A Compact and Power Efficient UV Dosimeter Design

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***Abstract*—This paper presents a compact and power efficient ultra-violet (UV) dosimeter design. The compact design is achieved by incorporating the principal dosimeter functions onto a CMOS integrated chip. Besides, the external components are arranged in order to minimize the global board BoM (Bill of Materials). On the power consumption side, the CMOS integration aims to reduce the maximum power consumption levels. In addition, a regular sleep/wake-up technique is employed to further decrease the global average power consumption. The high-power blocks are driven by a variable duty-cycle integrated oscillator and turned ON only during short time slots. The device is powered by a primary solar rechargeable battery and a secondary standard emergency battery. The emergency battery is only used when the rechargeable battery gets unable to supply the circuit. The proposed solution aims to prevent any battery replacement during the life-time of the product. An external tri-color LED indicates the skin exposure risk level to UV rays.**

***Index Terms*—Ultra-violet, low-power, rechargeable battery, dosimeter.**

I. Introduction

Skin cancer is the most common type of cancer in fair-skinned populations in many regions in the world with increasing incidence and mortality rates [1]. In 2000, there were an estimated 200,000 cases of melanoma, 2.8 million cases of squamous cell carcinoma and 10 million cases of basal cell carcinoma worldwide [2]. Ultraviolet radiation (UVR) is the major etiologic agent in the development of skin cancers [1]. UVR causes genetic mutations, which is a precursor to skin cancer. Melanoma, a high-risk skin cancer, is associated with burning UV doses even in cases of intermittent exposure or during childhood [3].

UVR comprises approximately 5% of solar terrestrial radiation. UVR can also be generated by artificial sources. UVR spans the wavelengths from 100 to 400 nm subdivided into three regions: UVC (100-280 nm), UVB (280-315 nm) and UVA (315-400 nm). UVC is completely filtered by the atmosphere allowing UVR of wavelengths comprised of 95% UVA and 5% UVB [4]. The biological effects of UVR vary with the wavelength of the UVR. Despite the fact that UVB constitutes a small fraction of the UVR, UVB contributes to approximately 80% of the harmful radiation effects associated with sun exposure [5]. The amount of solar UVR reaching the surface of the earth depends on many factors, which include time of day, season, geographical latitude, stratospheric ozone, atmospheric pollutants, weather, ground reflectance and altitude [4].

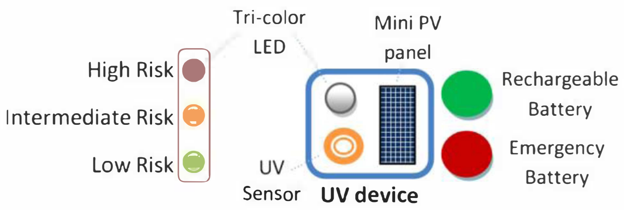

Fig. 1. Compact UV dosimeter employing a solar rechargeable battery and an emergency standard battery.

In order to reduce the risk of skin cancer, the World Health Organization has developed an international for UV measurement called the UV index (UVI). UVI is designed to indicate the potential for skin damage. The higher the UVI value, the greater the potential to skin damage and the less time it takes for harm to occur. The skin type is also a factor in the potential for UV skin damage. The darker the skin, the less damage is expected to occur [2]. The UV index is designed to indicate the potential for adverse health effects and to encourage people to use skin protection or stay away from the sun. UV dosimeters are also used to indicate skin damage potential.

II. Previuos Work In The Litterature

Personal UV dosimeters are commercially available but are not widely used. UV dosimeters are typically designed in the form of a wristwatch or keychain/badge. A small badge type personal dosimeter was recently introduced for research purposes [6]. The device included a microcontroller and data logger. The device had a battery with a 3 months operating life. The dosimeter had a 35 mm diameter and was10 mm thick. A device with similar design was introduced in the form of a wristwatch [7]. The dimensions of the wristwatch were 36 x 28 x 13 mm. We believe that the design of these devices is not convenient for potential users. A more appropriate design should have the following specifications:

1- Small size.
2- Be an integral part of the swimming suit.

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3- Have a long-term battery.
4- Have a simple indicator for the level of injury potential.
5- Have a simple operating procedure.
6- Include entry for user skin type.

III. Ultra Low Power Design

The main battery should be rarely changed or ideally never changed. To have this objective reached, three main techniques are applied:

A. Solar Rechargeable Battery Use

The UV-device is equipped with a rechargeable battery. Thanks to a mini-photovoltaic (PV) cell, the sunlight is converted to electrical energy and stored it in this battery. When the delivered voltage by the rechargeable source gets comparable to the voltage provided by the emergency battery, a switch selects the rechargeable source to feed the necessary current. When this voltage drops below the emergency battery voltage, the switch goes back to the rechargeable battery. The complete power supply management unit is shown in Fig. 2.

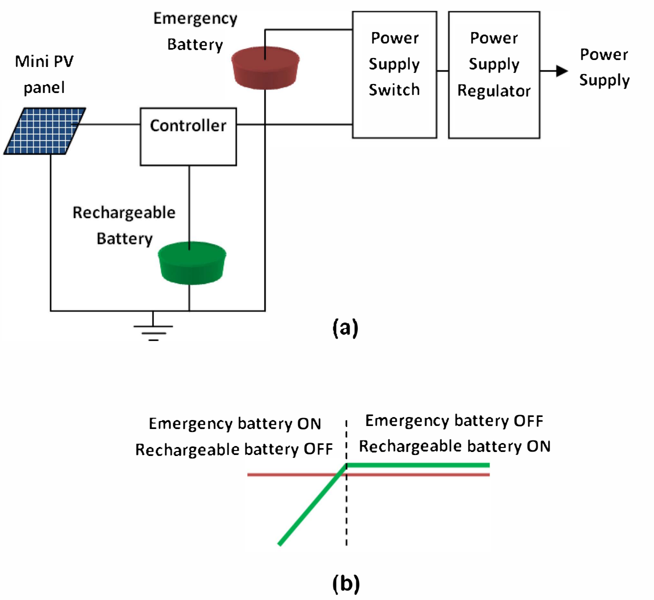

Fig. 2. (a) Power supply management unit equipped with a solar rechargeable battery and an emergency standard battery and (b) Switching behavior between the emergency battery and the rechargeable battery according to the delivered voltage level by the later.

A power supply regulator is required in order to reject the low-frequency noise. The high-frequency noise rejection is realized with external decoupling capacitors. This is mandatory since the low current levels dealt with in this circuit make the system extremely sensitive to any additional noise. Besides, a power level controller interfaces the rechargeable battery to avoid any over-charge behavior able to impact its charge cycle quality and its life-time.

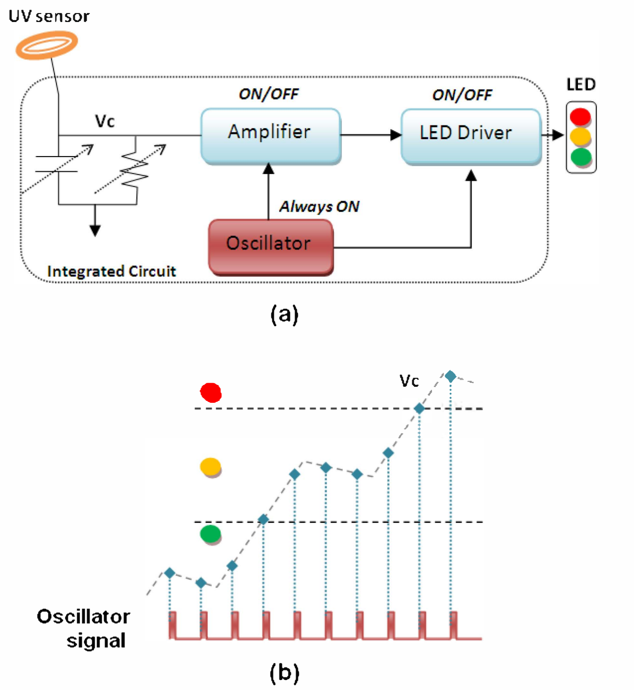

Fig. 3. (a) UV integrated circuit architecture showing the systematically active blocks and the other regularly woke-up blocks and (b) time diagram illustrating regularly sampled charge and discharge phases with evolution through different risk regions (low, medium and high).

B. Regular Sleep/Wake-Up Time Intervals

The UV exposure level does not need to be continuously sensed and checked. The accumulated UV energy evolves according to relatively slow variations. Therefore, a level check every few minutes, or even more, may provide an acceptable estimate of the accumulated UV energy evolution.

The circuit architecture is shown in Fig. 3a. The UV accumulator is realized with a simple RC circuit. The capacitor stores the delivered charge by the UV sensor under exposure. The parallel resistor is added either to slow-down the charging slope or to discharge some of the accumulated charge to the ground when no exposure to UV light is there. This effect aims to reproduce a comparable behavior to the human body UV energy evacuation in absence of exposure to UV rays. Both R and C values can be programmable thanks to parallel switched resistive and capacitive banks. This programmability is required to adapt the charging and discharging responses to the relative sensitivity of different skin colors.

The available voltage signal (Vc) across the RC-circuit is then amplified and led to a LED driver. According to the input level, the driver draws a proportional current into the LED and displays one out of three possible colors (red, yellow and green). These colors indicate the total accumulated charge

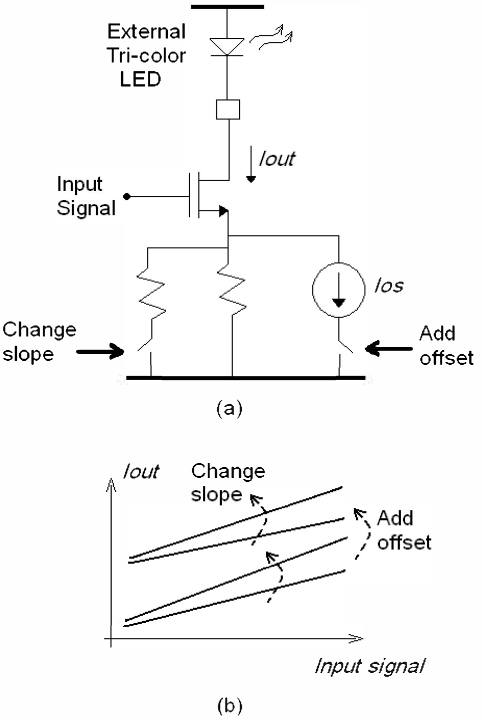

Fig. 4. (a) Integrated LED driver schematic providing the possibility to change the speed of LED colors variation as well as to add a certain light offset and (b) relative evolution of the output drive current with respect to the presented features.

amount and therefore the relative risk degree to UV exposure. Three risk levels are thus available: low, medium and high.

Note that the thresholds between the different risk zones depend on the skin type and require therefore to be set differently according to the user's skin. This can be done whether by the final user or the product provider or manufacturer. The thresholds can be internally realized by adding a programmable current offset to the LED driver as well as by adding a programmable current slope. The current offset does not generate any additional DC power consumption and can be turned ON or OFF along with the driver itself (Fig. 4).

The oscillator signal synchronizes the ON and OFF switching times of both the amplifier and the LED driver blocks. The duty cycle can be set such that the ON intervals last for a few tens of seconds and the OFF intervals for few minutes. Parasitic charge injection effects should be carefully considered to avoid any added offset to the sensed voltage value at the input. This can be done by both controlling the rise and fall times of the oscillator command signal and by employing known charge switching compensation techniques. Guard delays should also be added around the switching instants before transferring any measured signal from the input to the driver output.

The oscillator block is kept active during the complete operation time of the UV device. To avoid drawing any

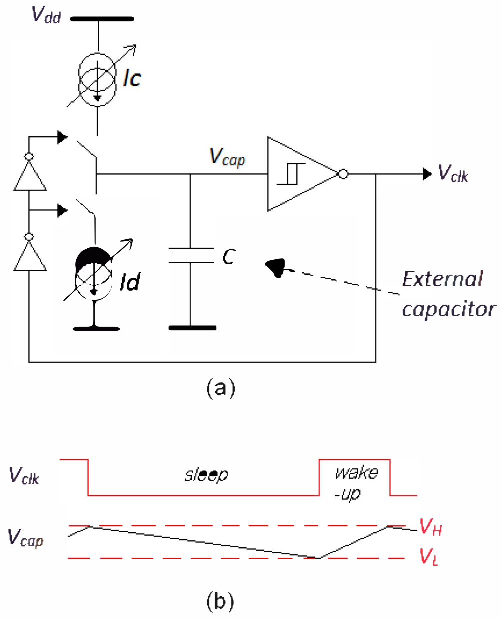

Fig. 5. Integrated low power relaxation oscillator design providing programmable sleep/wake-up intervals through the control of charging and discharging currents values (I_c and I_d). The high capacitor value (e.g. 1 mF) is placed off-chip.

supplementary current when the device is not used, the oscillator must be turned OFF. Two options are possible in this case.

The first option consists of simply having a switch button activated by the user to turn ON/OFF the oscillator and to reset the charge accumulator.

The second option relies on sensing the dropping curve of the accumulator signal (Vc) while the dosimeter is not exposed to UV light (Fig. 3). When this signal reaches a certain low threshold level, the oscillator is automatically switched OFF. This effect can be related to human skin exposure recovery from the accumulated UV energy so that a new sensing cycle can be launched. Inversely, when the device starts receiving again UV light, the increasing (Vc) level enables the oscillator as it reaches up the comparator threshold level. During a certain start-up time, the LED display is not available at the output, which is acceptable as long as the sensed level is far below the transition to medium-risk zone.

C. Low Power CMOS Integrated Design

The oscillator design should exhibit an extremely low current consumption since it is designed to be active continueously. The other power consuming circuit is the LED driver involving relatively high current levels.

Many options can be considered for the oscillator design. A capacitor based relaxation oscillator (Fig. 5) presents the advantage of direct control of the oscillator signal duty-cycle, and consequently the sleep and wake-up time intervals. These intervals are defined by the capacitor charging and discharging currents I_c and I_d, respectively, in addition to the hysteris trigger swithcing levels, V_H and V_L. The relative equations to the sleep and wake-up time intervals, t_{sleep} and $t_{wake\text{-}up}$, are given by

$$t_{sleep} = \frac{C(V_H - V_L)}{I_d}, \qquad t_{wake-up} = \frac{C(V_H - V_L)}{I_c}$$

Thus, with typical values of $V_H - V_L = 1$ V, C = 1.8 mF (off-chip), I_d = 3 µA and I_d = 90 µA, sleep and wake-up intervals of 10 minutes and 20 seconds, respectively, can be reached.

D. Power Budget

A total current consumption less than 0.5 mA (i.e. P < 0.6 mW under 1.2-V supply) is targeted in our case. The photovoltaic (PV) cell delivers around 10 mW/cm^2 peak power density under maximum lighting. With 1 cm^2 PV cell area and an average available power of 5 mW, the delivered power to the rechargeable battery is large enough to achieve a high autonomy and keep the main battery as an emergency source.

Note that the power budget has a direct consequence on the CMOS technology node choice (regarding the integrated circuit part). The total stand-by current is defined by the components (and mainly the MOS transistor) leakage currents. Recent or very advanced CMOS technologies might not be the optimum choice to achieve the targeted low power consumption goals.

IV. Compact Dosimeter Design

The compact design is realized by using a double-side layout on a single board support. The front and back side layouts are shown in Fig. 6.

The PV cell, the UV sensor, and the LED are mounted on the top side. Possible more miniaturized design may be obtained by including the UV sensor and the LED in the mini PV cell design area. On the back side, the rechargeable battery, the emergency battery, the integrated circuit, and all the other external components are placed (oscillator's capacitor, decoupling capacitors, etc.). Passive components integration technology may allow to further integrate the external components into the IC package, leading to a more compact design. The presented design in Fig. 6 has a 1 cm by 2 cm dimensions. The height can be minimized to less than 1 cm.

V. Conclusion

In this paper, a compact and power efficient UV dosimeter design has been presented. The target design achieves less than 2 cm^2 implementation area and enables therefore a wide range

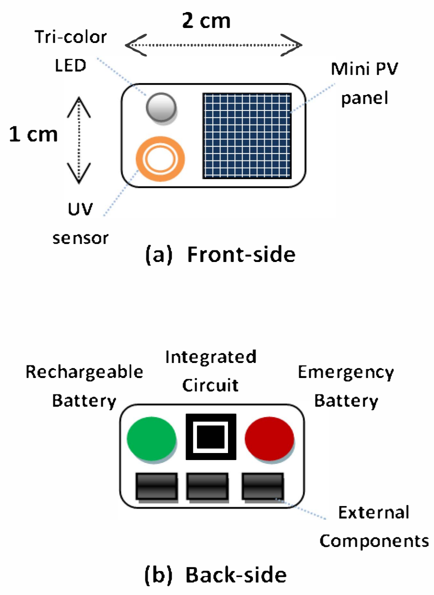

Fig. 6. Compact UV dosimeter including the integrated circuit and showing the front and back sides design.

of applications. The ultra low power characteristics can be achieved using CMOS integration and specific PWM sensing techniques. The programmability or calibration features can be performed whether by the final user or the product assembler or manufacturer.

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