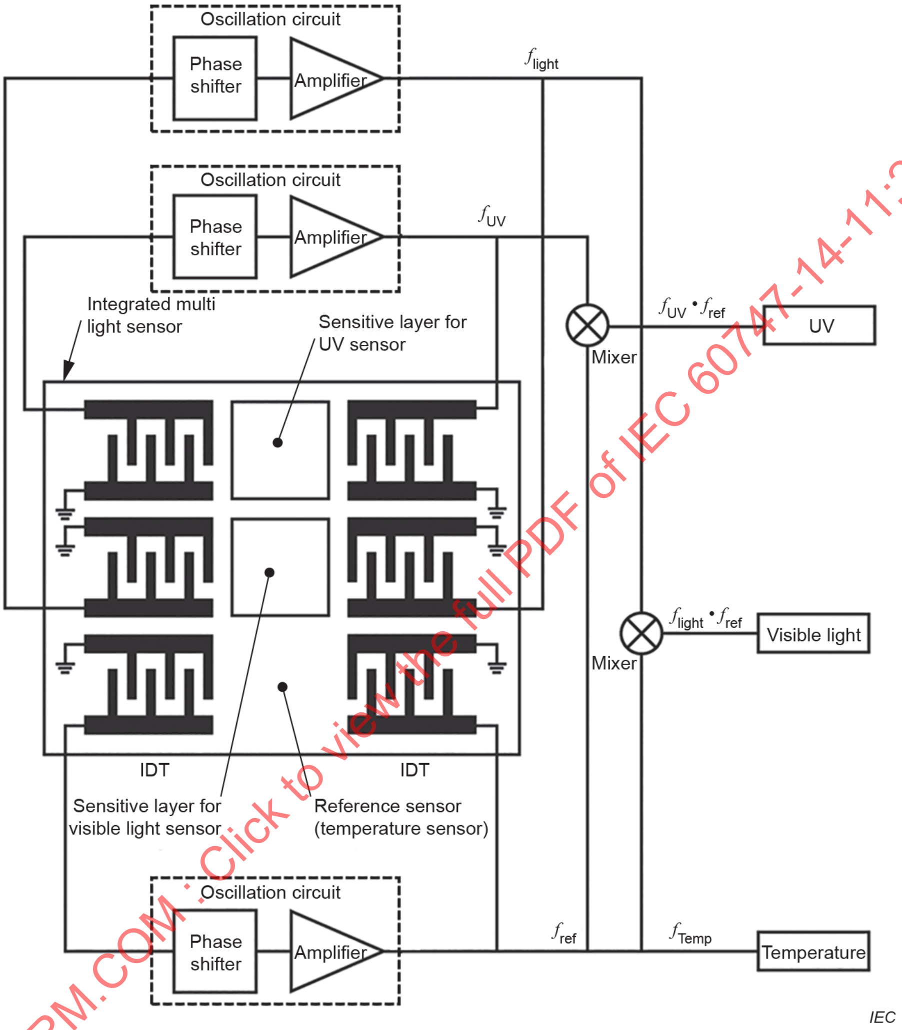
In the differential amplifier mode method, the light sensor operates like an excited oscillator by making an oscillation loop. The light device's input and output transducers in the detecting part were connected by an oscillator circuit that consists of an amplifier with a low gain, a phase shifter, a mixer, and an LC filter.

The detecting part's output signal was mixed to reduce the thermal effect and provide low-frequency signals in the kHz range. The amplitude and velocity of the wave are changed (ΔV_c), and this change induces a shift in the oscillation frequency (Δf_c) for the sensing oscillator. Measuring the frequency difference between the sensing and reference oscillators, the input rotation can be evaluated without temperature effects. The nature of the piezoelectric substrate means that the temperature can change the oscillation frequency. To eliminate this effect (Δf_{temp}), a dual-delay line structure was applied. Because temperature affects both the reference and the sensing element, the following method can be applied:

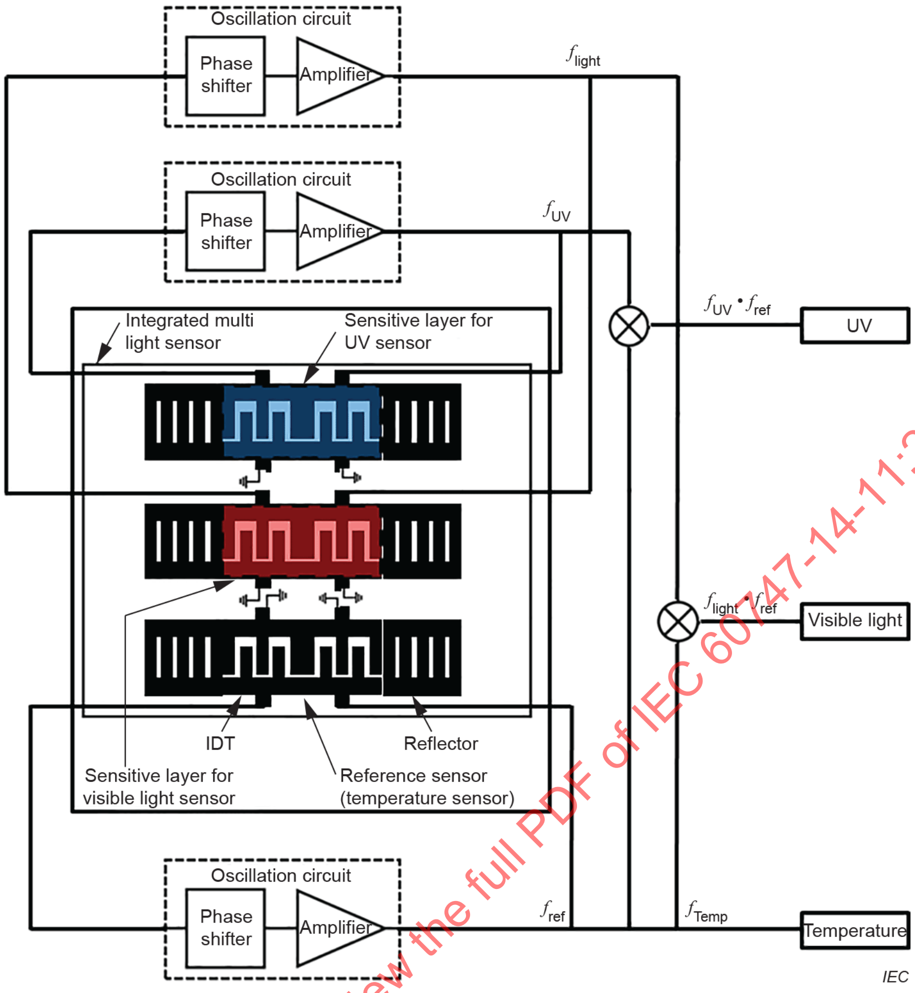
A: Output frequency of the sensing part
(fundamental frequencies f_2 (sensing part) + Δf_c + Δf_{temp})

B: Output frequency of the reference part
(fundamental frequencies f_1 (reference part) + Δf_{temp})

$$A - B = (f_2 + \Delta f_c + \Delta f_{temp}) - (f_1 + \Delta f_{temp}) = f_2 - f_1 + \Delta f_c \approx \Delta f_c \because (\text{Ideally } f_2 - f_1 = 0) \quad (1)$$



a) Differential amplifier mode method for delay line type



b) Differential amplifier mode method for two-port resonator type

Figure 9 – Differential amplifier mode method

Figure 9 shows the differential amplifier mode method. The measurement methods of the differential mode are explained in the following sequence. Figure 10 shows the measurement results for UV and visible-light sensors using the differential amplifier mode method.

a) Place a semiconductor light-sensor module in a dark room chamber and fix the sensor at the light's centre.

b) Connect the oscilloscope to the measuring terminal in the sensor module and apply a ±5 V input voltage to the sensor module through a power supply.

c) Check the sinusoidal signal with the fundamental frequencies of f_{ref} and $f_{sensing}$.

d) Measure the amount of light according to the height change with the visible-light meter in the dark room chamber.

e) Meanwhile, measure the mixed shift in the oscillation frequency (Δf_c) that corresponds to the amount of light.

f) Repeat steps d) and e) to measure the resonance frequency, which changes according to the light intensity from 0 mW/cm^2 to 1 mW/cm^2 or 0 lux to 40 000 lux, observing a change as a function of UV or visible light intensity.

g) Determine the sensitivity of the sensor from the graph's frequency shift.

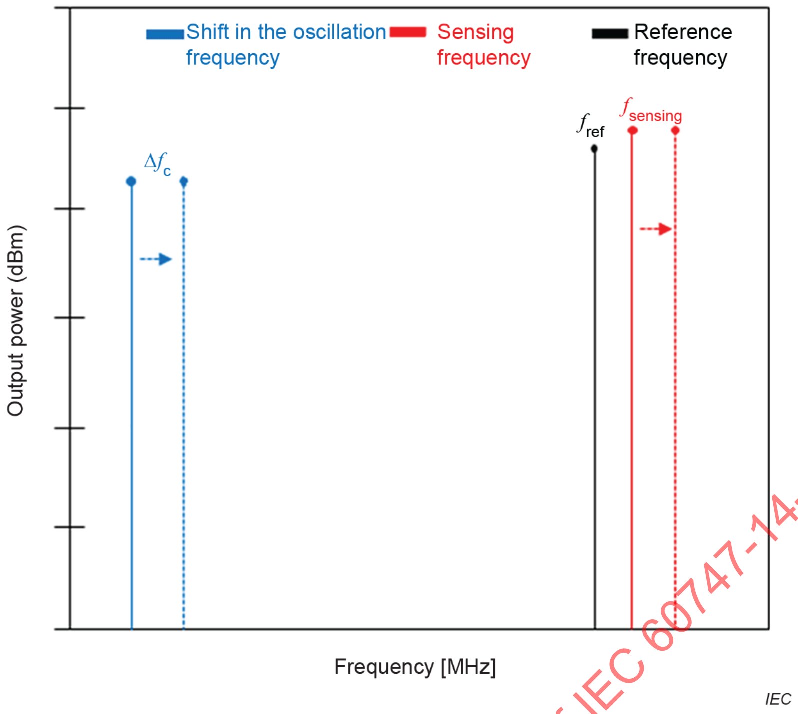


Figure 10 – Measurement results of UV and visible-light sensors using differential amplifier mode

Annex A
(informative)

Ultraviolet and visible light characteristics of the sensitive layer

The sensitive layer such as ZnO, ZnO nano particle (NP), ZnS, CdSe, or CdS-based layers is exposed to UV radiation and illumination, to generate electron hole pairs in the layer. For ease of understanding, it is assumed that ZnO (or ZnO NP) was used as the sensitive layer for UV detection. Figure A.1 and Figure A.2 show the sensitive layer's operating principle. In the absence of UV light, oxygen molecules are absorbed on the surface of the ZnO based layer. These captured oxygen molecules induce a depletion region, and lead to a reduction in the ZnO conductivity and the formation of oxygen ions, such as O_2^-, O, or surface O_2. The photo-generated holes move to the ZnO surface and react with the negatively charged adsorbed oxygen ions to narrow the depletion zone of the ZnO-based layer. At the same time, oxygen molecules are desorbed from the surface and electrons are accumulated in the conduction band by the photo-generated electrons. As a result, electrical conductivity increases, and electrical resistance and depletion layers decrease.

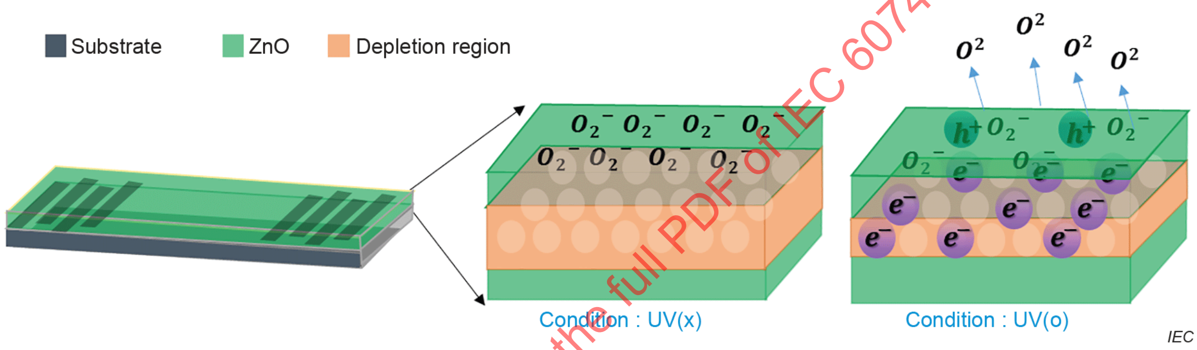


Figure A.1 – Operation principle of the ZnO sensitive layer for UV sensing