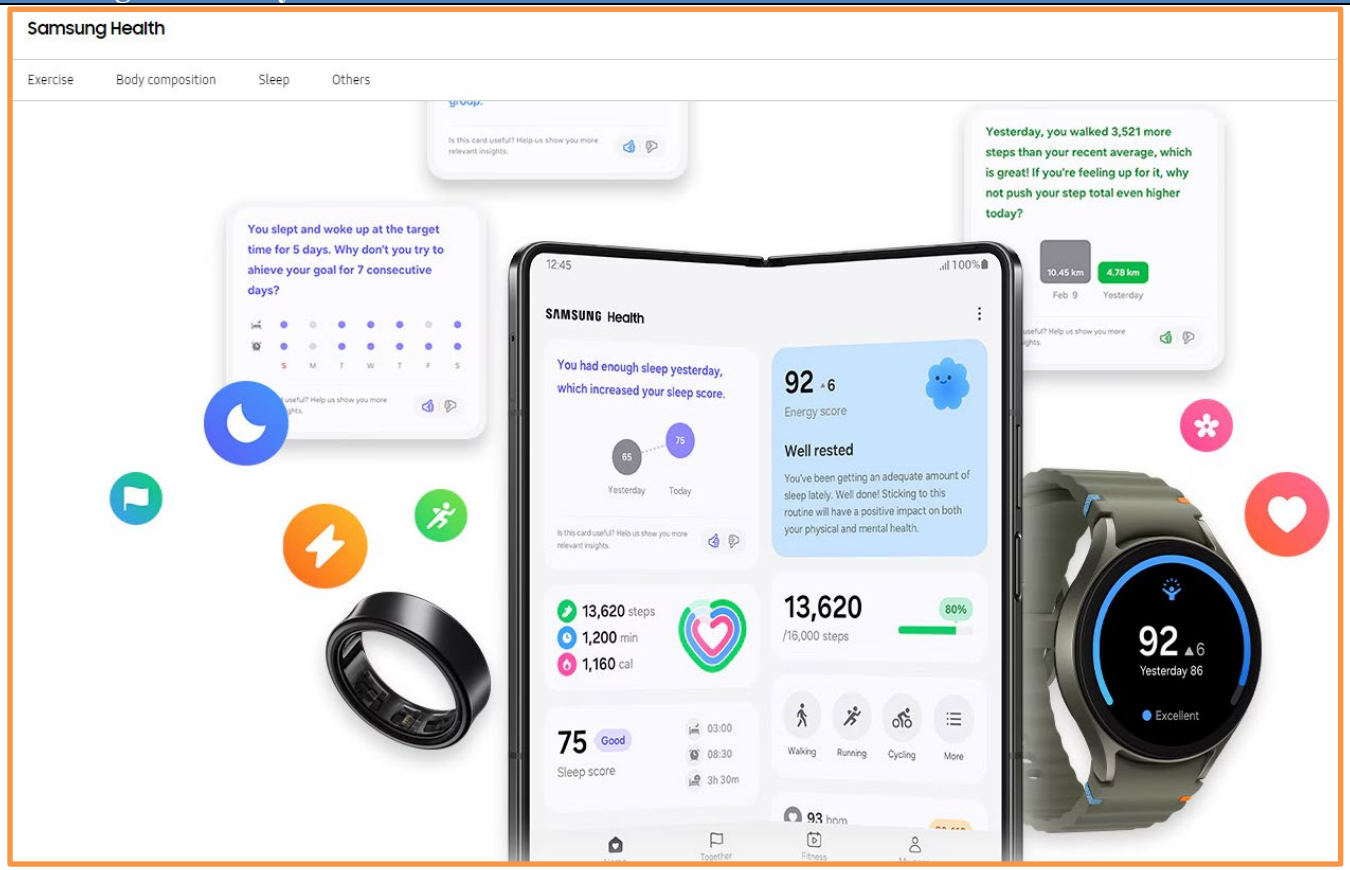
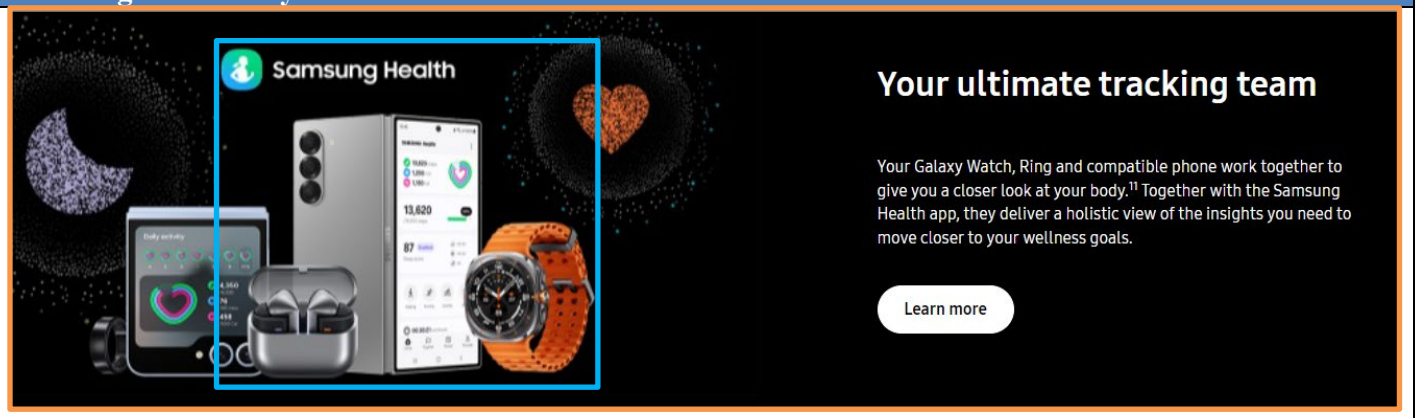
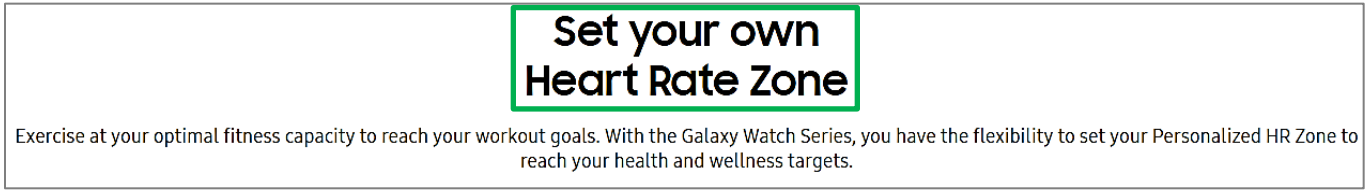
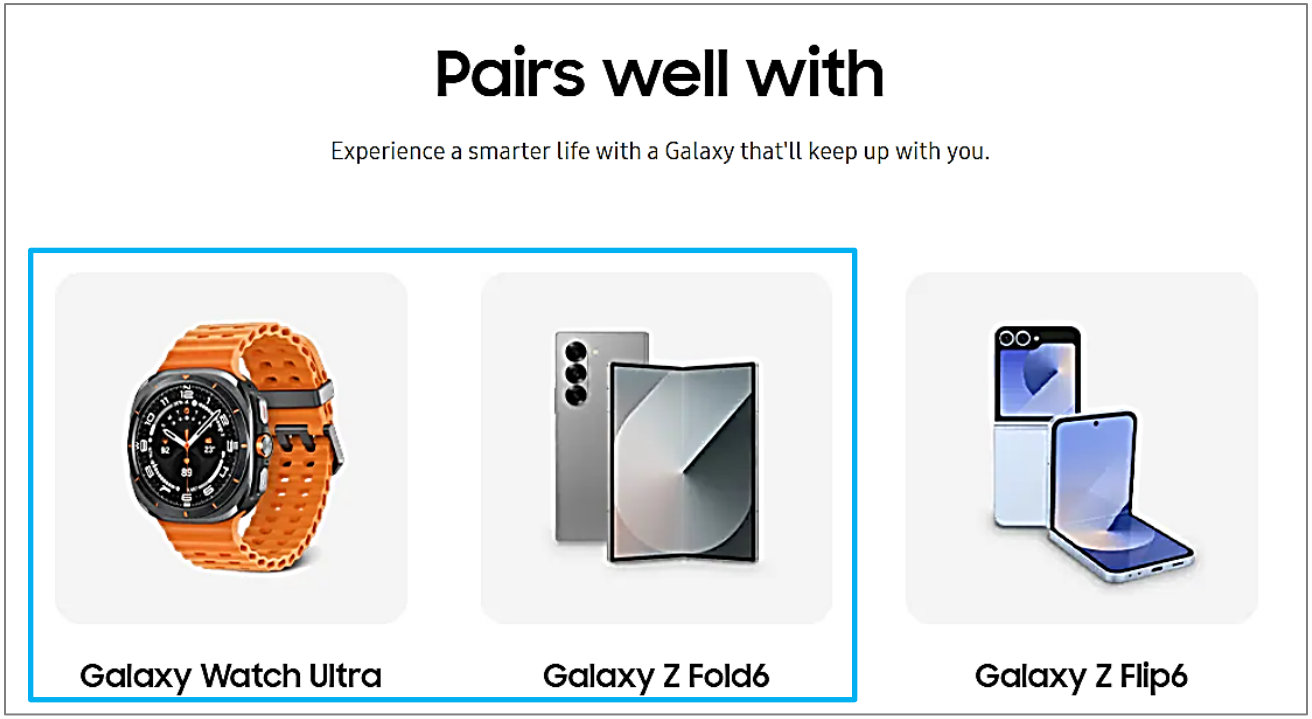
'455 Patent Claim	Samsung Accused System[1]
1[pre] A system for measuring one or more physiological parameters and for use with a smart phone or tablet, the system comprising:	Without conceding that the preamble of Claim 1 is limiting, Samsung Electronics, Co. Ltd. and Samsung Electronics America, Inc. (collectively, "Samsung") have made, used, offered to sell, sold in the United States, and/or have imported into the United States, and/or, continue to make, use, offer to sell, and sell within the United States, and/or import into the United States, Accused Systems for measuring one or more physiological parameters and for use with a smart phone or tablet, either literally or under the doctrine of equivalents. For example, Samsung provides a system, including a Galaxy Watch Ultra, a Samsung smartphone or tablet, and Samsung Cloud ("system") for measuring "one or more physiological parameters" of a user, such as heart rate, blood oxygen level, and electrocardiogram. When the user wears a Galaxy Watch Ultra on their wrist, the watch measures physiological parameters using various hardware components, such as Samsung's "BioActive sensor," and transfers the information related to these parameters to an Accused Phone/Tablet and to the Accused Cloud.

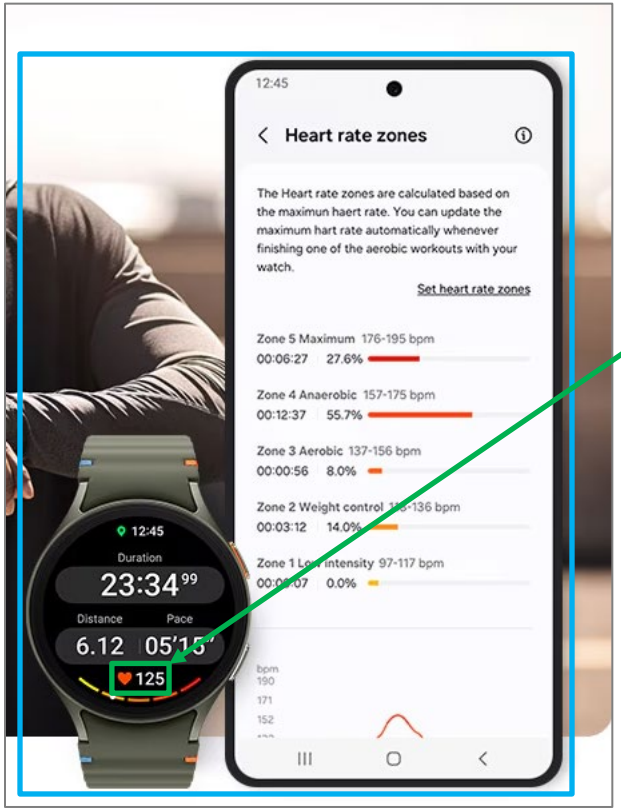
[1] The Accused System includes a Samsung smartwatch, such as the Galaxy Watch, the Galaxy Watch Active and Active2, the Galaxy Watch3, the Galaxy Watch4, the Galaxy Watch5, the Galaxy Watch6, the Galaxy Watch7, and the Galaxy Watch Ultra (each an "Accused Smartwatch"); a smart phone or tablet, such as the Samsung Galaxy A series phones, the Samsung Galaxy M series phones, the Samsung Galaxy S series phones, the Samsung Galaxy Z series phones, the Samsung Galaxy Tab A series tablets, the Samsung Galaxy Tab S series tablets, and the Samsung Galaxy Tab Active series tablets (each an "Accused Phone/Tablet"); and a cloud, such as the Samsung Cloud (the "Accused Cloud"), which collectively provide a system for measuring one or more physiological parameters of a user. Smart phones and tablets from other manufacturers, such as OnePlus, and clouds provided by others, such as Strava, may also be used as part of the Accused System. The Samsung Galaxy Watch Ultra, Samsung Galaxy Z Fold6, and the Samsung Cloud are charted here as representative of the Accused System. The citations to evidence contained within this chart are illustrative and should not be understood to be limiting. Plaintiff expressly reserves the right to rely upon additional or different evidence, or to rely on additional citations to the evidence already cited herein.

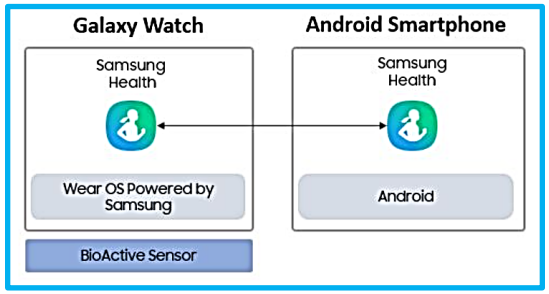
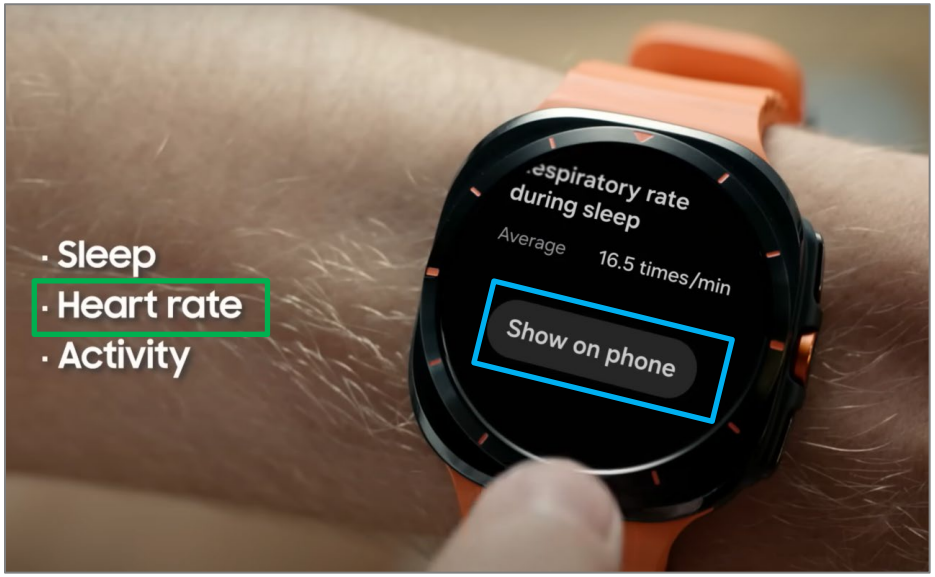
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

'455 Patent Claim	Samsung Accused System[1]
	 **More precise Heart Rate Tracking** Zero in on more precise readings during workouts using Heart Rate Tracking[3, 4, 5] with Galaxy AI[2] that filters out the physical movements of your body. Insights are collected by your Watch and analyzed on your phone. Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/buy/galaxy-watch-ultra-47mm-titanium-gray-sm-l705udaaxaa/

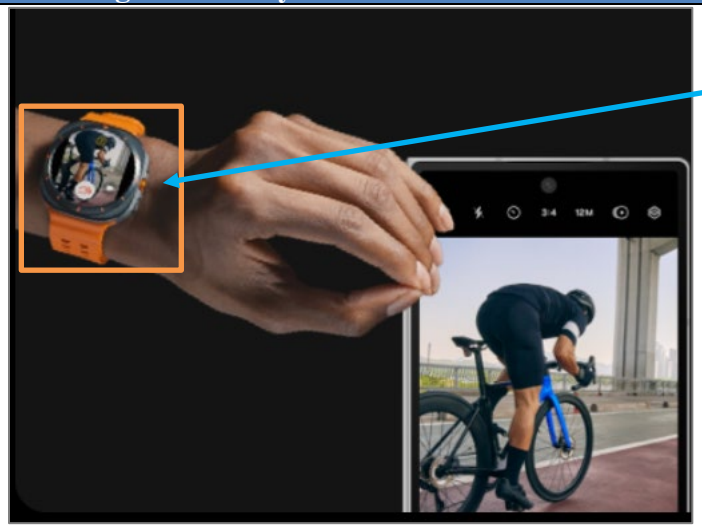
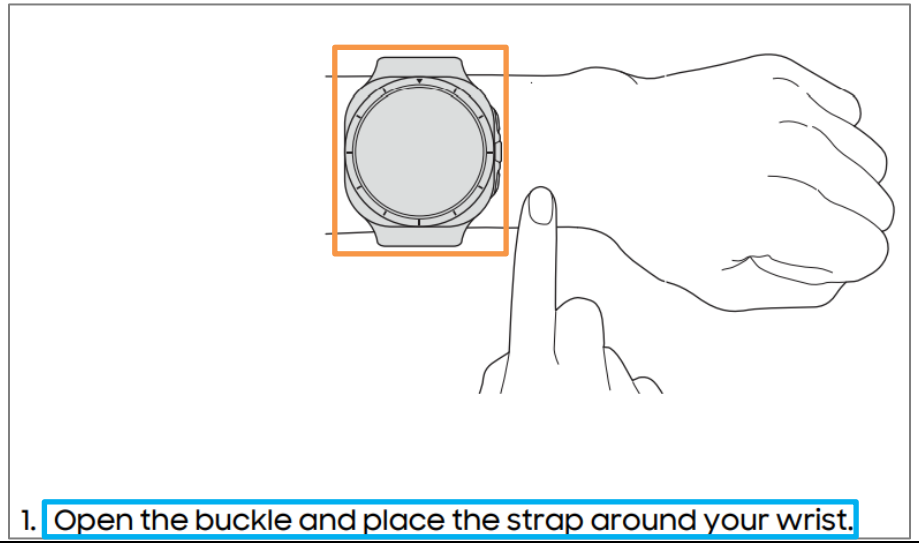
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/#Improve_your_life  Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/#Improve_your_life

'455 Patent Claim	Samsung Accused System[1]
	The Samsung Health application is installed on both the Galaxy Watch and a smartphone. The application synchronizes the measurements between both devices and manages the user's health data securely on them.  Figure 1: Samsung Health on Galaxy Watch and Android smartphone Source: https://developer.samsung.com/health/blog/en/health/blog/accessing-samsung-health-data-through-health-connect 

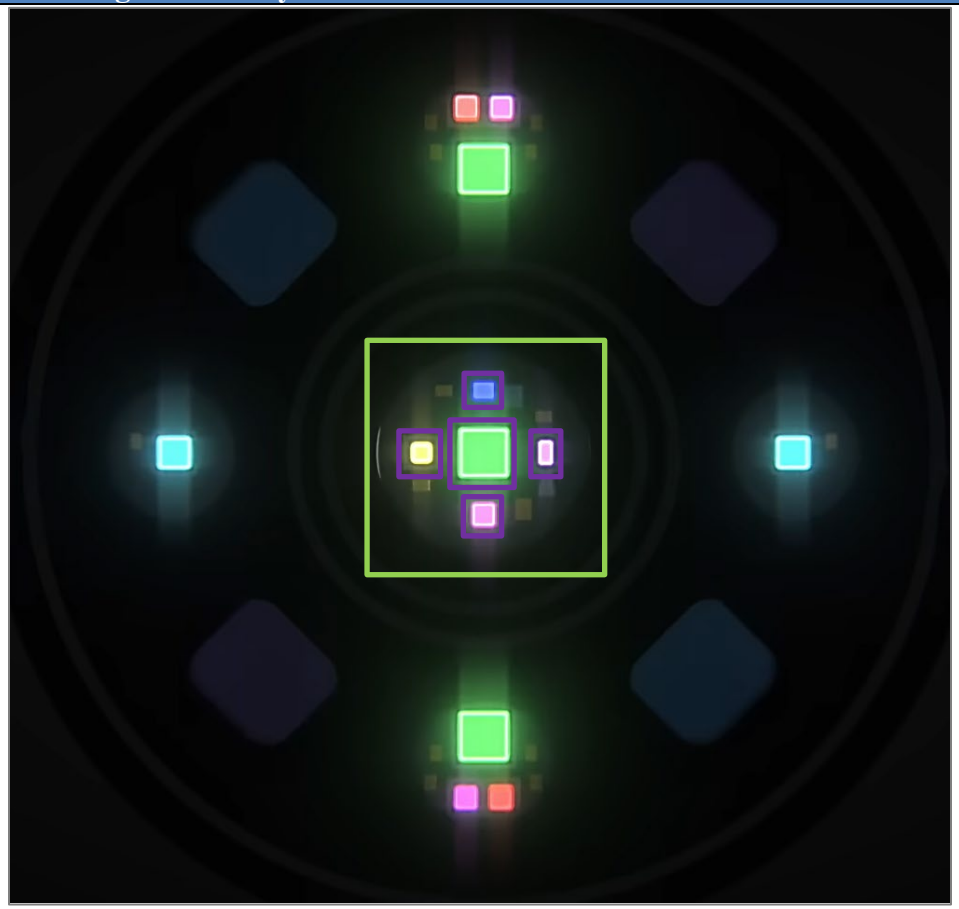
’455 Patent Claim	Samsung Accused System[1]
	Source: https://www.youtube.com/watch?v=VQW-ZpdAm5M  Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/
1[a] a wearable device adapted to be placed on teeth, a wrist, or an ear of a user, and including a light source comprising a driver	The Accused System comprises **a wearable device adapted to be placed on** teeth, **a wrist,** or an ear **of a user, and including a light source comprising a driver and a plurality of semiconductor sources** literally or under the doctrine of equivalents. For example, the Accused Smartwatch (“wearable device”) is worn on the wrist of the user.

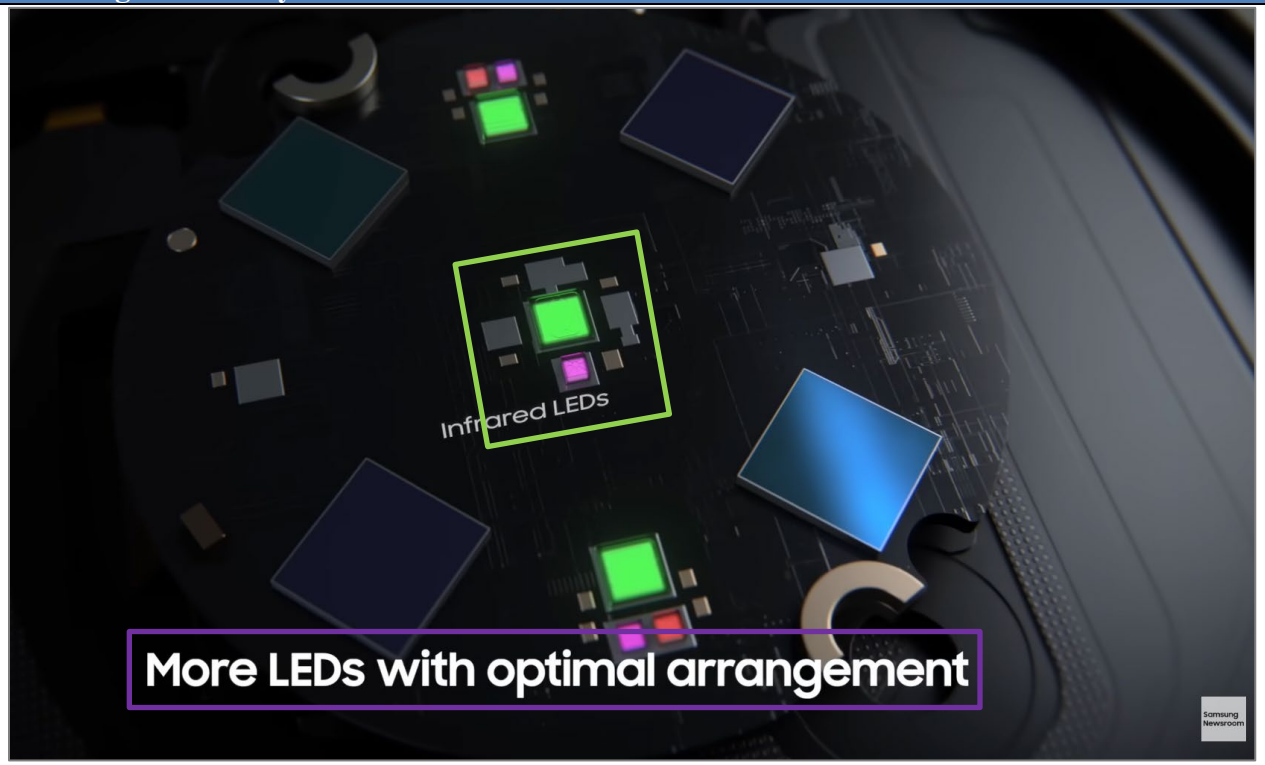
'455 Patent Claim	Samsung Accused System[1]
and a plurality of semiconductor sources,	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/buy/galaxy-watch-ultra-47mm-titanium-gray-sm-l705udaaxaa/

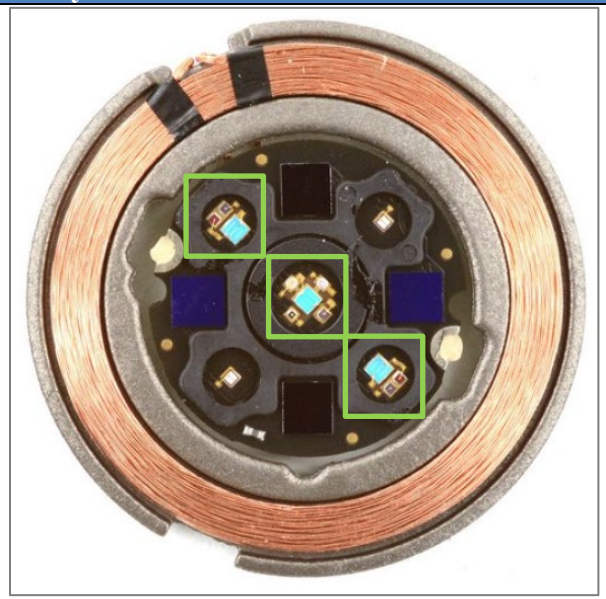
’455 Patent Claim	Samsung Accused System[1]
	 Accused Smartwatch is adapted to be placed on a wrist of a user. Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/  1. Open the buckle and place the strap around your wrist.

’455 Patent Claim	Samsung Accused System[1]
	Source: Samsung Galaxy Watch7 | Watch Ultra User Guide at p. 10, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240717003704208/WEA_L30X_L31X_L70X_EN_UG_XF3_070324_FINAL.pdf. The Accused Smartwatch includes a light source comprising multiple light emitting diodes (“LEDs”), such as a green LED, a red LED, and an infrared LED, each of which includes a “semiconductor source.” Samsung states, for example, that its “BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of light-receiving photodiodes, **adding additional colors of light-emitting diodes (LEDs)** and arranging them optimally across the sensor.” Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor Samsung further states that “[**t]he optimal allocation of Green, Red and Infrared LEDs** sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor.” Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

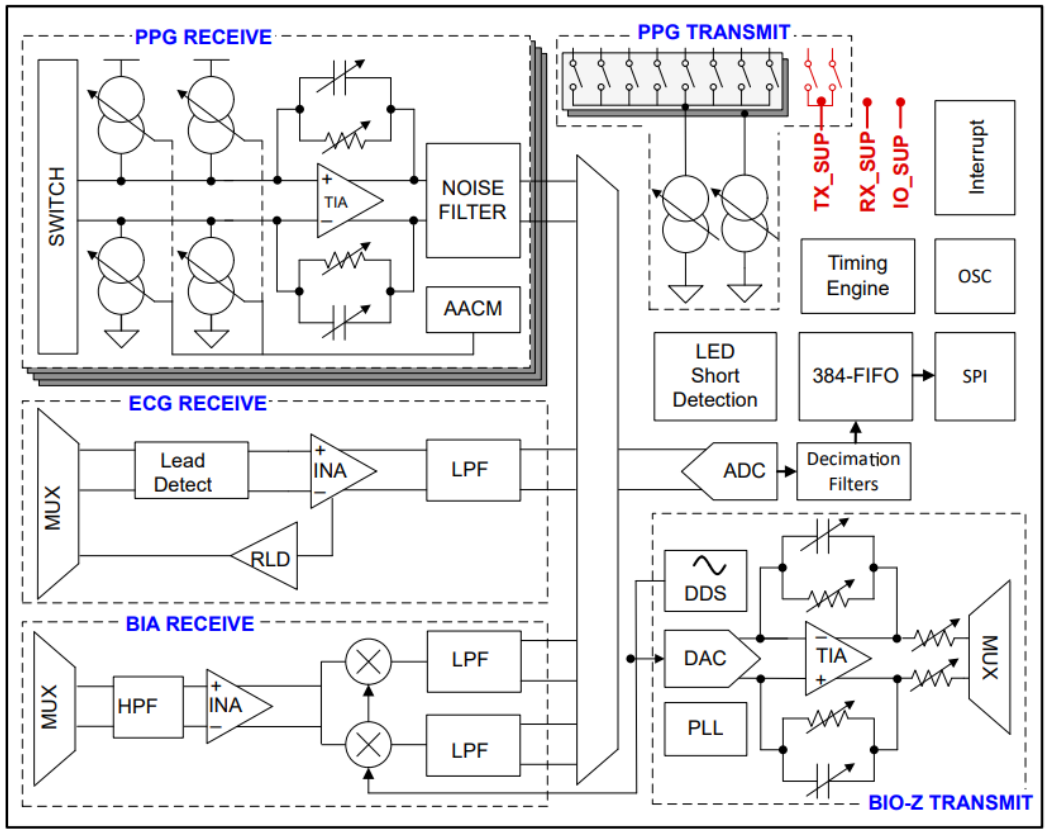
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

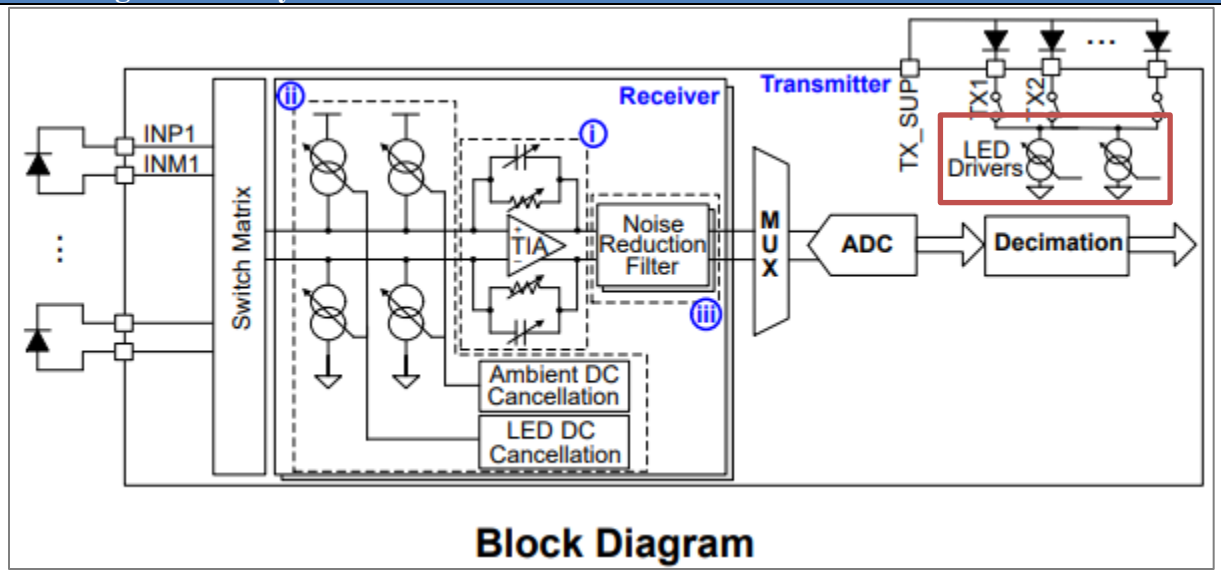
’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 “The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. A PPG signal chain comprises **a current driver for LEDs** and a receiver that senses the signal from PDs. An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.” Texas Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]

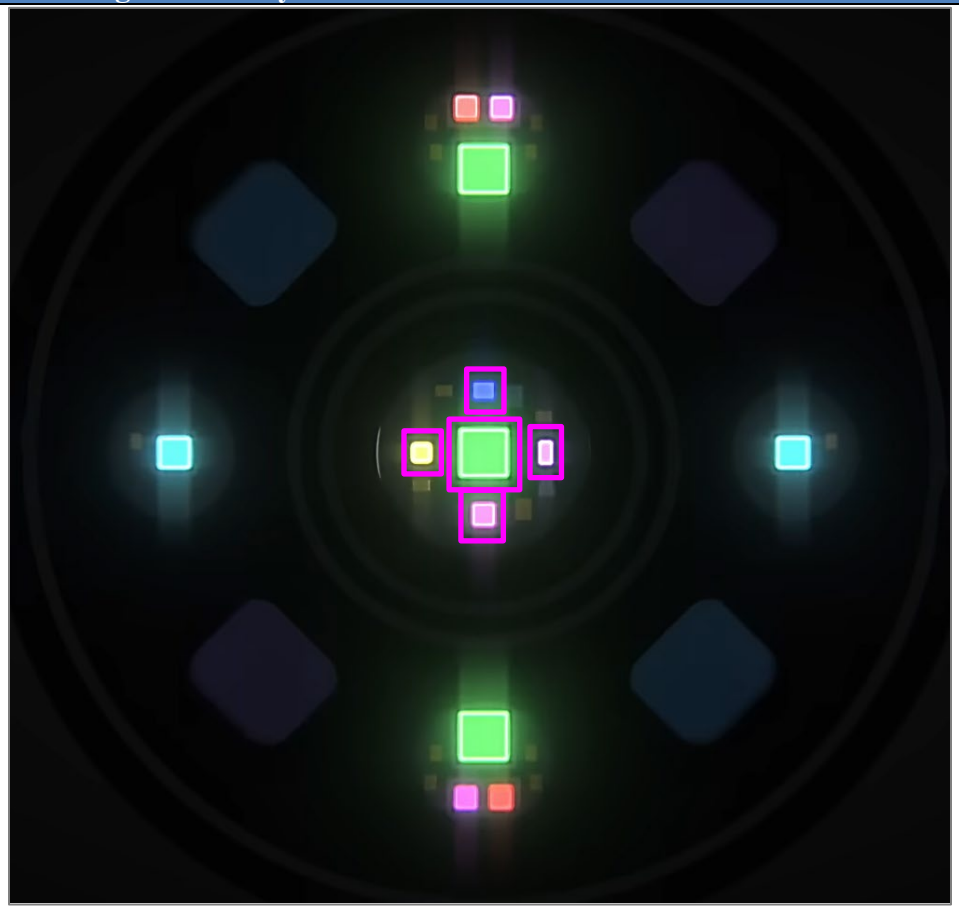


Simplified Schematic

Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]
	 Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.
1[b] the plurality of semiconductor sources configured to generate an output optical light having a plurality of optical wavelengths;	In the Accused Smartwatch, **the plurality of semiconductor sources are configured to generate an output optical light having a plurality of optical wavelengths**, literally or under the doctrine of equivalents. For example, the Accused Smartwatch includes multiple LEDs (“semiconductor sources”), such as a green LED, a red LED, and an infrared LED. Different color LEDs and infrared LEDs each generate output optical light having different optical wavelengths.

’455 Patent Claim	Samsung Accused System[1]
	Samsung states that “[t]he optimal allocation of **Green, Red and Infrared** LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor.” Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor The following data types are supported by the Samsung Privileged Health SDK: **PPG green** — Raw data from PPG green LED. Provided as a batching event. **PPG IR** — Raw data from PPG infrared LED. Provided as an on-demand event. **PPG red** — Raw data from PPG red LED. Provided as an on-demand event. Source: Samsung Developer, Samsung Privileged Health SDK, *available at* https://developer.samsung.com/health/privileged/overview.html

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327

<table>
<tr><th>’455 Patent Claim</th><th>Samsung Accused System[1]</th></tr>
<tr><td></td><td>LEDs outputting light at different colors do so at different optical wavelengths. For example, a green LED, a red LED, and an infrared LED all output light at different optical wavelengths:

<table>
<tr><th colspan="2">Table 1. LEDs – Wavelengths and Applications</th></tr>
<tr><th>LED Wavelength (Color)</th><th>LED Applications</th></tr>
<tr><td>410–420 nm (Violet)</td><td>Skin therapy</td></tr>
<tr><td>430–470 nm (Blue)</td><td>Dental curing instruments</td></tr>
<tr><td>470 nm (Blue)</td><td>White LEDs using phosphor</td></tr>
<tr><td>520–530 nm (Green)</td><td>Green traffic signal lights</td></tr>
<tr><td>580–590 nm (Amber)</td><td>Amber traffic signal lights</td></tr>
<tr><td>630–640 nm (Red)</td><td>Red signal lights</td></tr>
<tr><td>660 nm (Deep Red)</td><td>Blood oximetry</td></tr>
<tr><td>680 nm (Deep Red)</td><td>Blood analysis</td></tr>
<tr><td>800–850 nm (Near-IR)</td><td>Night-vision illuminators and beacons for use with night-vision goggles or CCDs</td></tr>
<tr><td>850–940 nm (Near-IR)</td><td>Photoelectric controls</td></tr>
<tr><td>940 nm (Near-IR)</td><td>Covert illumination CCD-based systems</td></tr>
</table>
Source: https://www.photonics.com/Articles/Light-Emitting_Diodes_A_Primer/a36706</td></tr>
<tr><td><u>1[c]</u> the wearable device comprising one or more lenses</td><td>The Accused System comprises a wearable device comprising one or more lenses configured to receive at least a portion of the output optical light and to deliver a lens output light to tissue, literally or under the doctrine of equivalents.</td></tr>
</table>

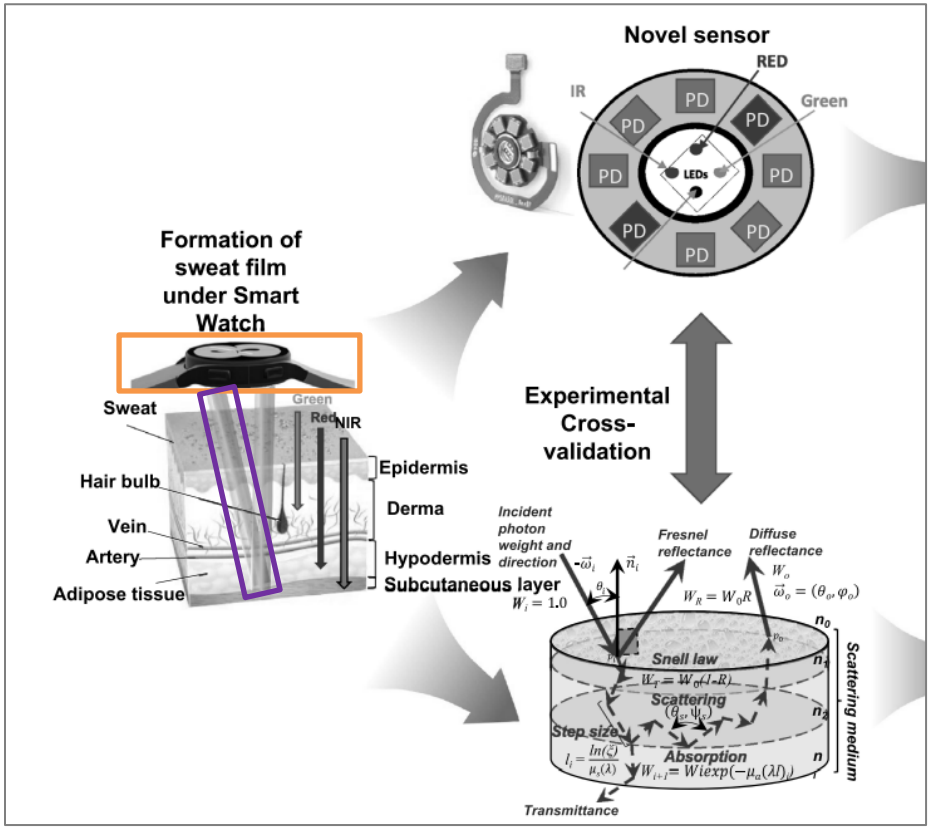
'455 Patent Claim	Samsung Accused System[1]
configured to receive at least a portion of the output optical light and to deliver a lens output light to tissue;	For example, the Accused Smartwatch ("wearable device") comprises one or more lenses positioned between LEDs and the wrist of a user when worn by the user. The lenses receive output optical light from the LEDs and deliver the light to tissue of the user (*e.g.*, skin, blood vessels, veins).  Source: https://www.youtube.com/watch?v=lZ6Q7JqtiA0 Samsung states that "[t]he **Galaxy Watch** uses light sensors that operate within the limits set by the IEC62471 safety regulations. However, **people with photosensitive skin may have adverse reactions to light,** such as skin discoloration or a rash." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor. Thus, the one or more lenses in the Accused Smartwatch delivers light that is output from the LEDs to skin of the user ("lens output light to tissue").

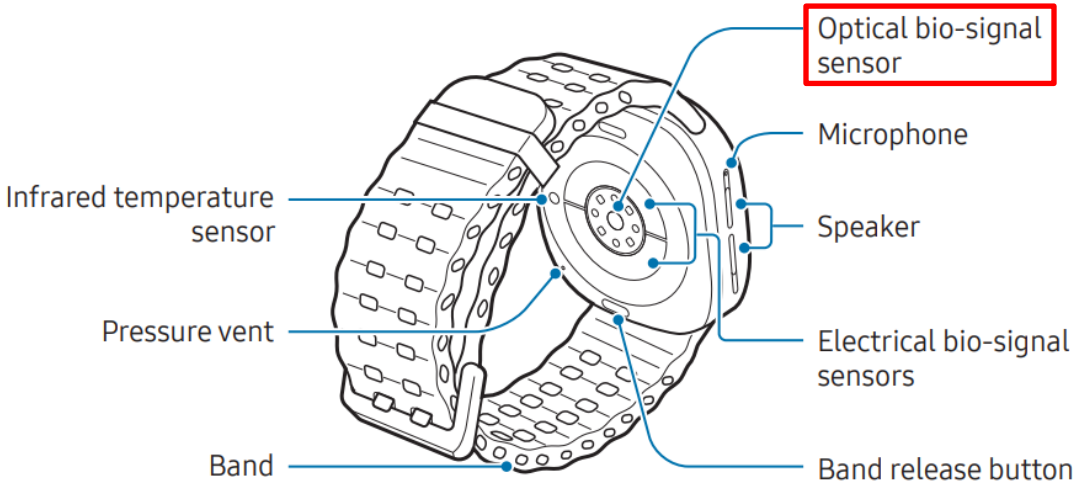
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=lZ6Q7JqtiA0 

'455 Patent Claim	Samsung Accused System[1]
	Source: https://www.youtube.com/watch?v=jlW0i7u4FVk Additionally, in a technical paper, Samsung engineers and pixel designers for photoplethysmography ("PPG") sensors explained "**applying micro lenses**" and using "**micro lens** focusing" techniques to enhance the delivery of infrared ("IR") light sources. J. Lim et al., "A single chip PPG sensor with enhanced IR sensitivity for low power and small size," 2021 IS&T Int'l Symp. Elec. Imaging, at 2-3, *available at* https://library.imaging.org/admin/apis/public/api/ist/website/downloadArticle/ei/33/7/art00002. Samsung's Galaxy Watch7 and Watch Ultra user guide also states the following: "The accuracy of the information and data provided by this device and its related software, including heart rate readings, may be affected by factors such as environmental conditions, **skin condition**, specific activity performed while using/wearing the device, settings of the device, user configuration/user-provided information, **placement of the sensor on the body**, and other end-user interactions." Samsung Galaxy Watch7 | Watch Ultra User Guide, at p. 42, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240717003704208/WEA_L30X_L31X_L70X_EN_UG_XF3_070324_FINAL.pdf. The Accused Smartwatch ("wearable device") utilizes a biosensor manufactured by Texas Instruments ("TI")—*e.g.*, an analog front end ("AFE") integrated circuit component for PPG, electrocardiography ("ECG") and other biosensing applications.

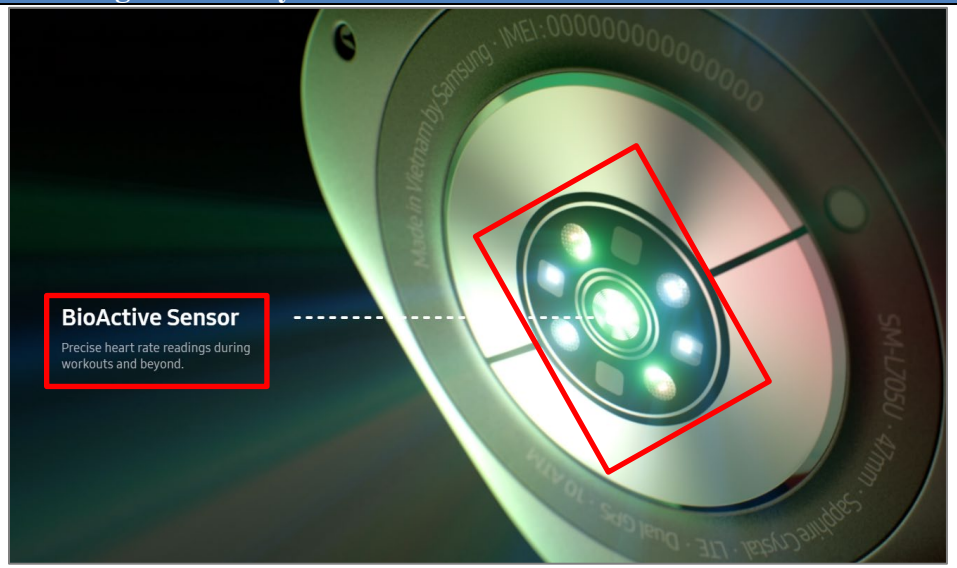
’455 Patent Claim	Samsung Accused System[1]
	Step 6 Bio Sensor Assembly   • Texas Instruments AFE4510 biosensing analog front-end Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw. Such AFEs from TI include AFE44S30, AFE4432, AFE44I30, AFE4460, AFE49I30, AFE4950, AFE4500. *See* Texas Instruments, Biosensing AFEs, https://www.ti.com/data-converters/integrated-special-function/medical-afes/biosensing-afes/overview.html. TI’s AFEs enable wearable devices to perform multiple optical biosensing applications. For example, TI explains in a technical paper:

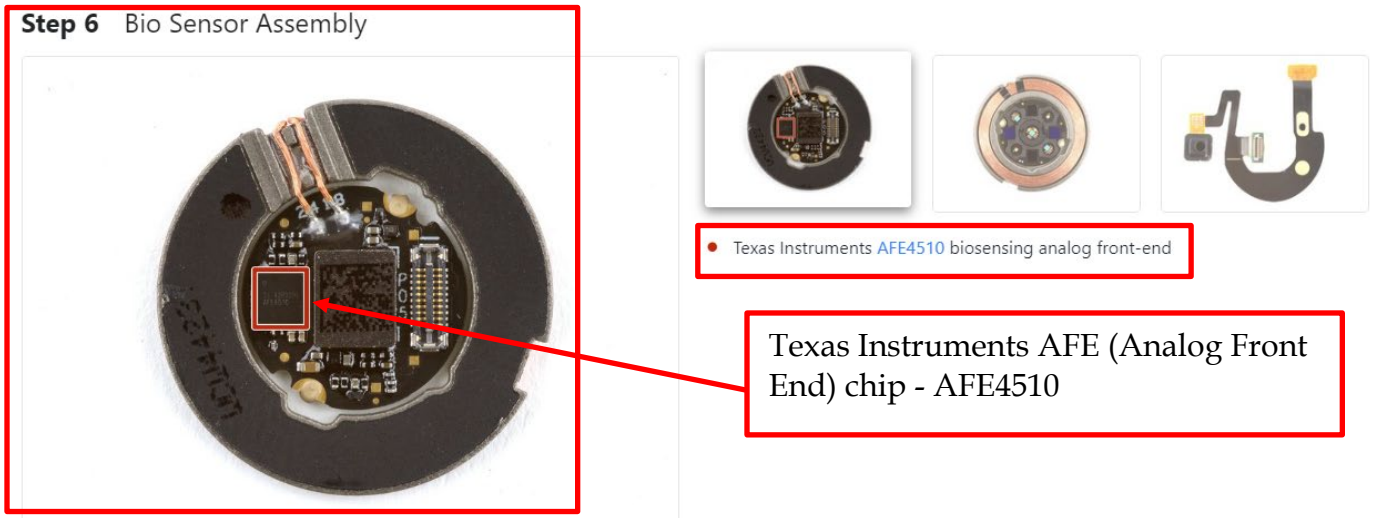
'455 Patent Claim	Samsung Accused System[1]
	Application *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR). In a device like a smartwatch, the LED and PD both face the wrist. The light from the LED is incident on the skin, and the reflection of the light from the artery results in a pulsating component. Typically, green LEDs are used, and the signal from multiple spatially-separated PDs are combined to mitigate effects such as motion. Texas Instruments, Application Brief, "Optical Heart Rate Monitoring (OHRM) on Wearables," SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

’455 Patent Claim	Samsung Accused System[1]
	Additionally, the following scientific report authored by multiple Samsung engineers further shows lens output light being delivered to tissue of the user:  Source: E. Volkova et al., “Multispectral sensor fusion in SmartWatch for in situ continuous monitoring of human skin hydration and body sweat loss,” Scientific Reports (2023), at 3, *available at* https://www.nature.com/articles/s41598-023-40339-7.pdf.

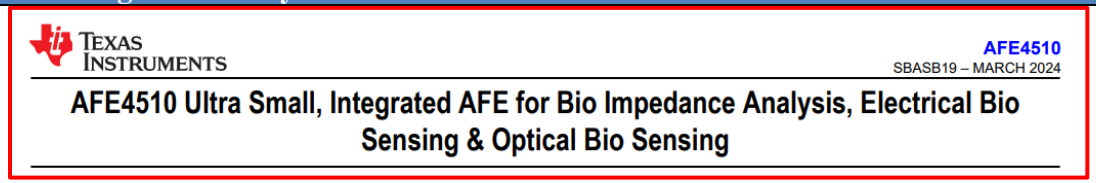
’455 Patent Claim	Samsung Accused System[1]
1[d] the wearable device further comprising a detection system configured to receive at least a portion of the lens output light reflected from the tissue and to generate an output signal having a signal-to-noise ratio,	The **wearable device** of the Accused System further comprises **a detection system configured to receive at least a portion of the lens output light reflected from the tissue and to generate an output signal having a signal-to-noise ratio**, literally or under the doctrine of equivalents. For example, the BioActive Sensor in the Accused Smartwatch (“wearable device”) comprises a detection system that: (a) receives light initially output from LEDs and then reflected from tissue of a user, and (b) generates an output PPG signal having a signal-to-noise ratio.  Source: Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 8, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf; *see also* Samsung Developer, Samsung Privileged Health SDK, *available at* https://developer.samsung.com/health/privileged/overview.html.

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 The AFE4510 specification (excerpts shown below) describes a PPG signal receiver, a PPG signal transmitter, and PPG signal acquisition functionality for receiving light output by LEDs that is reflected from skin and body tissue of the user (*e.g.*, by photodiodes (“PDs”)), and for converting the received light into—*i.e.*, generating—a PPG output signal having some signal-to-noise ratio (“SNR”).

’455 Patent Claim	Samsung Accused System[1]



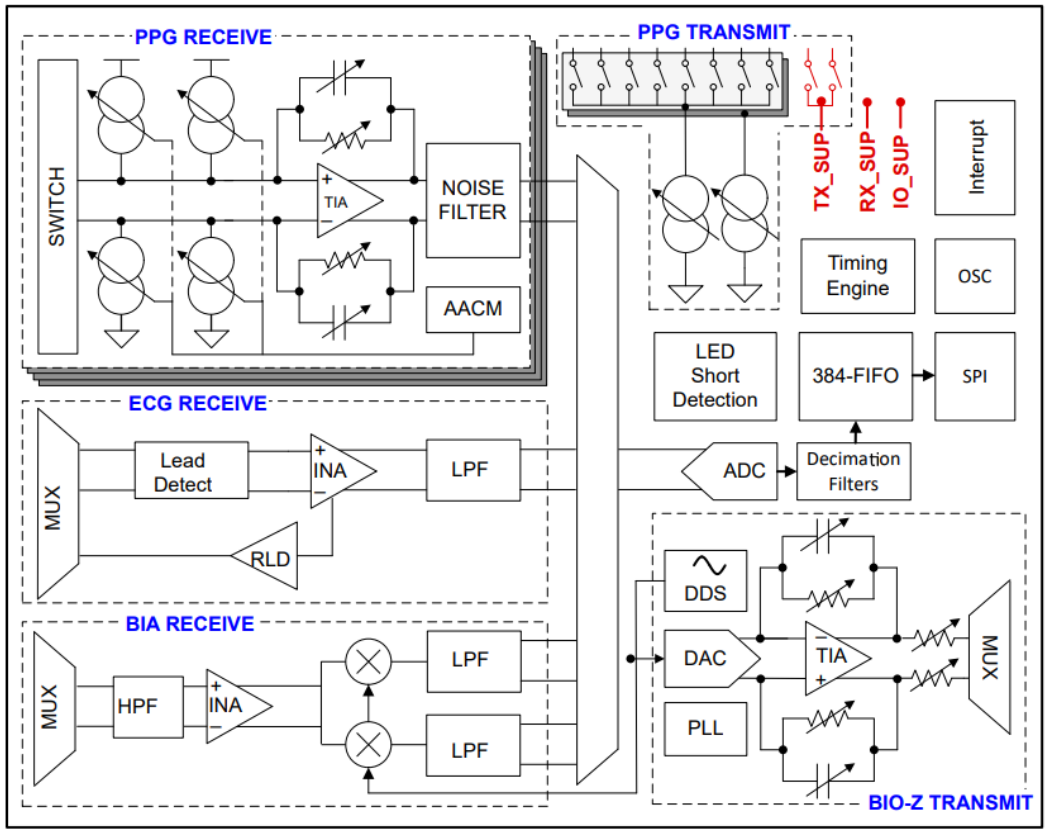
TEXAS INSTRUMENTS

AFE4510
SBASB19 – MARCH 2024

AFE4510 Ultra Small, Integrated AFE for Bio Impedance Analysis, Electrical Bio Sensing & Optical Bio Sensing

- **PPG signal acquisition:**
  - Acquisition of 24 PPG signal sets (LED, AMB)
  - Supports PPG sensors at different data rates
  - Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement
  - Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver
- **PPG Transmitter:**
  - 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA
  - LED Short Detection
  - Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy
- **PPG Receiver:**
  - Supports 5 PDs, 4 parallel receive paths
  - Noise filtering with programmable bandwidth
  - Trans-impedance Gain: 3.7kΩ to 1MΩ
  - 8-bit Ambient Offset Subtraction DAC up to 256µA
  - 9-bit LED Offset Subtraction DAC up to 64µA
  - Digital Ambient Subtraction at ADC Output

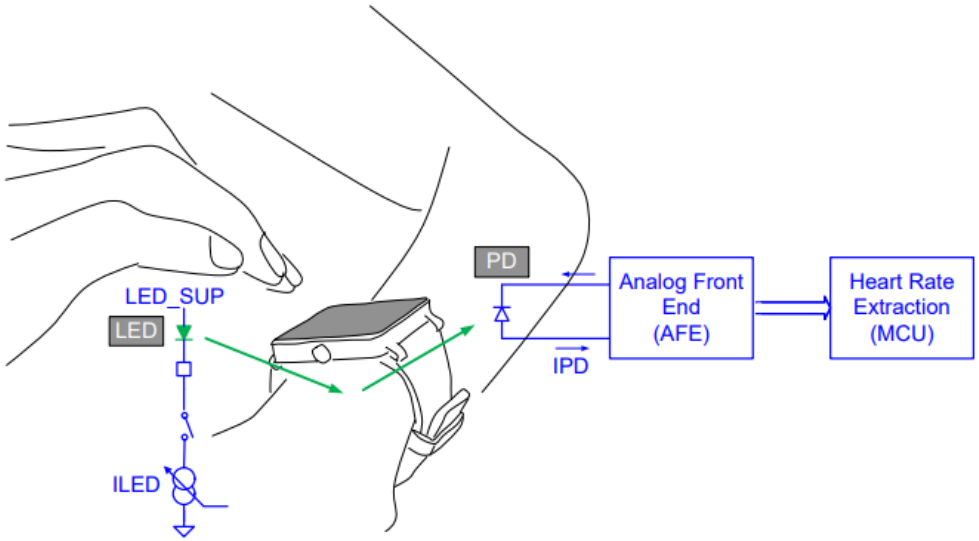
’455 Patent Claim	Samsung Accused System[1]



Simplified Schematic

Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

'455 Patent Claim	Samsung Accused System[1]
	The BioActive Sensor ("detection system") in the Accused Smartwatch is configured to receive lens output light that is reflected from body tissue of the user and to generate and output PPG signal to enable multiple biosensing applications, including optical heart rate monitoring ("OHRM"). For example, TI explains OHRM using its AFE biosensors as follows: *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR). In a device like a smartwatch, the LED and PD both face the wrist. The light from the LED is incident on the skin, and the reflection of the light from the artery results in a pulsating component. Typically, green LEDs are used, and the signal from multiple spatially-separated PDs are combined to mitigate effects such as motion.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 1. Heart Rate Monitoring on a Wearable Device** Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf. An exemplary “PPG signal chain” for a TI AFE biosensor (shown below) further illustrates how the BioActive Sensor (“detection system”) of the Accused Smartwatch is configured to receive a lens output light reflected from tissue of a user and generate a PPG output signal.

’455 Patent Claim	Samsung Accused System[1]

Figure 3 shows the PPG signal chain in AFE4432.

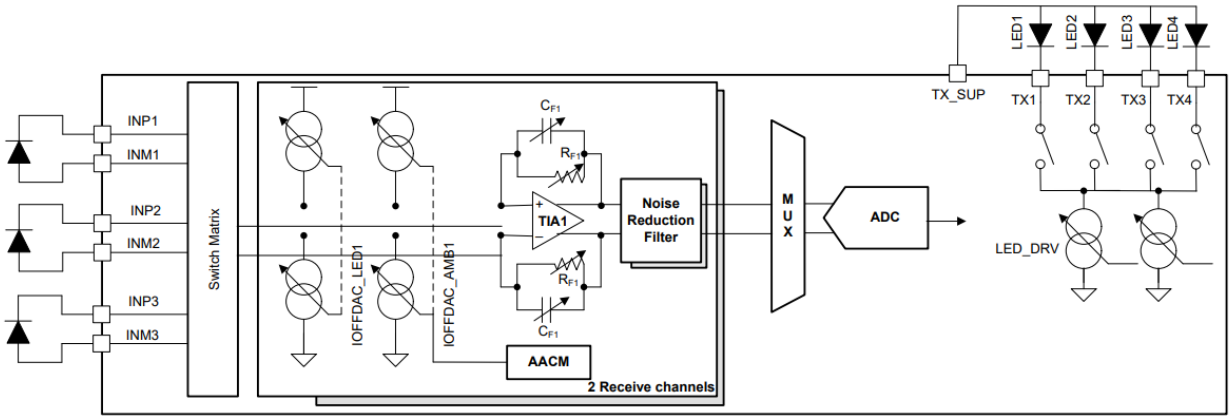


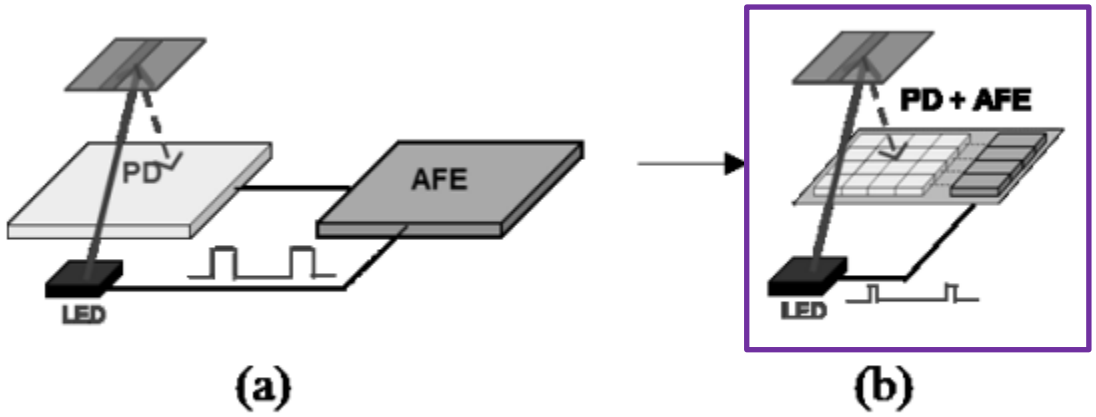
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

Samsung engineers further explain in technical papers a detection system configured to receive light reflected from tissue of a user and to generate an output PPG signal.

For example: “Recently, the technology is migrated to wearable devices such as wrist-worn smart watch or a wireless ear set. Among them, PPG sensor is a health sensor that measures the change in blood flow to be modulated by the heart rate. When a separate light source (LED) is irradiated to the skin, the light absorption by the blood vessel is changed in synchronization with the heart rate. **A sensor measures,**

’455 Patent Claim	Samsung Accused System[1]
	transmitted or **reflected signal** represented in Amplitude Modulation It has been used for a long time as a medical tool to measure oxygen saturation (SpO2) in a patient's finger in an emergency status [1]. For the use of PPG sensors as various health care products, features of low power and smaller size are essentially required.”  *Figure 1. (a) Separated chip PPG sensor and (b) Single chip PPG sensor* Source: J. Lim et al., “A single chip PPG sensor with enhanced IR sensitivity for low power and small size,” 2021 IS&T Int’l Symp. Elec. Imaging, at 2-3, *available at* https://library.imaging.org/admin/apis/public/api/ist/website/downloadArticle/ei/33/7/art00002. For example: “Nowadays, our Smart watches are equipped with Samsung’s BioActive Sensor which has evolved to become far more advanced and miniature technology and not only able to ‘just’ count HR, steps and calories, but also can monitor sleep, measure blood pressure and more. . . . At present, wearable devices, including smart watches and fitness trackers, routinely monitor/analyze the PPG signal and provide non-invasive information of the aforementioned human health indicators with recent additions of temperature, blood oxygen level (SpO2), etc. monitoring capabilities.”

’455 Patent Claim	Samsung Accused System[1]

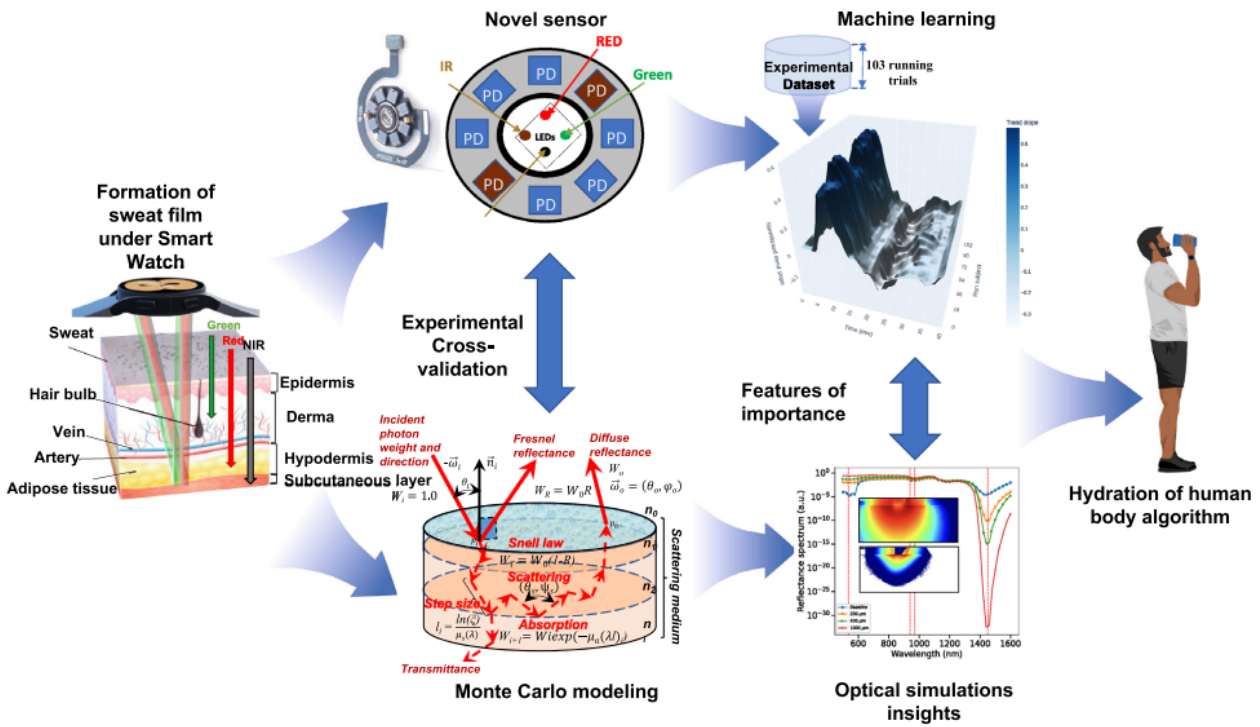
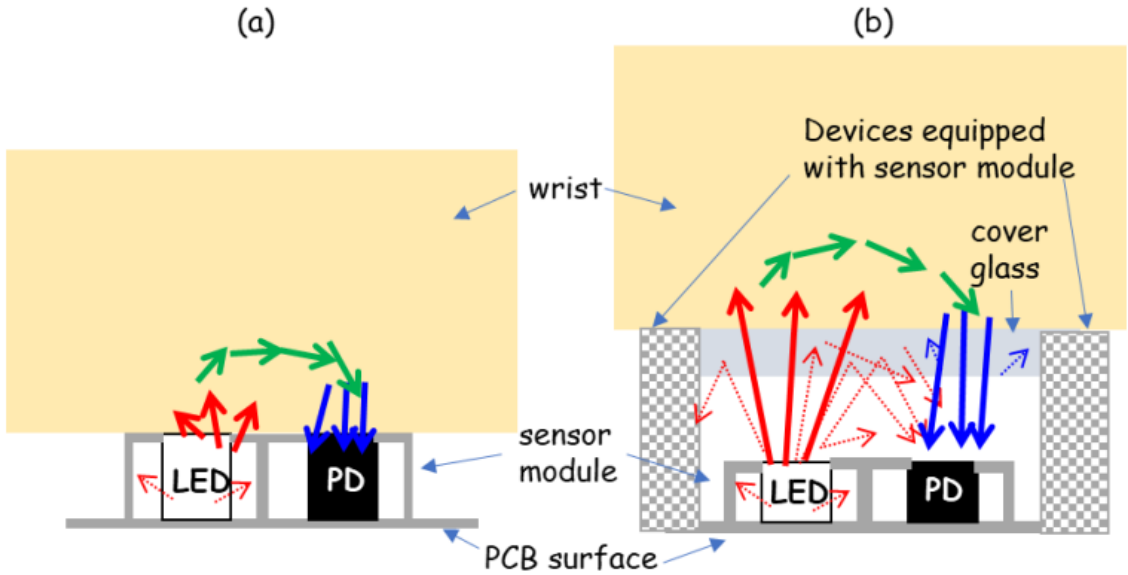
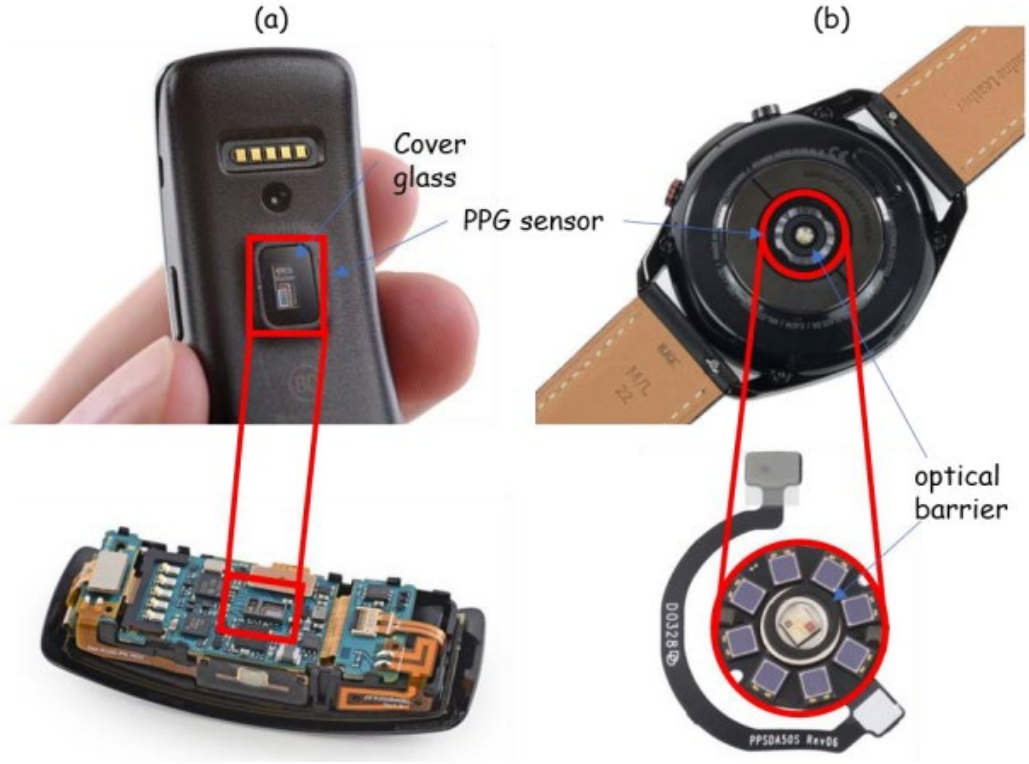


Figure 2. Our capture-to-sensing pipeline. Here: a sweat film is formed under the SmartWatch prototype; Custom-made sensor evaluates change in PPG signal at a range of wavelengths and distances; The trends in the signal are investigated using experimentally validated numerical algorithms of light transport in skin; Particular features of importance due to fluctuations of wet/dry skin optical properties are extracted based on their significance and a ML method is trained to readily detect them; Finally, sweat loss is quantitatively accessed and recommendations to consumer are made.

Source: E. Volkova et al., “Multispectral sensor fusion in SmartWatch for in situ continuous monitoring of human skin hydration and body sweat loss,” Scientific Reports (2023), at 1-3, *available at* https://www.nature.com/articles/s41598-023-40339-7.pdf.

’455 Patent Claim	Samsung Accused System[1]
	The detection system of the Accused Smartwatch has been detailed in other technical documents as well. For example:

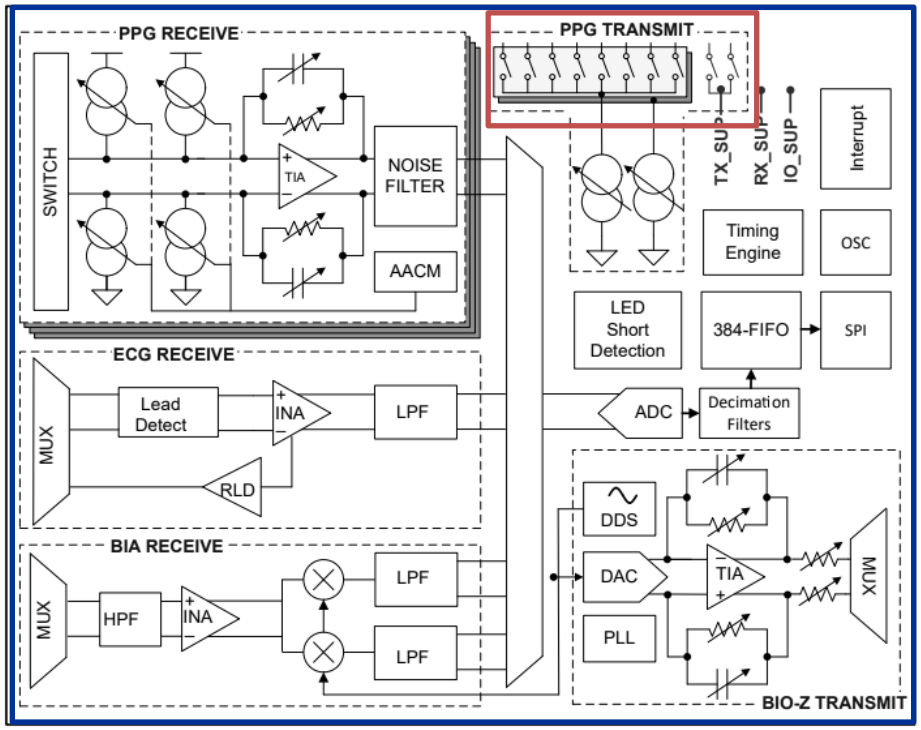
’455 Patent Claim	Samsung Accused System[1]
	 **Figure 3.** Conceptual diagram of a PPG sensor module with an embedded LED–PD pair. The diagram illustrates two scenarios: (**a**) when the integrated sensor module is in direct contact with the wrist and (**b**) when the sensor module is embedded in a device and covered with a glass surface. In the diagram, the red solid line represents incident light from the LED entering skin tissue, while the green solid line indicates light causing various reactions inside the tissue. The blue solid line represents light entering the PD from skin tissue and being detected. Additionally, the red dotted line in the diagram illustrates light reflected inside the sensor module that does not enter the skin, some of which directly enters the light-receiving unit. The blue dotted line represents the light that is reflected back by the cover glass among the light entering towards the PD.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 4.** Representative examples of PPG sensor systems applied to commercial wrist-worn wearable devices: (**a**) the Samsung Galaxy Gear Fit, released in 2014, utilizes a sensor module with an embedded LED–PD optopair, and (**b**) the Samsung Galaxy Watch 3, released in 2020, uses separate LEDs and PDs as a sensor. An analog front end (AFE) is employed in both devices to measure the PD output as a PPG signal.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 5.** Examples of PPG sensor configurations that use multiple LEDs and PDs, and their application to commercial smartwatches. (**a**–**d**) illustrate different PPG sensor structures, while (**e**) through (**h**) present examples of these structures in use: (**e**) structure (**a**) applied to the Samsung Galaxy Gear s3; (**f**) structure (**d**) applied to the Samsung Galaxy Watch; (**g**) shows the sensor structure of the Garmin Fenix 5 with three LEDs and one PD in the center, and (**h**) shows the sensor structure of the Apple Watch with two LEDs and two PDs. Source: Kim, K.B. et al., “Photoplethysmography in Wearable Devices: A Comprehensive Review of Technological Advances, Current Challenges, and Future Directions,” Electronics 2023, 12, 2923, at 7-9, *available at* https://www.mdpi.com/2079-9292/12/13/2923.
1[e] wherein the detection system is	The **detection system** in the Accused Smartwatch **is configured to be synchronized to the light source**, literally or under the doctrine of equivalents.

'455 Patent Claim	Samsung Accused System[1]
configured to be synchronized to the light source;	For example, the BioActive Sensor ("detection system") is connected to the light source containing multiple LEDs. It is configured to synchronize with the light source by controlling the LED current (light intensity) and the pulse rate of the LEDs using LED drivers. To measure heart rate, for example, green LEDs are used with a pre-determined intensity and pulse rate. Different LEDs are used to measure other parameters, such as blood oxygen levels. Green LEDs ("light source") blink when measuring heart rate, and both green and red LEDs ("light source") blink alternately when measuring blood oxygen levels. This, among other evidence below, shows that the BioActive Sensor ("detection system") is synchronized with the light source. The BioActive Sensor in the Accused Smartwatch features a biosensing AFE manufactured by TI (*e.g.*, AFE 4510). The AFE component used in the BioActive Sensor has a detection system that is synchronized to programmable LEDs (light source). **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy

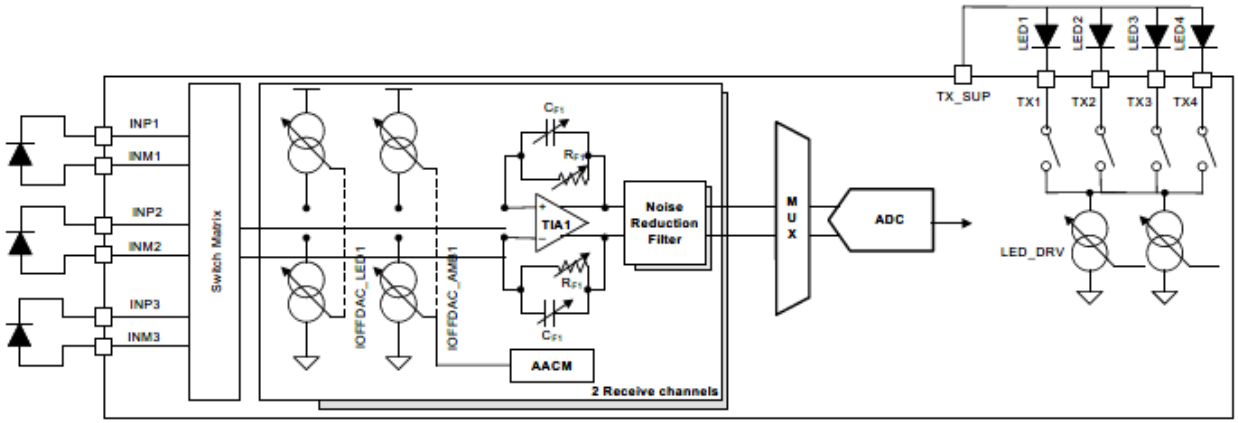
’455 Patent Claim	Samsung Accused System[1]



Simplified Schematic

“**The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. A PPG signal chain comprises a current driver for LEDs** and a receiver that senses the signal from PDs. An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.”

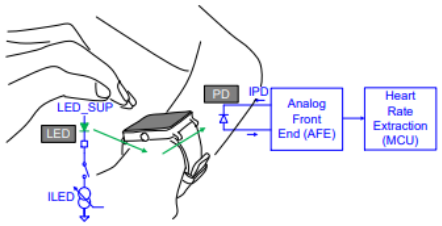
Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 3. PPG Signal Chain in AFE4432** The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices. Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

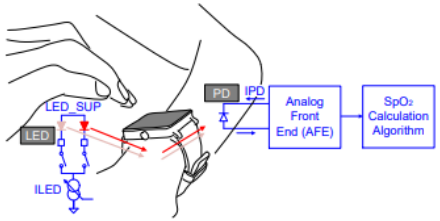
’455 Patent Claim	Samsung Accused System[1]

TEXAS INSTRUMENTS

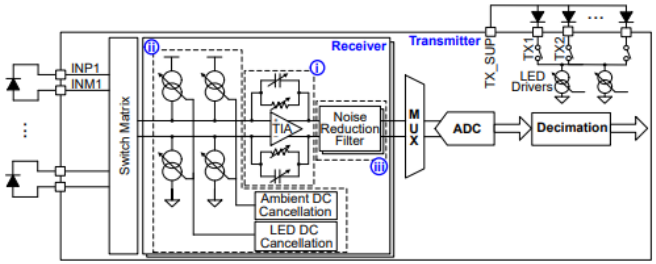
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI's signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.



Heart Rate Monitoring



SpO_2 Monitoring

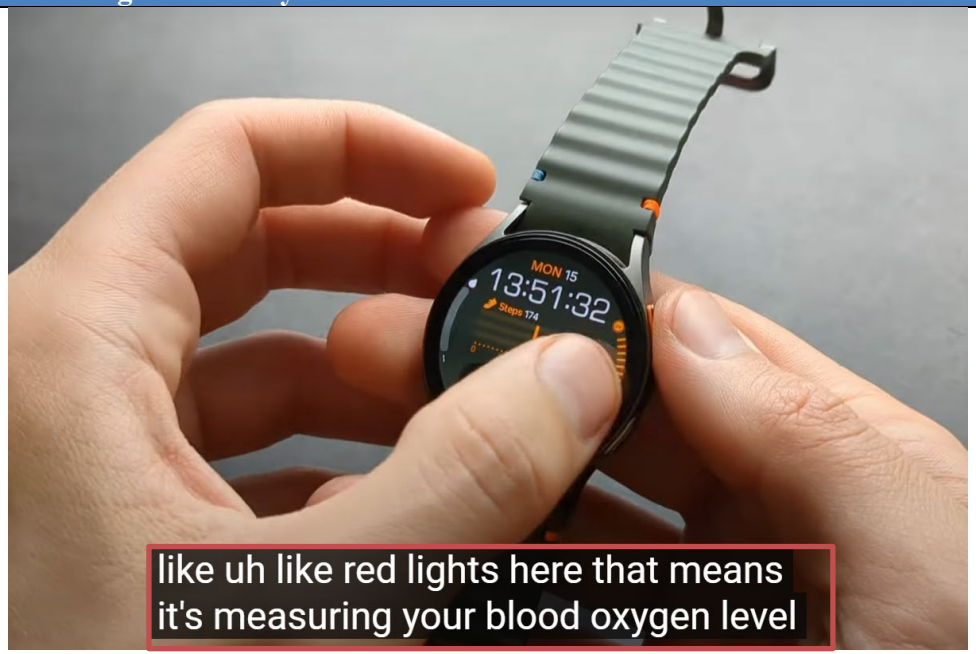


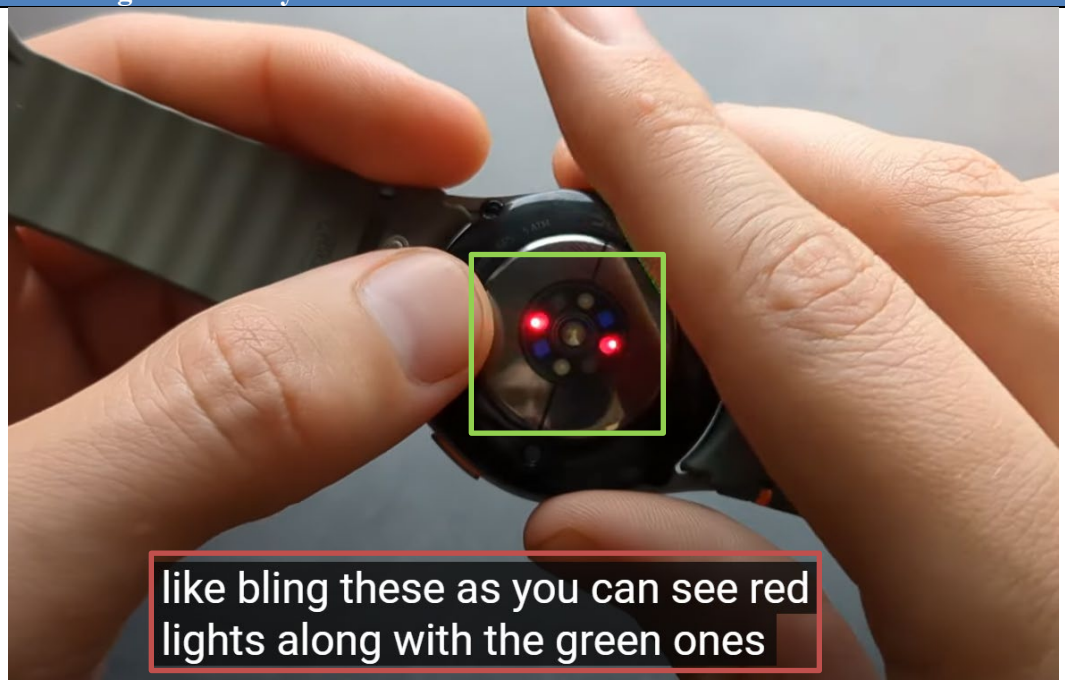
Block Diagram

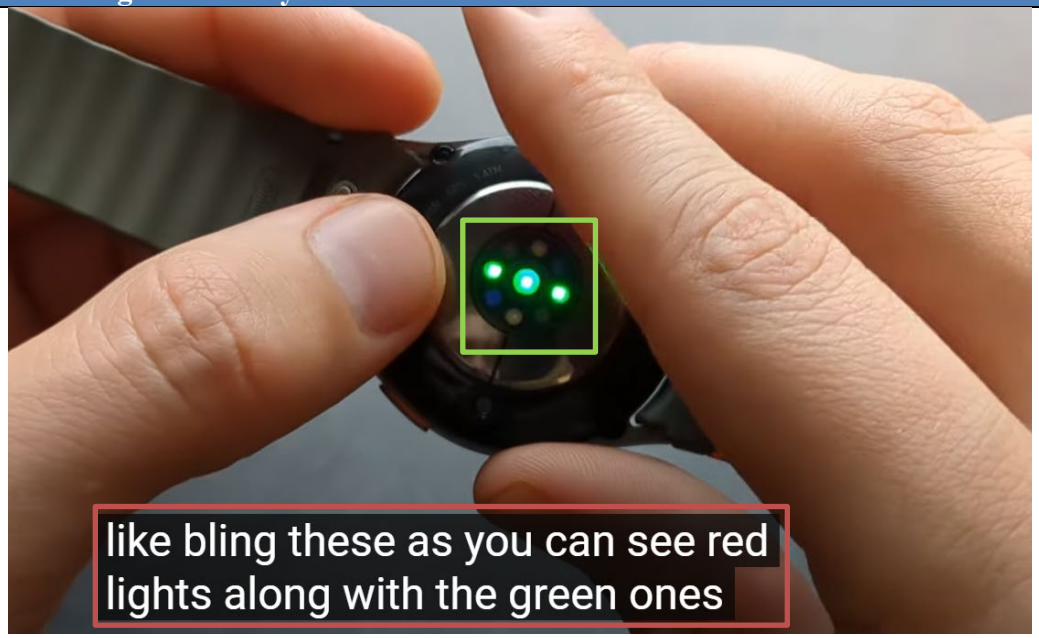
Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

’455 Patent Claim	Samsung Accused System[1]
	“The BioActive sensor has three sensors integrated inside. Apart from body composition, it can measure heart rate, ECG, and blood pressure. . . . It is one of the common uses of the BioActive sensor on your Galaxy Watch. **The sensor relies on built-in green LEDs and infrared lights to calculate heart rate.** These green LEDs are slotted between the BioActive sensor chips.” P. Shah, “What is Samsung BioActive sensor?” Android Police, July 17, 2024, https://www.androidpolice.com/samsung-bioactive-sensor-guide/. “The **diverse colors of LEDs and new photodiodes enable the sensor** to unlock new possibilities in **health monitoring**. One of the new features is the advanced glycation end products (AGEs) index, which is an indicator of metabolic health and biological aging.” “Samsung details BioActive Sensor ahead of Galaxy Unpacked,” fonearena, July 9, 2024, https://www.fonearena.com/blog/428320/samsung-bioactive-sensor-galaxy-unpacked-2024.html. A product video further explains functionalities of the light source (LEDs) and detection system, including how the detection system is configured to synchronize to differing flashing LED colors on the Accused Smartwatch to facilitate calculating different physiological parameters.

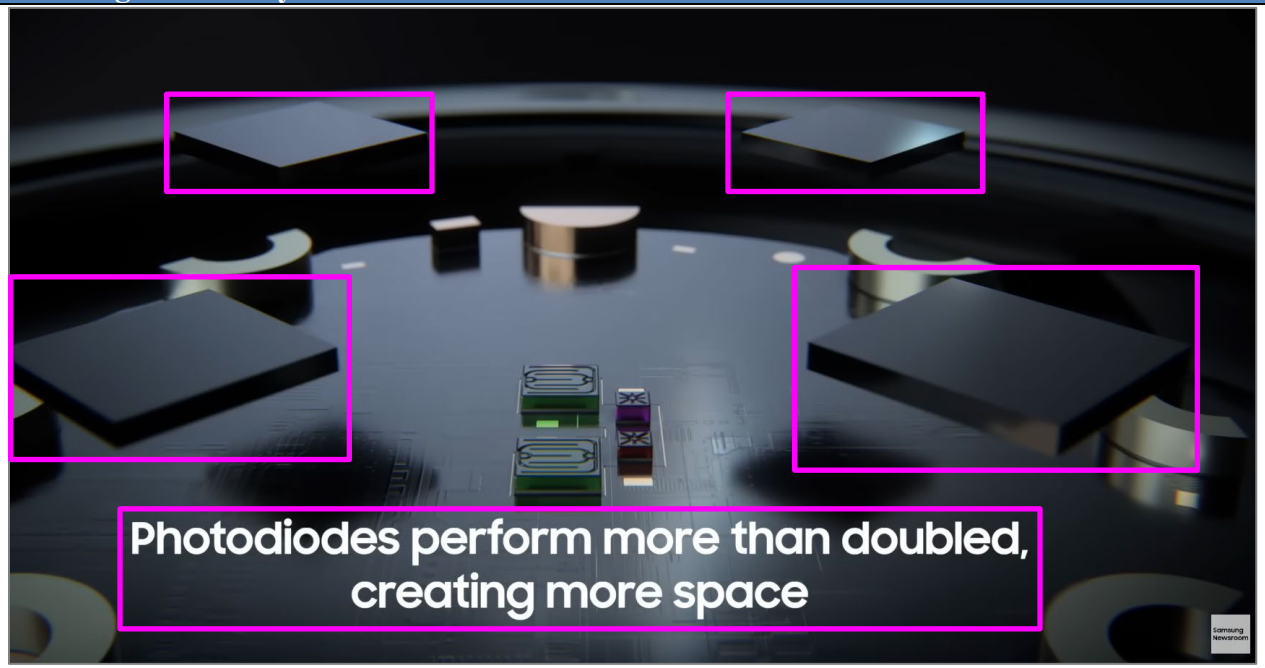
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:24, https://www.youtube.com/watch?v=JG9pGlqmges&t=23s.

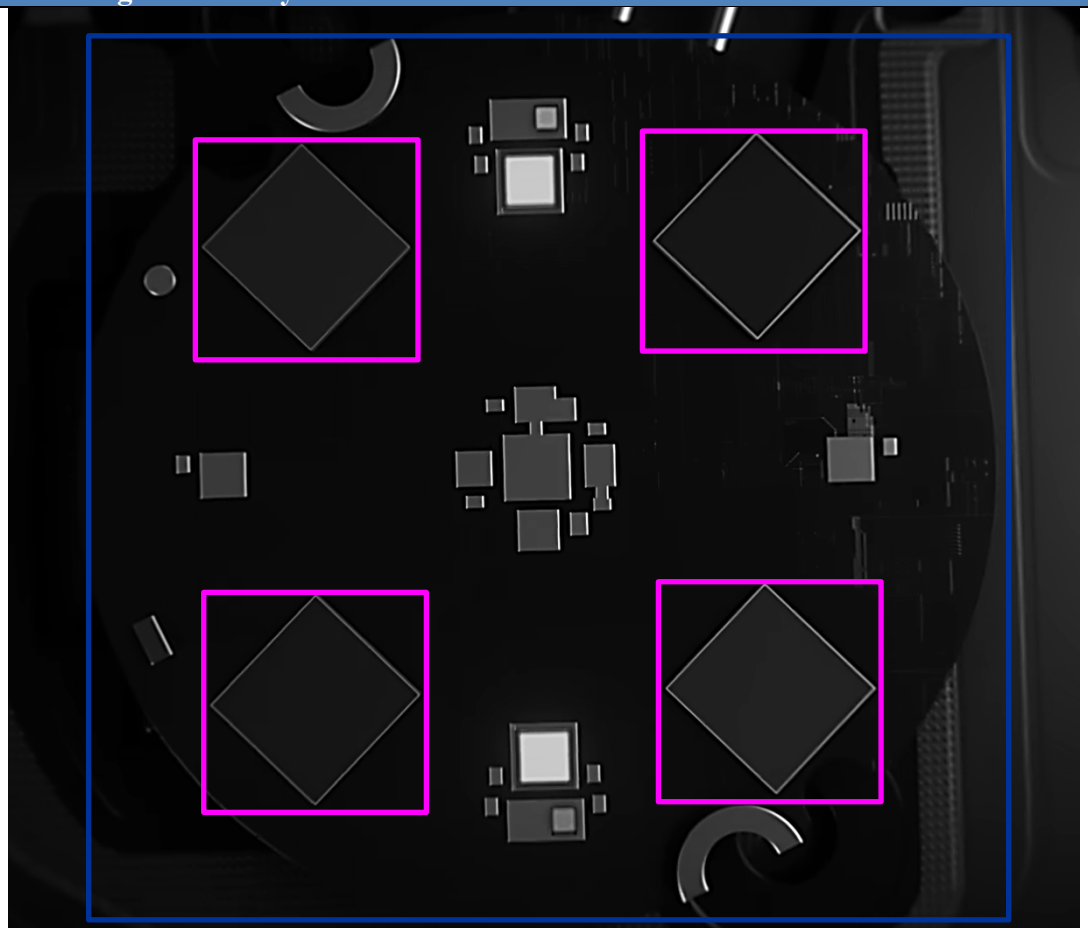
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:37, https://youtu.be/JG9pGlqmges?si=IrcplcEOdHE3cB3l&t=37

’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:53, https://youtu.be/JG9pGlqmges?si=xMBhD11dBJQoADTO&t=53

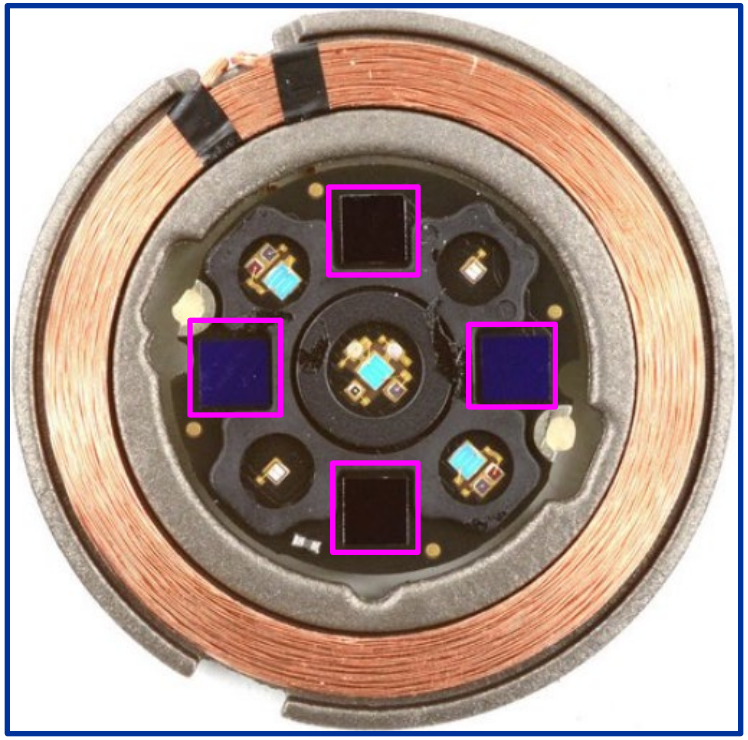
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:53, https://youtu.be/JG9pGlqmges?si=YV8CQ6yVqkvL7ITZ&t=53
1[f] wherein the detection system comprises a plurality of detectors that are spatially separated from each other, and	The **detection system** in the Accused Smartwatch comprises **a plurality of detectors that are spatially separated from each other**, literally or under the doctrine of equivalents. For example, the BioActive Sensor (“detection system”) includes multiple photodiodes/PDs (“detectors”) that are spatially separated from each other. “**The all-new BioActive Sensor** is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of **light-receiving**

’455 Patent Claim	Samsung Accused System[1]
	photodiodes, adding additional colors of light-emitting diodes (LEDs) and arranging them optimally across the sensor.” **Samsung more than doubled the performance of each photodiode, successfully decreasing the number needed to maintain capacity from eight to four.** This redesign freed up additional space for the integration of a larger number and variety of LEDs and ensured their optimal placement across the sensor. The new sensor now includes Blue, Yellow, Violet and Ultraviolet LEDs in addition to an increased number of Green, Red and Infrared LEDs. With the integration and arrangement of these LEDs, photodiodes and specially designed photodiode, Samsung is taking innovation one step further and is now able to pursue unexplored aspects of health monitoring on wearables. . . . The more diverse colors of LEDs and **newly designed photodiodes** unlock new possibilities and empower you to better predict trends and take proactive steps for preventative care. The first of these features will be an advanced glycation end products (AGEs) index — an indicator of metabolic health and biological aging strongly influenced by overall lifestyle and dietary habits. Used as an insightful biomarker, this index provides a snapshot of your biological age to help you make more informed decisions about your wellness journey and work towards a healthier future. The addition of an AGEs index is just one of the many new advanced features planned for the next Galaxy Watch.” Samsung Newsroom, “Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor,” Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor.

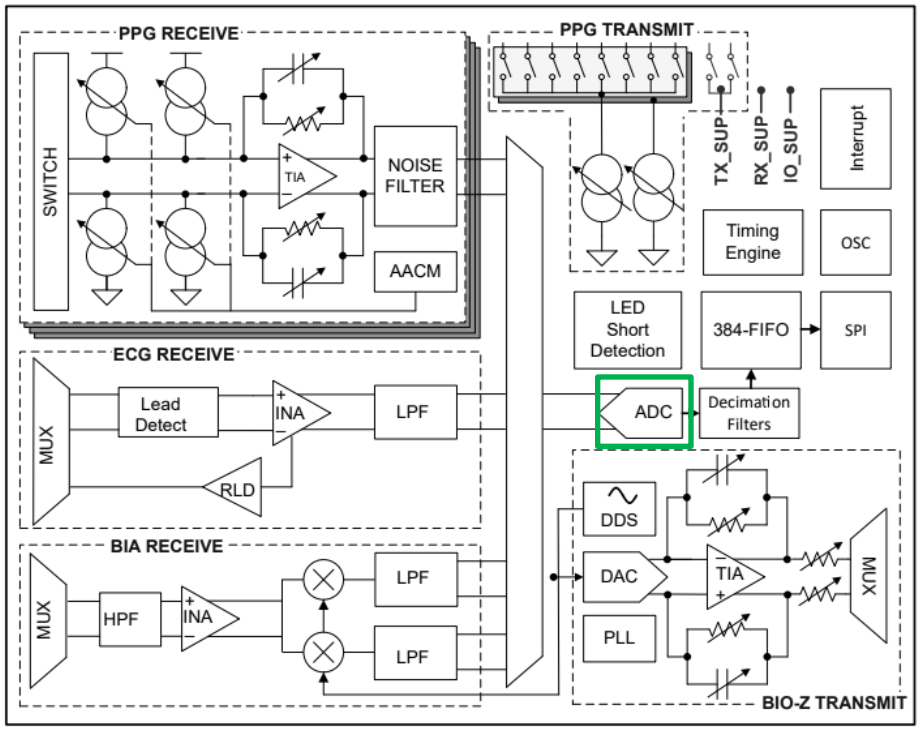
’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung Newsroom, “Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor,” Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor; Samsung Newsroom, “Introducing Samsung’s New BioActive Sensor,” July 8, 2024, https://www.youtube.com/watch?v=snMLajaf0tc&t=7s.

’455 Patent Claim	Samsung Accused System[1]
	

Source: Source: Samsung Newsroom, “Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor,” Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor; Samsung Newsroom, “Introducing Samsung’s New BioActive Sensor,” July 8, 2024, https://www.youtube.com/watch?v=snMLajaf0tc&t=7s.

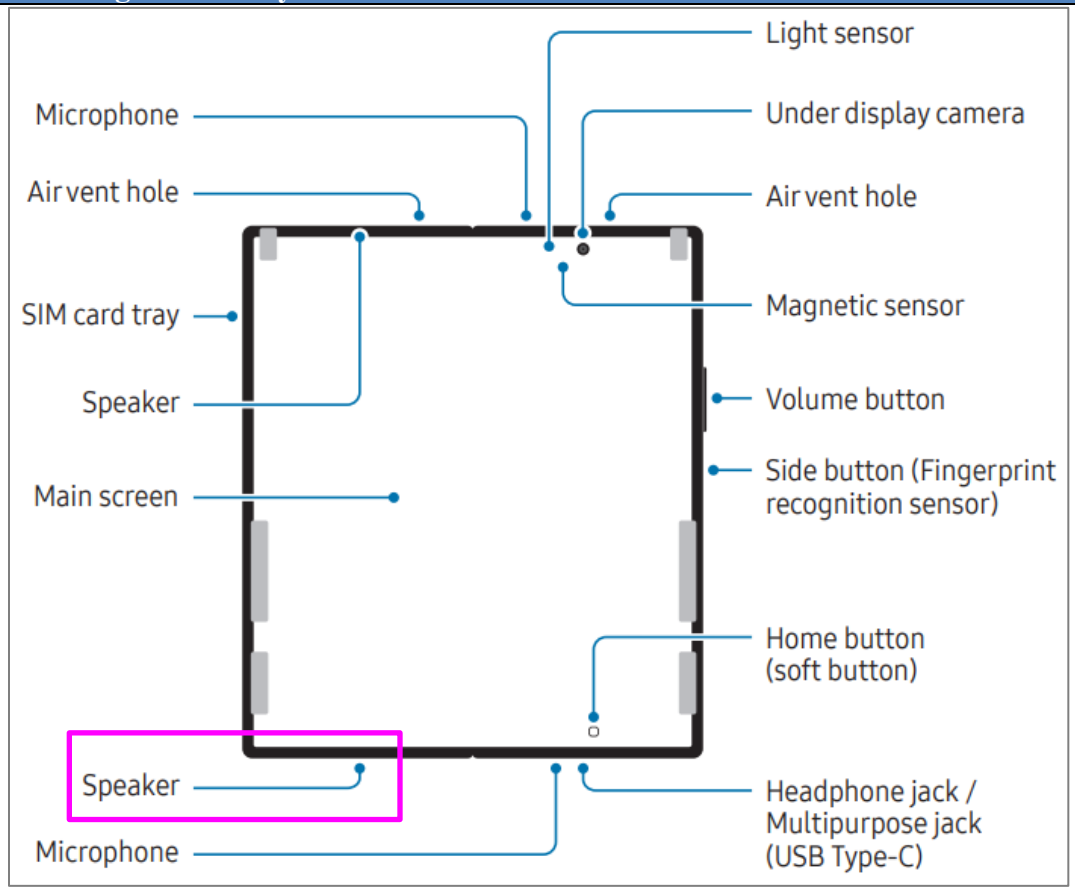
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 “**The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals.** A PPG signal chain comprises a current driver for LEDs and **a receiver that senses the signal from PDs.** An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.” Texas

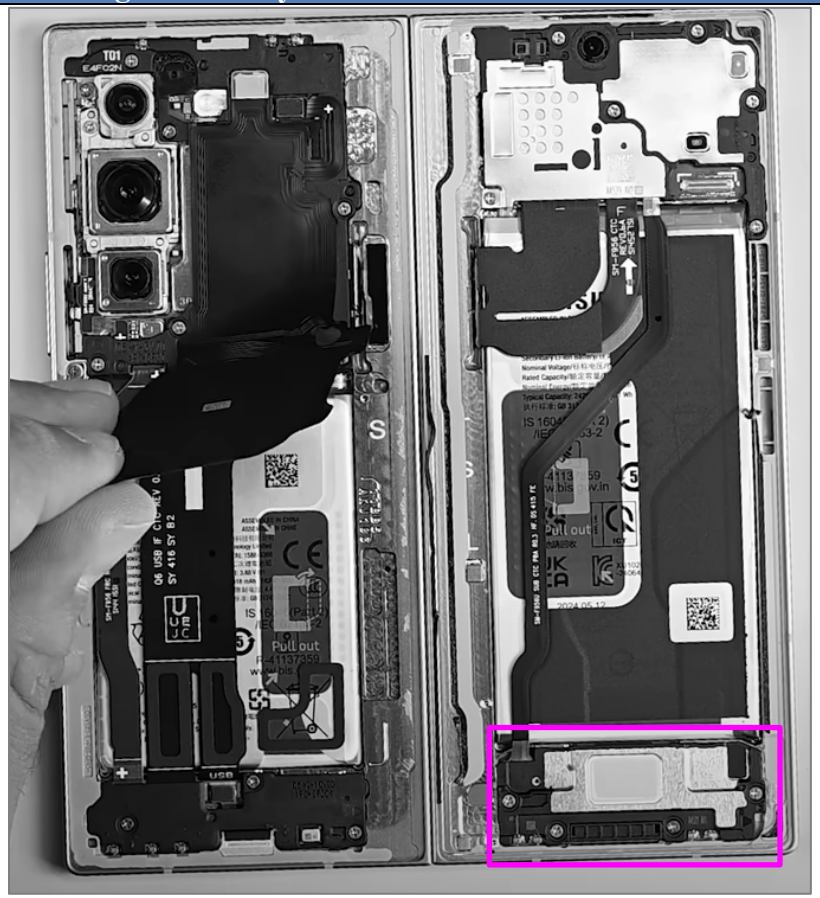
'455 Patent Claim	Samsung Accused System[1]
	Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.
1[g] wherein at least one analog to digital converter is coupled to at least one of the spatially separated detectors;	In the Accused Smartwatch, there is **at least one analog to digital converter** that is coupled to **at least one of the spatially separated detectors**, literally or under the doctrine of equivalents. For example, there is at least one analog to digital converter ("ADC") coupled to at least one of the photodiodes/PDs ("detectors") in the BioActive Sensor in the Accused Smartwatch. "The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. **A PPG signal chain comprises** a current driver for LEDs and **a receiver that senses the signal from PDs.** An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. **The outputs of the various signal chains are digitized by a common ADC** and stored in a FIFO which can be read out using an SPI interface." Texas Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

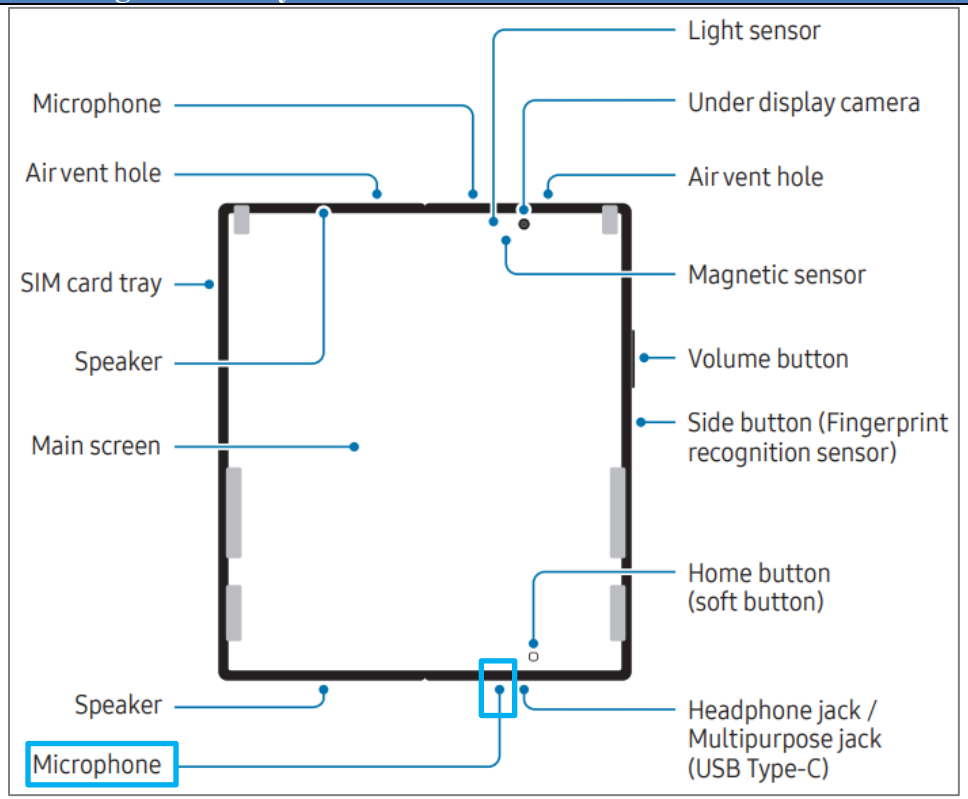
'455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic** Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.
1[h] the smart phone or tablet comprising a wireless receiver, a wireless transmitter, a display, a speaker,	The Accused System comprises an **Accused Phone/Tablet** comprising **a wireless receiver, a wireless transmitter, a display, a speaker, a voice input module, a microprocessor** and **a touch screen**, literally of under the doctrine of equivalents.

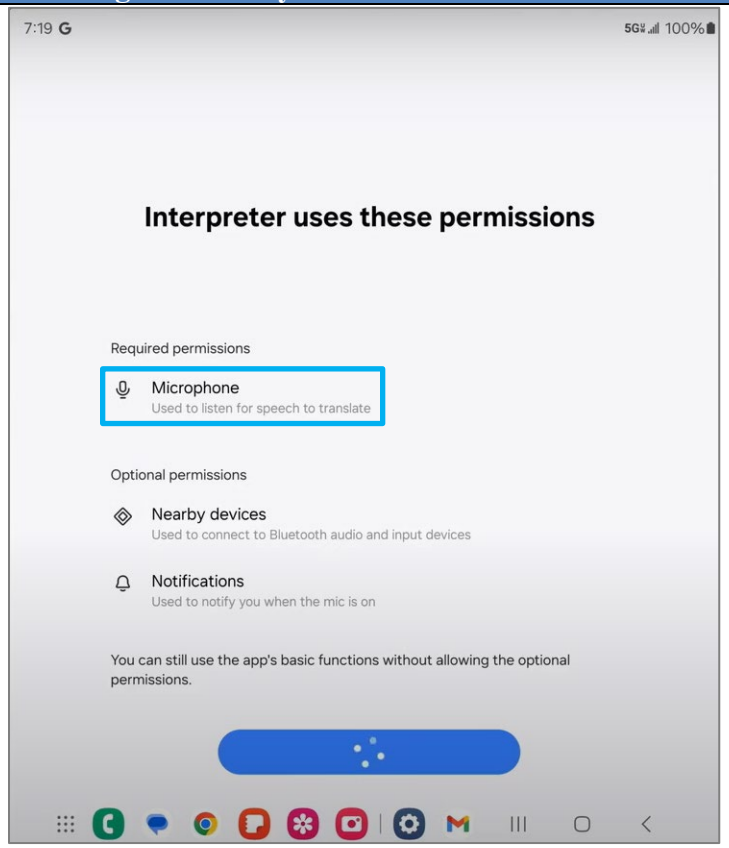
’455 Patent Claim	Samsung Accused System[1]
a voice input module, a microprocessor and a touch screen,	For example, the Galaxy Watch Ultra pairs with the Galaxy Z Fold6 (“smart phone”). The Galaxy Z Fold6 includes Wi-Fi connectivity, which requires the smart phone to include both **a wireless receiver** and **a wireless transmitter**.  Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/

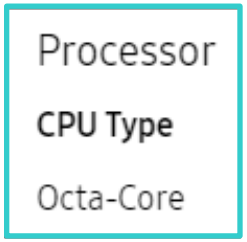
’455 Patent Claim	Samsung Accused System[1]
	Connectivity **Wi-Fi Connectivity** 802.11a/b/g/n/ac/ax 2.4GHz+5GHz+6GHz, HE160, MIMO, 1024-QAM Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/ The Galaxy Z Fold6 (“smart phone”) further includes **a display,** **a speaker,** and a microphone (“**a voice input module**”). Display **Resolution (Main Display)**: 2160 x 1856 (QXGA+) **Main Display Size**: 193.2mm (7.6" full rectangle) / 192.5mm (7.6" rounded corners) **Technology (Main Display)**: Dynamic AMOLED 2X Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/

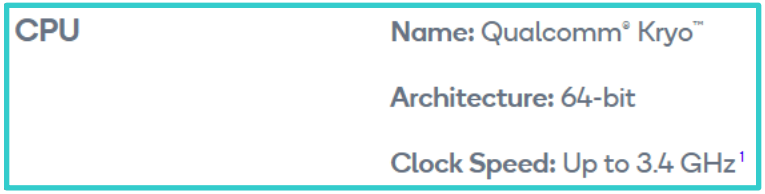
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 5]

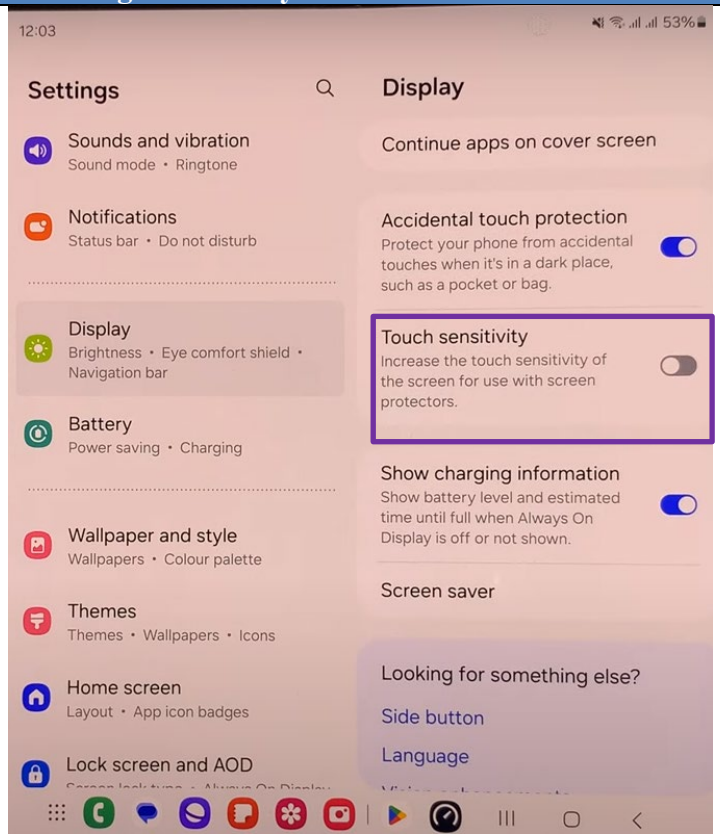
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=xYIe5uDVDWI

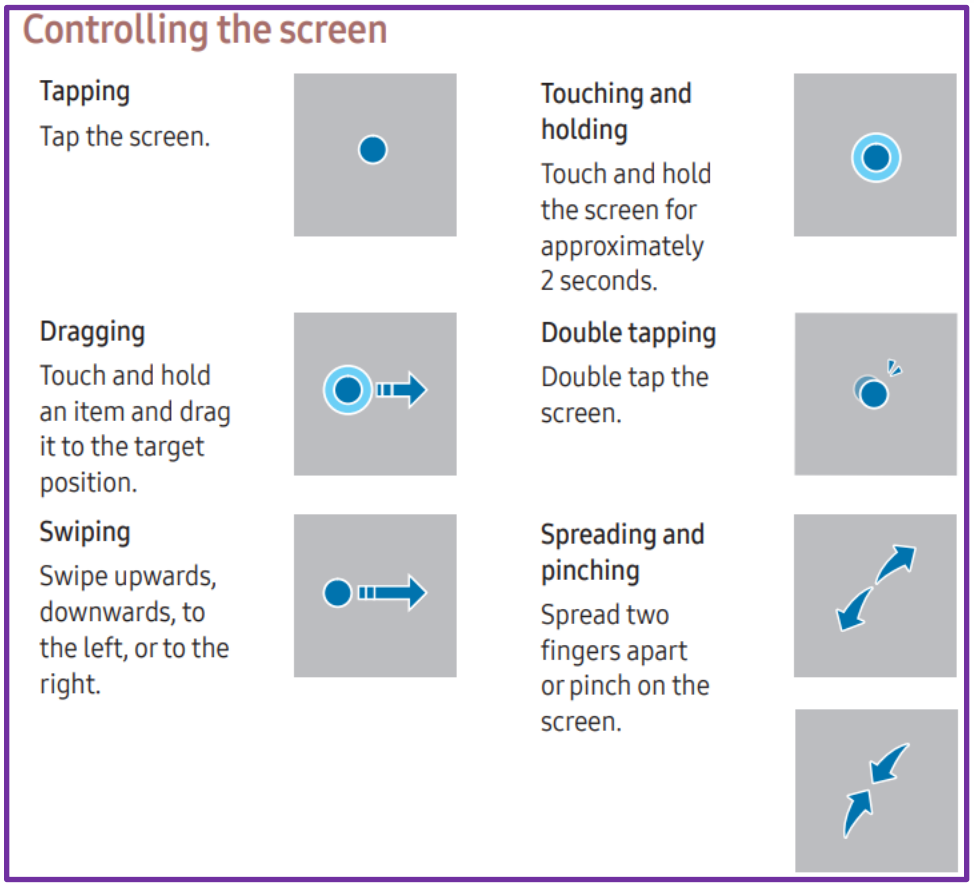
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 5]

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=sPP6NW89Am0 The Galaxy Z Fold6 further includes **a microprocessor** (*e.g.*, Snapdragon 8 Gen 3 SoC (system on chip) having Qualcomm Kryo microprocessor) and **a touch screen**.

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/  Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/

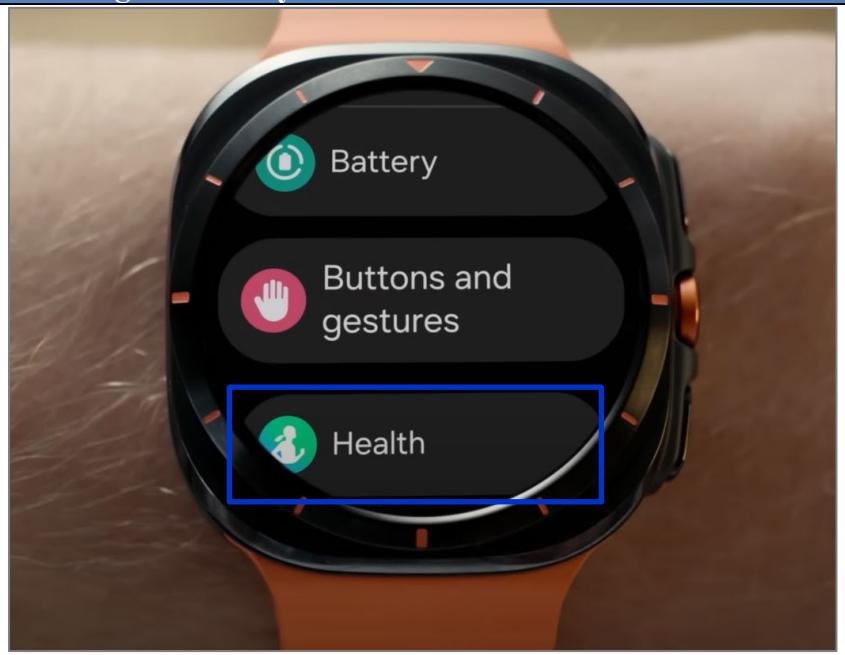
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.qualcomm.com/products/mobile/snapdragon/smartphones/snapdragon-8-series-mobile-platforms/snapdragon-8-gen-3-mobile-platform

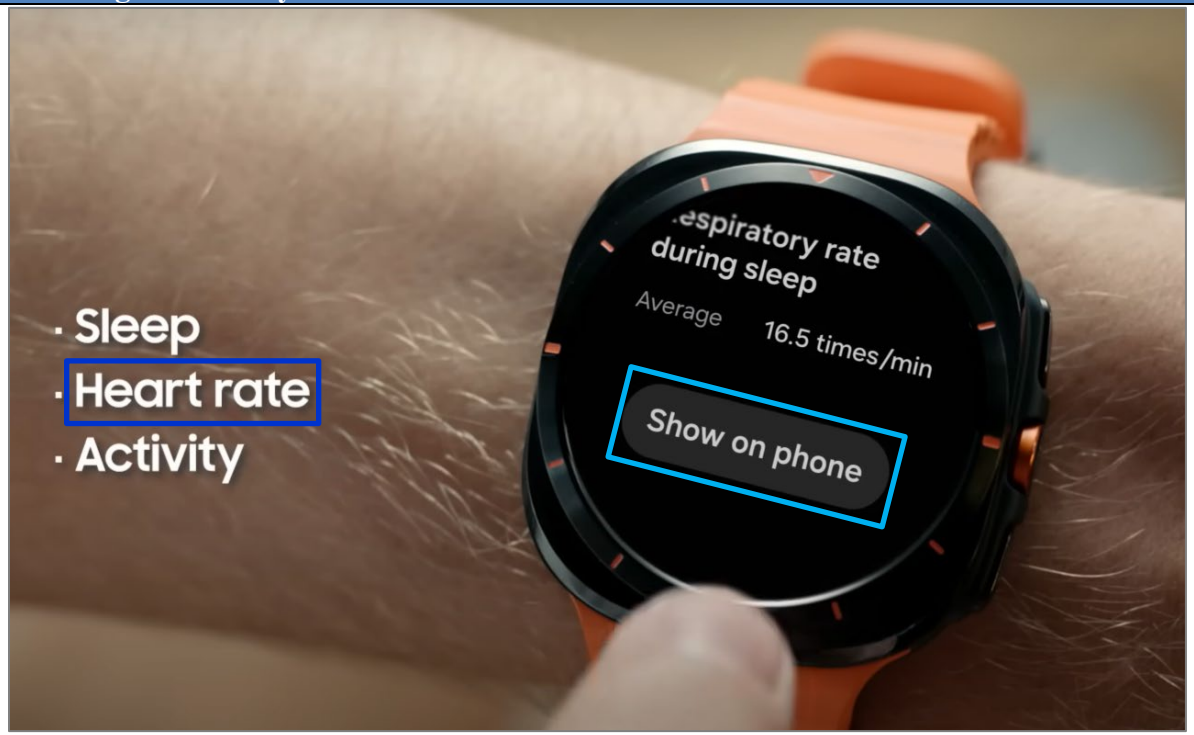
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=cn2UQ6Fr4hM

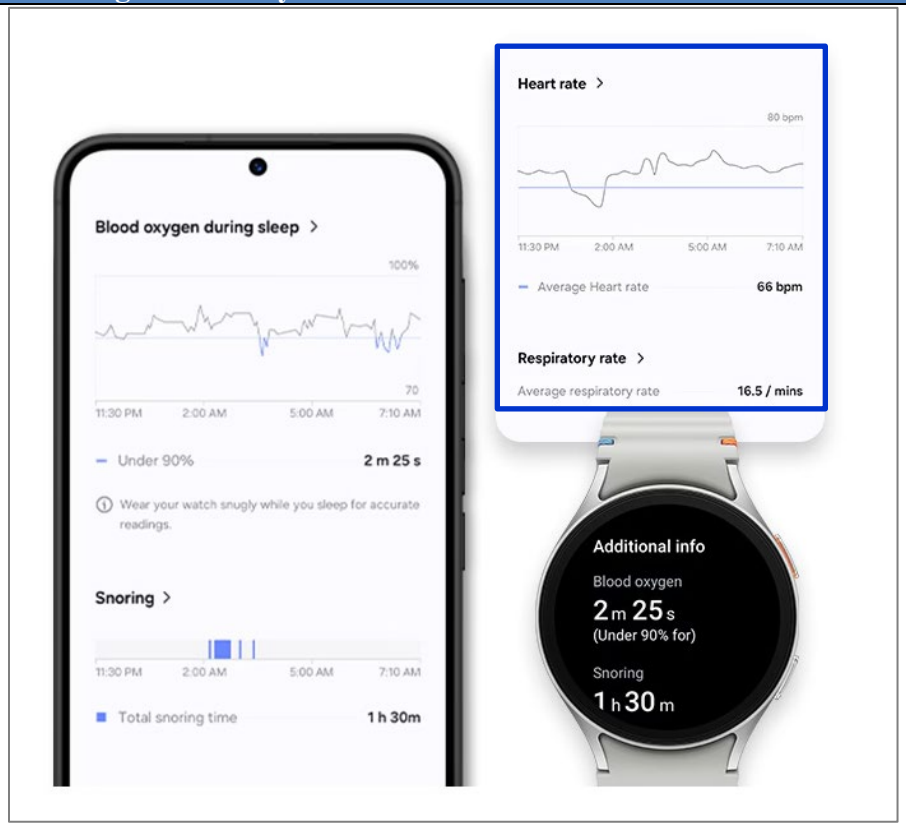
'455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 26]
1[i] the smart phone or tablet configured	The Accused Phone/Tablet is configured **to receive and process at least a portion of the output signal**, and the Accused Phone/Tablet is configured **to store and display the processed output signal**, wherein **at**

'455 Patent Claim	Samsung Accused System[1]
to receive and process at least a portion of the output signal, wherein the smart phone or tablet is configured to store and display the processed output signal, and wherein at least a portion of the processed output signal is configured to be transmitted over a wireless transmission link;	**least a portion of the processed output signal** is configured **to be transmitted over a wireless transmission link**, literally or under the doctrine of equivalents. For example, the Galaxy Z Fold6 ("the **smart phone**") receives the output signal from the BioActive Sensor via the Samsung Health app, processes the signal (*e.g.*, generates Heart Rate Zones, in addition to other health and wellness metrics and reports), and then stores and displays the Heart Rate Zones ("processed signal"). "The Samsung Privileged Health SDK is specialized for Galaxy Watch4 devices or later. **It provides both raw sensor signal data from the Samsung BioActive Sensor** and processed data with our differentiated features. The SDK supports an improved health tracking capability to allow your applications to track the user's health data accurately with the accelerometer, raw ECG (Electrocardiogram), **PPG (Photoplethysmogram), and heart rate including inter-beat interval.**" Samsung Developer, "Samsung Privileged Health SDK," *available at* https://developer.samsung.com/health/privileged/overview.html.

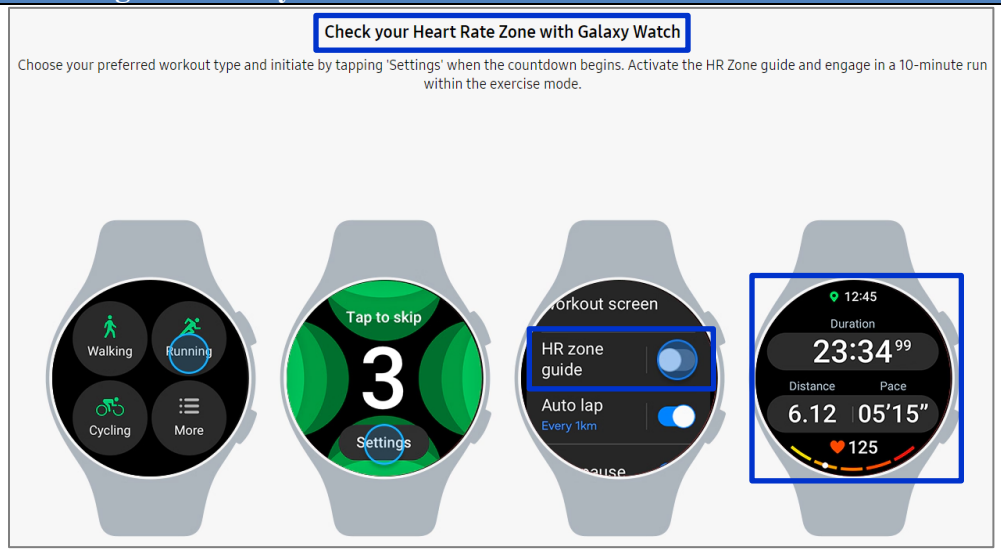
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/.

’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “A friendly guide to Galaxy Watch Ultra, Watch7 and Buds3Pro,” July 24, 2024, https://www.youtube.com/watch?v=VQW-ZpdAm5M.

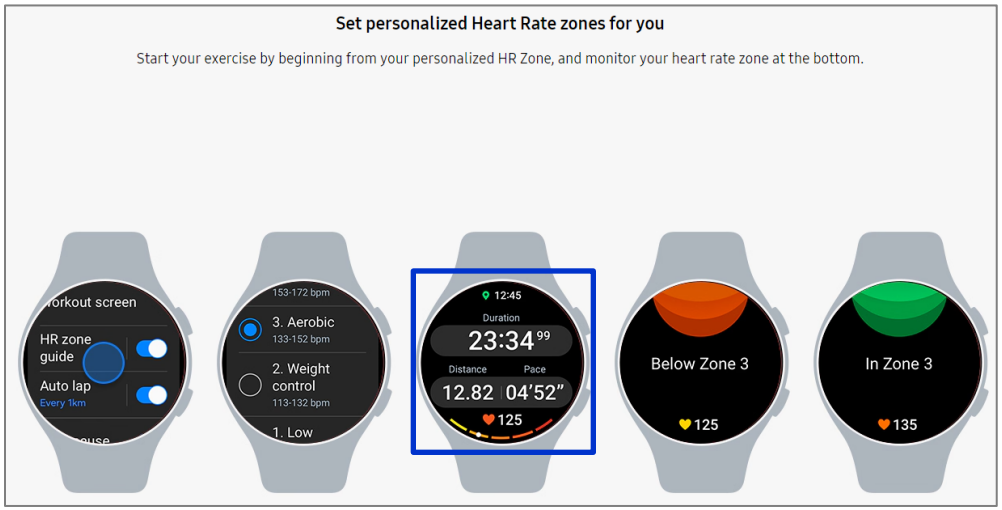
’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “A friendly guide to Galaxy Watch Ultra, Watch7 and Buds3Pro,” July 24, 2024, https://www.youtube.com/watch?v=VQW-ZpdAm5M

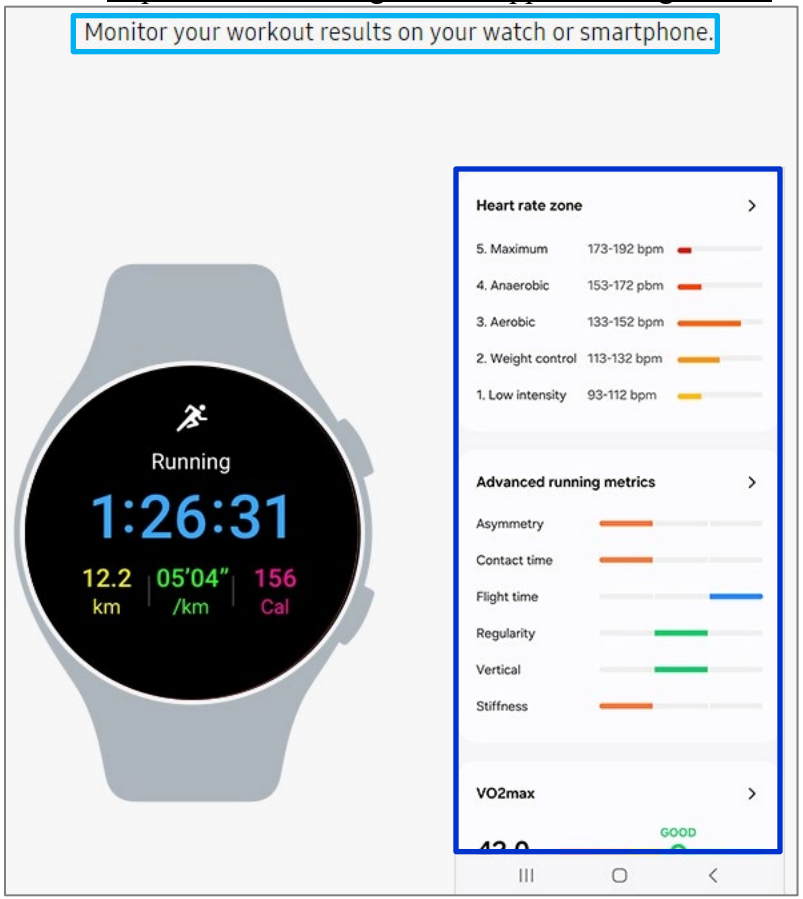
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/

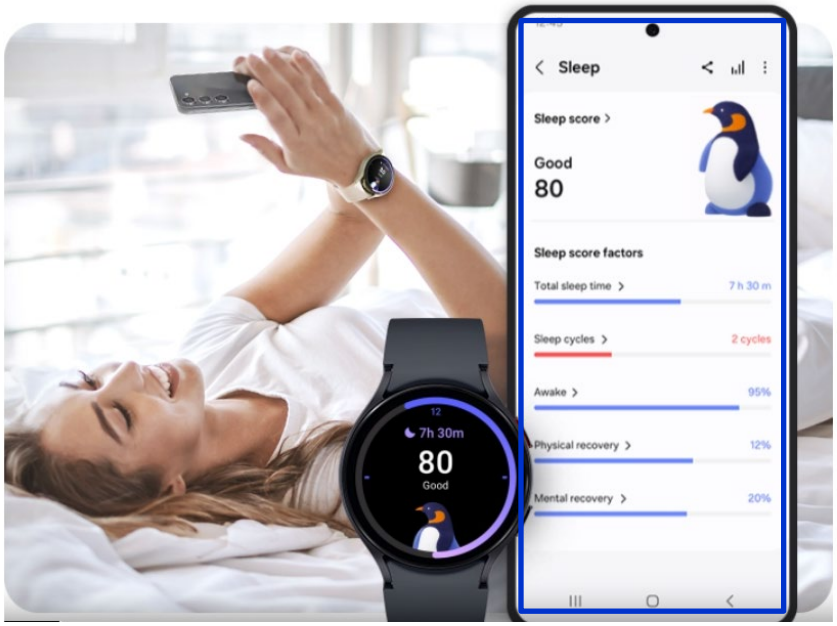
’455 Patent Claim	Samsung Accused System[1]

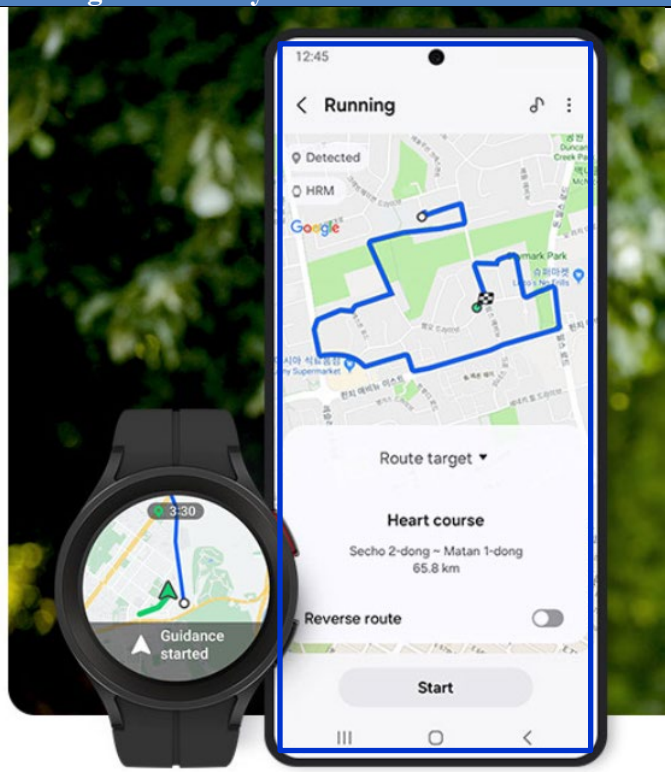


Source: https://www.samsung.com/us/apps/samsung-health/

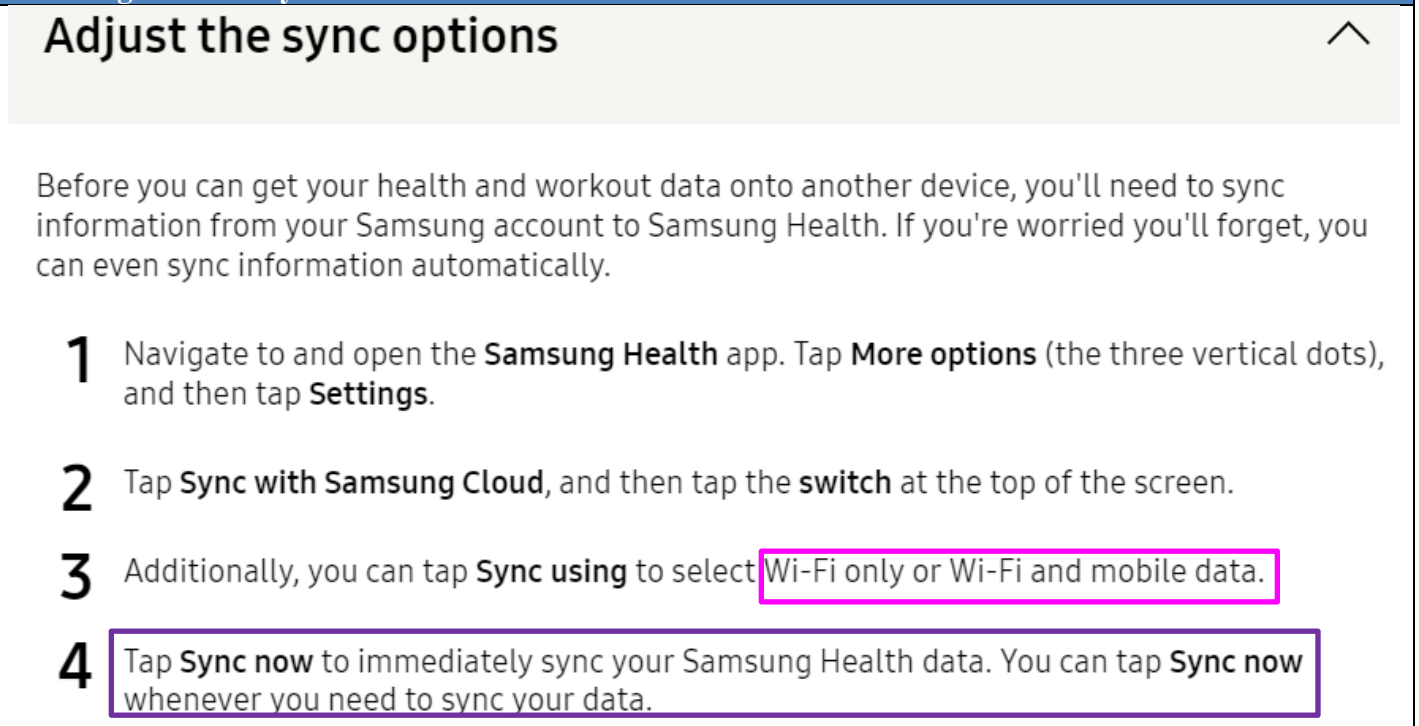


’455 Patent Claim	Samsung Accused System[1]
	Source: https://www.samsung.com/us/apps/samsung-health/  Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/global/galaxy/apps/samsung-health/

'455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/global/galaxy/apps/samsung-health/ "The **Energy score feature** is available **if the connected phone** has version 6.27 or later of the Samsung Health app installed." Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 53, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf.

’455 Patent Claim	Samsung Accused System[1]
	“The sleep pattern will have its four states (Awake, REM, Light, Deep) analysed by using your movement and changes in your **heart rate** while you are sleeping. **You can check the recommended ranges for each measured sleep state in the graph on your connected phone**.” Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 71, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf. The Samsung Health app data (“a portion of the processed output signal”) is synchronized with Samsung Cloud to enable transmission of data to Samsung Cloud over Wi-Fi (“wireless transmission link”). “If you just got a new phone or tablet, it doesn’t mean you have to lose your hard work in **Samsung Health. Your workout and health information can be transferred to the new device**; you just need to **sync your Samsung Health profile with your Samsung account!** Once your data is synced, you'll be able to access it on a different device.”

’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “Sync your data in Samsung Health,” https://www.samsung.com/us/support/answer/ANS10001399/.
1[j] wherein the output signal is indicative of one or more of the physiological parameters;	The Accused Smartwatch generates an **output signal** that **is indicative of one or more of the physiological parameters**, either literally or under the doctrine of equivalents. For example, the PPG signal (“output signal”) from the BioActive Sensor indicates, among other things, heart rate and blood oxygen levels (“one or more of the physiological parameters”).

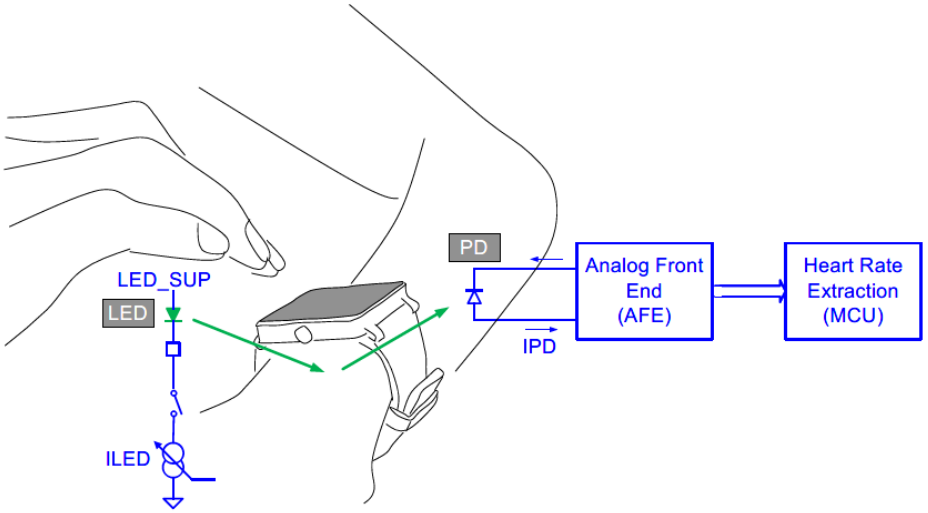
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

'455 Patent Claim	Samsung Accused System[1]
	Introducing Samsung's New BioActive Sensor The all-new BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of light-receiving photodiodes, adding additional colors of light-emitting diodes (LEDs) and arranging them optimally across the sensor. **Bringing Greater Accuracy and New Possibilities for Preventative Wellness** The optimal allocation of Green, Red and Infrared LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure,[2] blood oxygen levels and stress levels.[3] Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor. The more diverse colors of LEDs and newly designed photodiodes unlock new possibilities and empower you to better predict trends and take proactive steps for preventative care. The first of these features will be an advanced glycation end products (AGEs) index[4] – an indicator of metabolic health and biological aging strongly influenced by overall lifestyle and dietary habits. Used as an insightful biomarker, this index provides a snapshot of your biological age to help you make more informed decisions about your wellness journey and work towards a healthier future. The addition of an AGEs index is just one of the many new advanced features planned for the next Galaxy Watch. Source: Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	3 Description The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bio-impedance signals. A PPG signal chain comprises a current driver for LEDs and a receiver that senses the signal from PDs. An ECG receiver with a Right-leg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface

'455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy **OHRM**: Optical Heart-rate monitoring Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-4, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]
	Application *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR).

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 1. Heart Rate Monitoring on a Wearable Device** Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

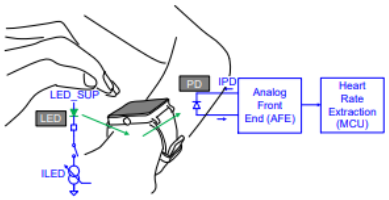
'455 Patent Claim	Samsung Accused System[1]

Product Overview

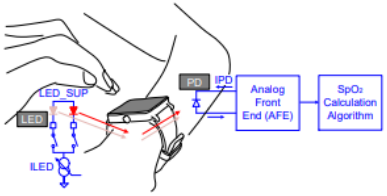
Photoplethysmography (PPG) With Integrated AFE for Optical Biosensing

TEXAS INSTRUMENTS

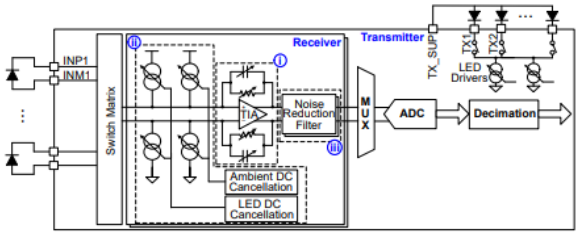
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI's signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.



Heart Rate Monitoring

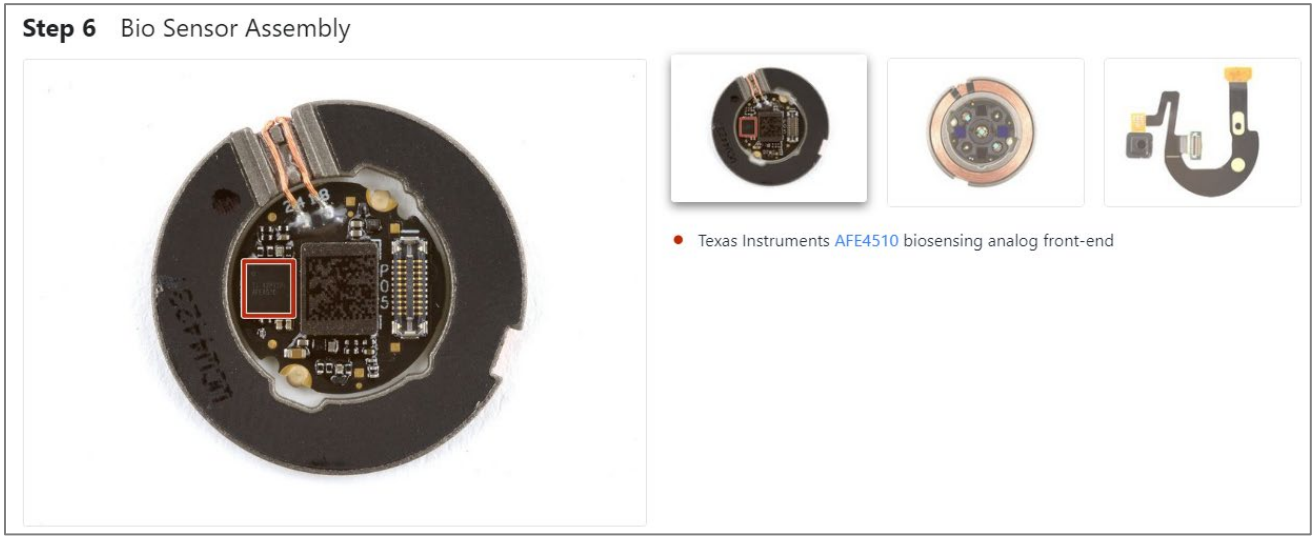


SpO_2 Monitoring



Block Diagram

Source: Texas Instruments, Product Overview, "Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing," Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

’455 Patent Claim	Samsung Accused System[1]
	See also https://www.samsung.com/us/apps/samsung-health/; https://www.samsung.com/sg/apps/samsung-health-monitor/; https://www.youtube.com/watch?v=snMLajaf0tc&t=7s; https://news.samsung.com/global/samsung-leads-holistic-health-innovation-with-galaxy-watch5-and-galaxy-watch5-pro.
1[k] the wearable device configured to increase the signal-to-noise ratio by increasing light intensity of at least one of the semiconductor sources from an initial light intensity;	The Accused Smartwatch is **configured to increase the signal-to-noise ratio by increasing light intensity of at least one of the semiconductor sources from an initial light intensity**, either literally or under the doctrine of equivalents. For example, the Galaxy Watch Ultra increases the signal-to-noise ratio (“SNR”) of the PPG signal received from the BioActive Sensor. The BioActive Sensor has a peak system SNR of 115 dB, which indicates that the general output SNR is lower than this peak value. To achieve the peak SNR, the sensor is configured to increase the LED current (“light intensity”) of the LEDs (“semiconductor sources”). 

’455 Patent Claim	Samsung Accused System[1]
	Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw. **3 Description** The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bio-impedance signals. A PPG signal chain comprises a current driver for LEDs and a receiver that senses the signal from PDs. An ECG receiver with a Right-leg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface

’455 Patent Claim	Samsung Accused System[1]
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’455 Patent Claim	Samsung Accused System[1]

Figure 3 shows the PPG signal chain in AFE4432.

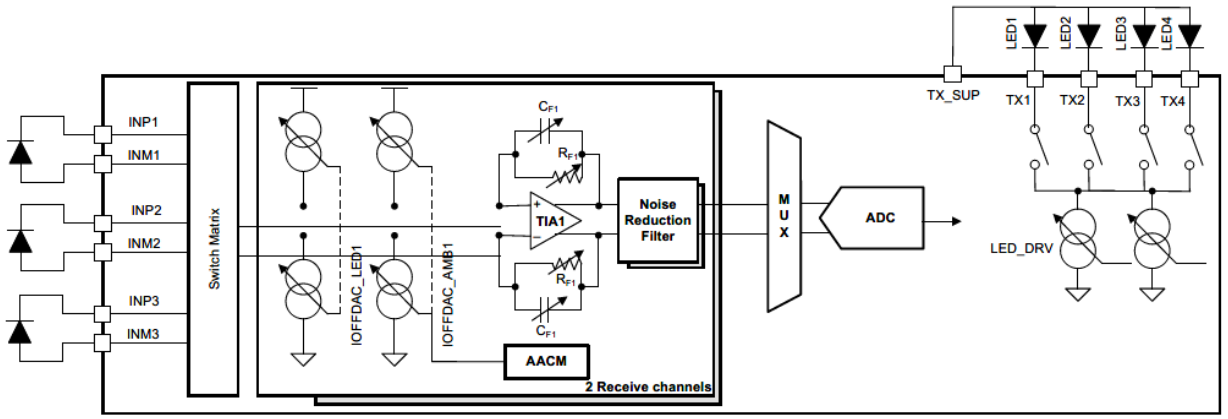
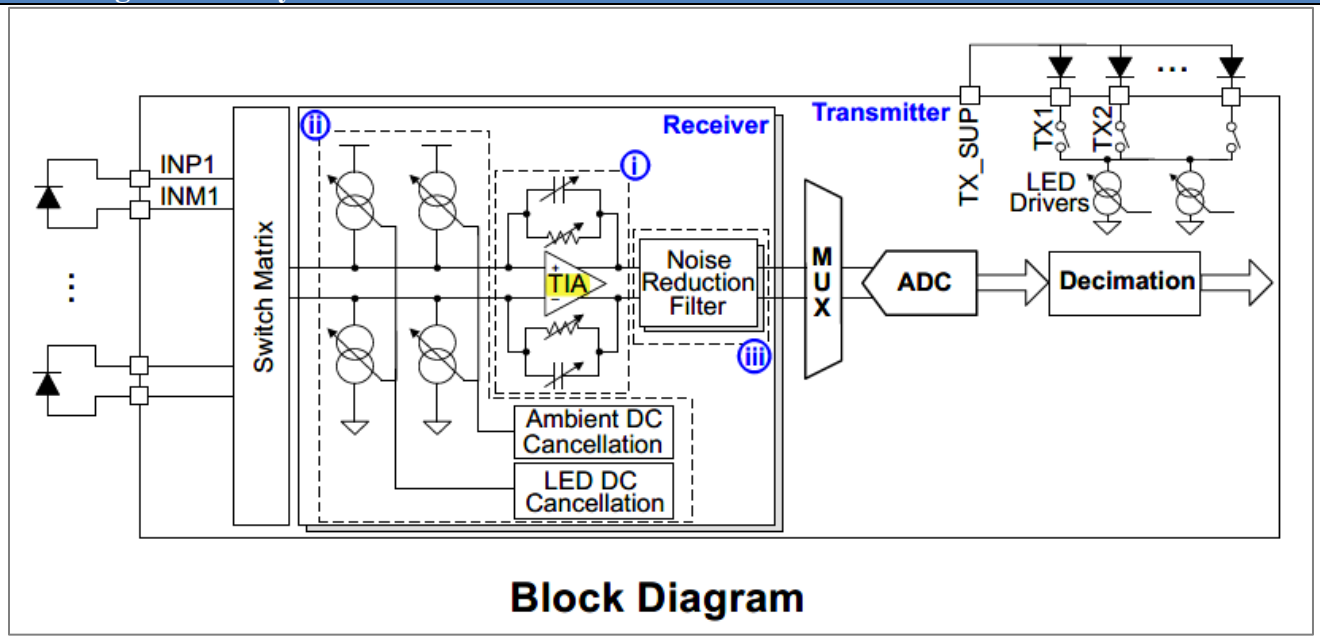


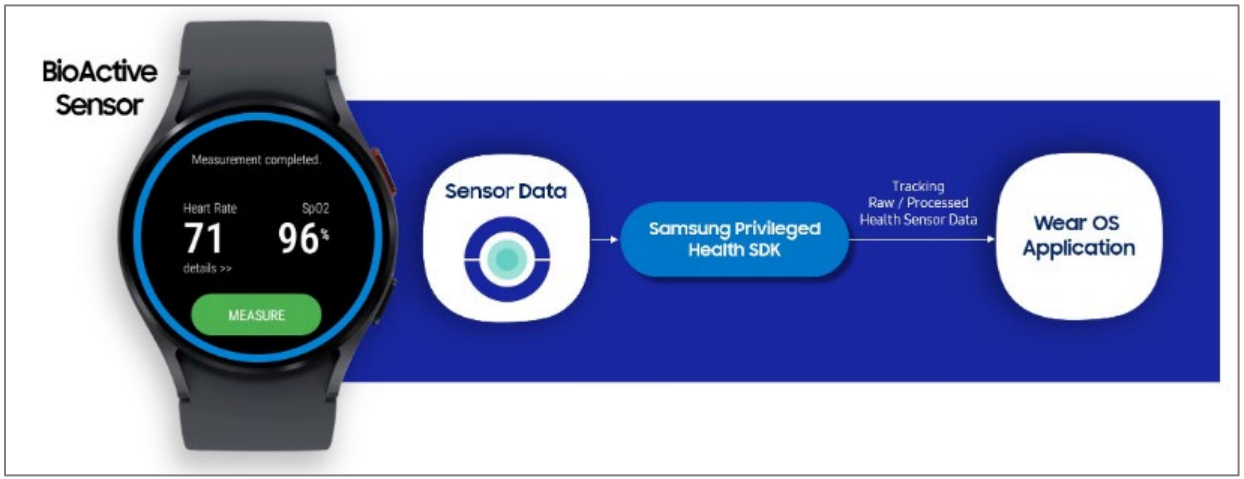
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

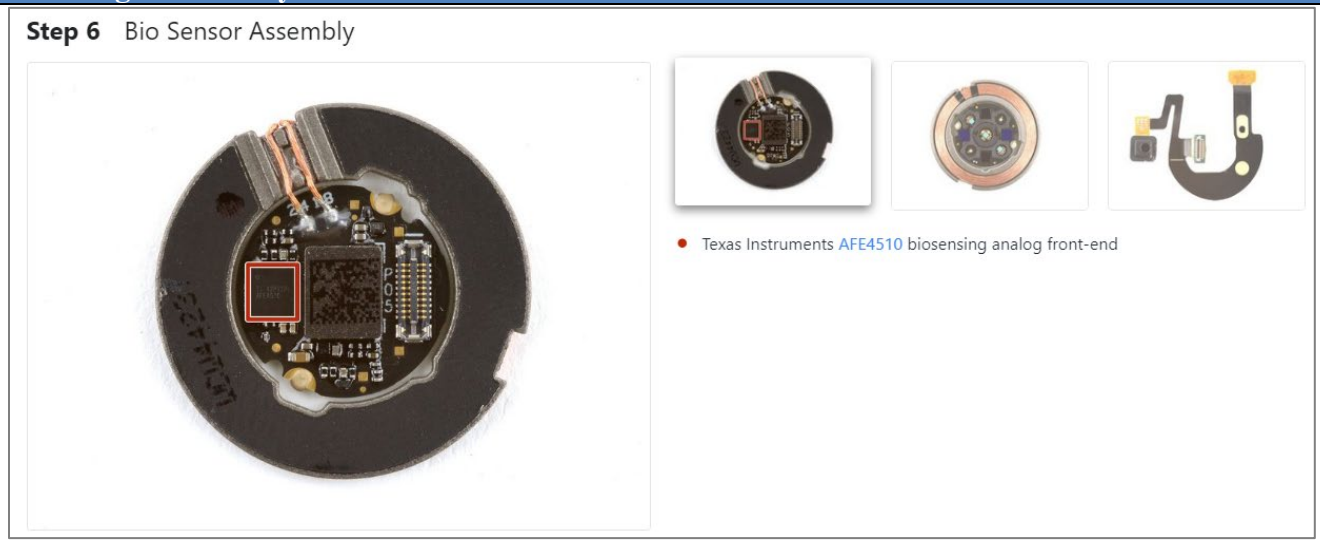
Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

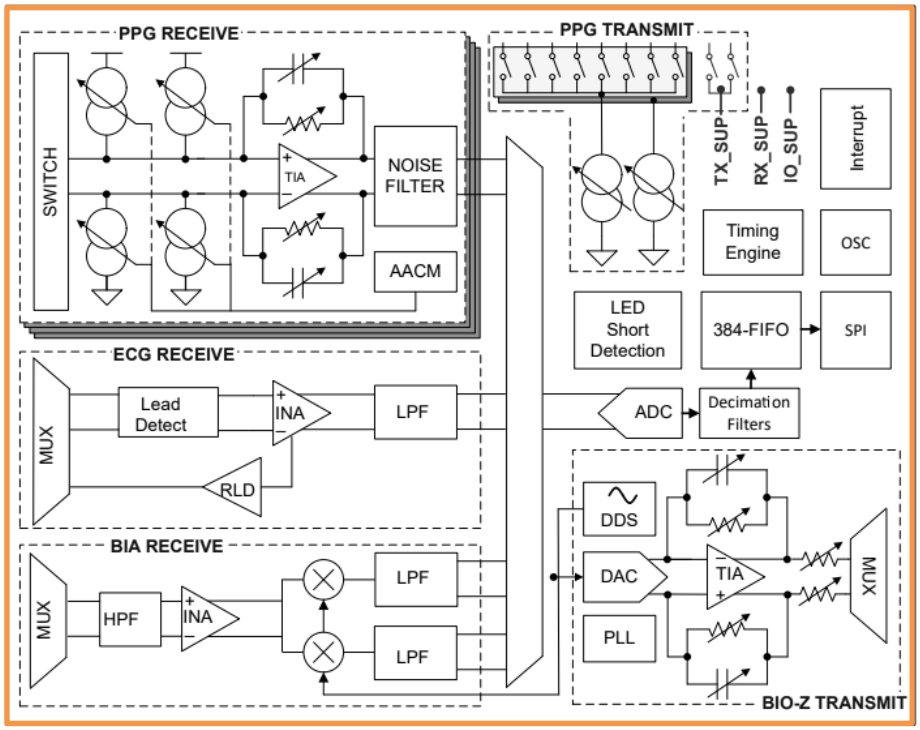
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI’s signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.

’455 Patent Claim	Samsung Accused System[1]
	 Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F. “However, **increasing the LED current gives better signal quality from the SNR perspective.** The optimal AFE configuration settings are completely dependent on the application. This includes the separation of LED and PD, location of the sensor, and other factors.” Texas Instruments, Application Report, “How to Design Peripheral Oxygen Saturation (SpO_2) and Optical Heart Rate Monitoring (OHRM) Systems Using the AFE4403,” SLAA655 – Mar. 2015, at 3, *available at* https://www.ti.com/lit/an/slaa655/slaa655.pdf.

'455 Patent Claim	Samsung Accused System[1]
	"Coming to the next Galaxy Watch, the new sensor will enable advanced predictive and preventative wellness features never before seen on a wearable device — in addition to **more accurate health measurements**. . . . The all-new BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that **enable even more precise health insights**. . . . This allows the new BioActive Sensor to **more accurately measure** health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is **30% more accurate** compared to its predecessor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor  "The SDK supports an improved health tracking capability to **allow your applications to track the user's health data accurately** with the accelerometer, raw ECG (Electrocardiogram), **PPG (Photoplethysmogram)**, and **heart rate including inter-beat interval**. In addition, it provides more advanced health features such as the body composition measurement, to enable compelling use cases for

'455 Patent Claim	Samsung Accused System[1]
	health and fitness applications. The blood oxygen level and sweat loss after a running workout are also useful data to check a user's health status." Source: Samsung Developer, "Samsung Privileged Health SDK," https://developer.samsung.com/health/privileged/overview.html
1[l] the detection system further configured to: generate a first signal responsive to light received while the semiconductor sources are off, generate a second signal responsive to light received while at least one of the semiconductor sources is on; and	The **detection system** in the Accused Smartwatch is further configured to **generate a first signal responsive to light received while the semiconductor sources are off,** and **generate a second signal responsive to light received while at least one of the semiconductor sources is on**, either literally or under the doctrine of equivalents. For example, the BioActive Sensor includes a PPG sensor that operates in multiple phases, including (1) Ambient (when the LEDs, or "semiconductor sources," are off) and (2) LED (when the LEDs, or "semiconductor sources," are on). During the Ambient phase, the sensor receives light with the LEDs off and generates a first signal. In the LED phase, the sensor receives light from the LEDs and generates a second signal.

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw.

’455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic**

’455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy **PPG Receiver:** – Supports 5 PDs, 4 parallel receive paths – Noise filtering with programmable bandwidth – Trans-impedance Gain: 3.7kΩ to 1MΩ – 8-bit Ambient Offset Subtraction DAC up to 256µA – 9-bit LED Offset Subtraction DAC up to 64µA – Digital Ambient Subtraction at ADC Output Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

'455 Patent Claim	Samsung Accused System[1]

5.1 PPG Configuration

5.1.1 Phase Definition

This sheet is used to specify number of phases, timing, signal chain parameters associated with each phase, and the LED/PD association for each phase. The phase type is selected from the drop down menu (Ambient and LED) and the appropriate parameters for the phase type are automatically shaded in blue. Specify only the parameters that show up in the Blue boxes. Manually fill each cell using the drop down boxes (do not cut and paste values across cells). Also, fill only the boxes that show up in blue. Do not modify the cream- colored boxes.

3		tLED_SAMP	0	us (LED ON start to SAMP start)		1	No data written into FIFO							Single or Dual TIA		Single		
4						2	Phase [N] - Phase [N-1]							PPG Decimation Fa	PPG_DEC_FA	2	ble PPG Decim	EN_PPG_DEC
5	Phase parameter table					3	Phase [N-1] - Average(Phase [N], Phase [N-2])							TIA1				
6	Phase	Phase type	LED drv1 connects to	LED drv2 connects to	NUMAV	Stagger LED?	4 Phase[N] - Phase [N-2]	FIFO data word	SAMP time (us)	Filter BW Selection	Connect PD4?	Connect PD3?	Connect PD2?	Connect PD1?	Rf (kOhm)	Cf (pF)	IOFFDAC_ TIA1 (uA)	AACM TYPE
7	1	Ambient			2	0	Never mask	1	115	Set1			1		100	20	0	ANA AACM
17	2	LED	TX5	TX5	2	0	Never mask	1	115	Set1			1		100	20	0	LED_DC Cancel
27	3	Ambient			2	0	Never mask	3	115	Set1			1		100	20	0	ANA AACM
37																		
47																		
57																		
67																		
77																		
87																		
97																		
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Figure 5-1. PPG per-phase configuration

’455 Patent Claim	Samsung Accused System[1]



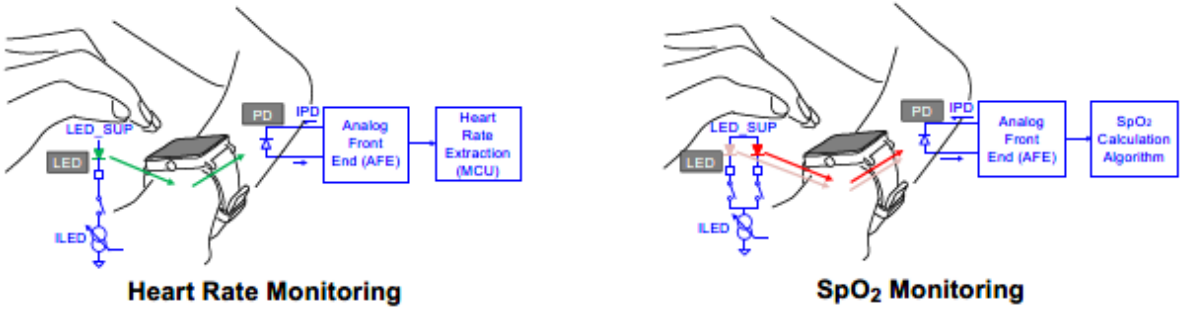
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
3		tLED_SAMP	0	us (LED ON start to SAMP start)			1	No data written into FIFO						Single or Dual TIA		Single		
4							2	Phase [N] - Phase [N-1]						PPG Decimation Fa	PPG_DEC_FA	2	le PPG Decim	EN_PPG_DEC
5	Phase parameter table						3	Phase [N-1] - Average(Phase [N], Phase [N-2])										
							4	Phase[N] - Phase [N-2]			TIA1							
6	Phase	Phase type	LED drv1 connects to	LED drv2 connects to	NUMAV	Stagger LED?	Fractional masking	FIFO data word	SAMP time (us)	Filter BW Selection	Connect PD4?	Connect PD3?	Connect PD2?	Connect PD1?	Rf (kOhm)	Cf (pF)	IOFFDAC_ TIA1 (uA)	AACM TYPE
7	1	Ambient			2	0	Never mask	1	115	Set1			1		100	20	0	ANA AACM
17	2	LED	TX5	TX5	2	0	Never mask	1	115	Set1			1		100	20	0	LED_DC Cancel
27	3	Ambient			2	0	Never mask	3	115	Set1			1		100	20	0	ANA AACM
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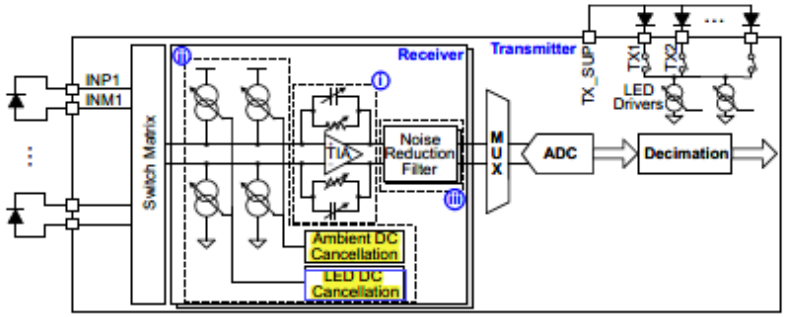
Figure 5-1. PPG per-phase configuration

Source: Texas Instruments, AFE4500 EVM User Guide, SBAU370 – April 2021, at 23, *available at* https://www.manualslib.com/download/2652772/Texas-Instruments-Afe4500evm.html.

“To save power, the LED is pulsed at the PRF rate, turning on for a short window in each PRF cycle. Each turning on of the LED results in one sample in the digital data stream. . . . Input offset cancellation DAC cancels DC from both **ambient** and **LED**, and allows a high TIA gain setting for the best noise performance.” Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

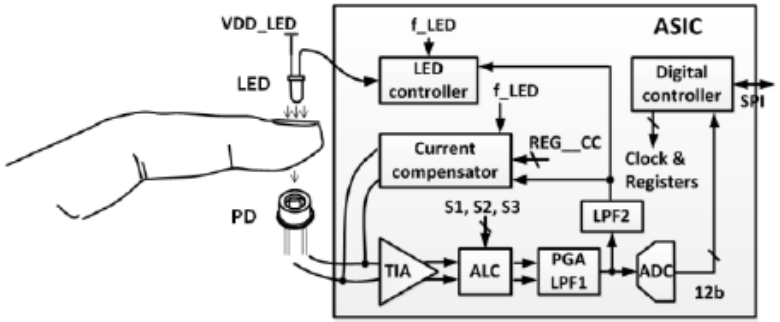
’455 Patent Claim	Samsung Accused System[1]

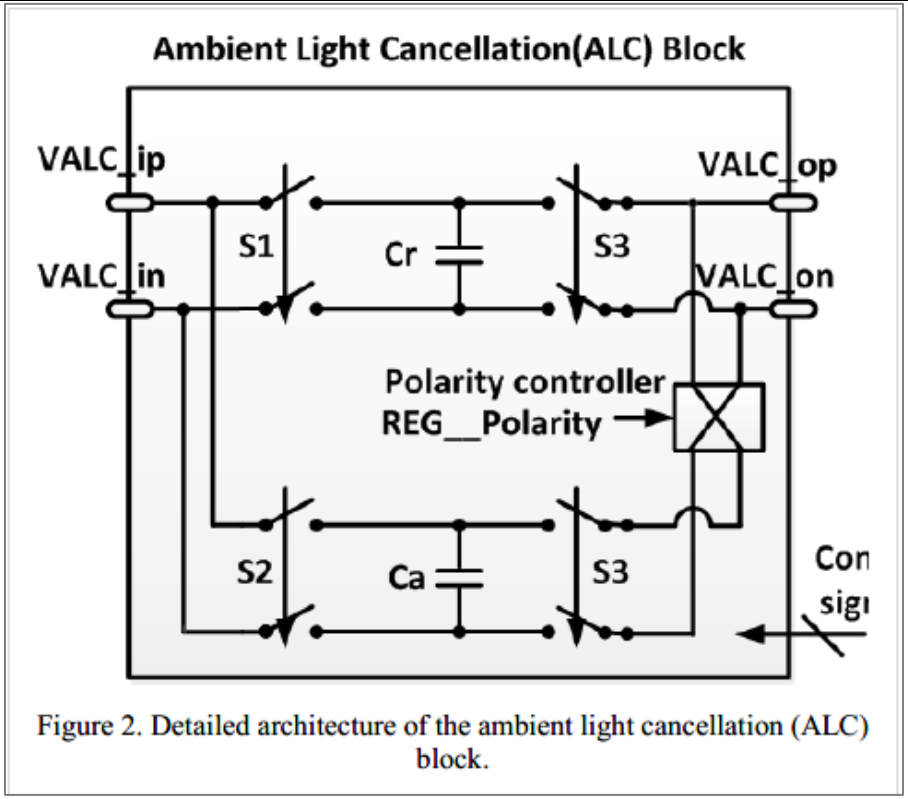


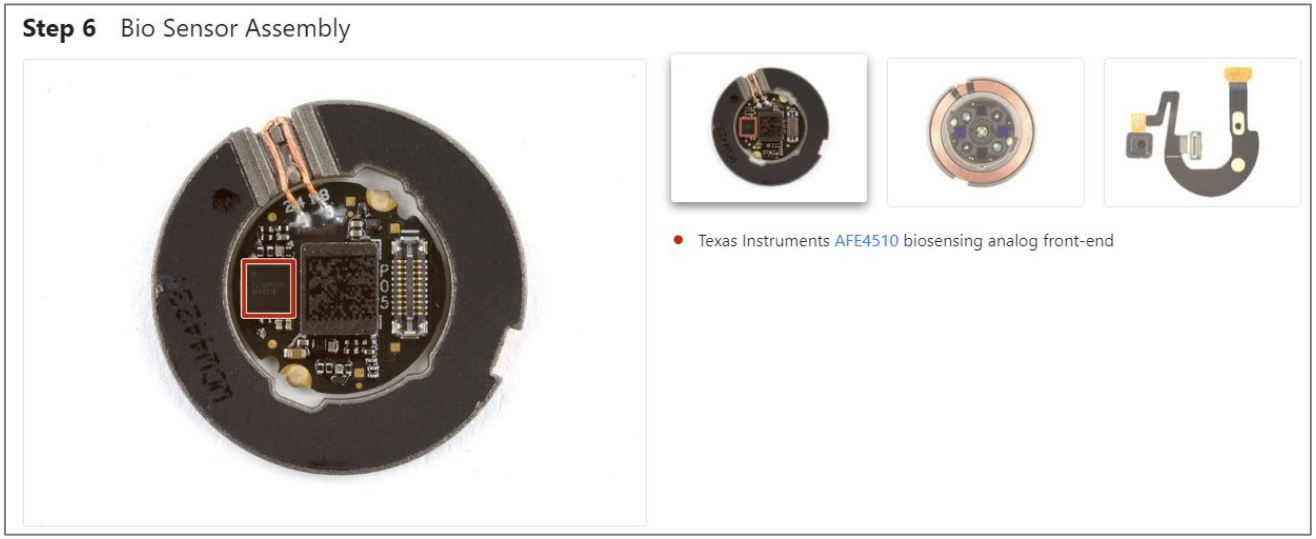


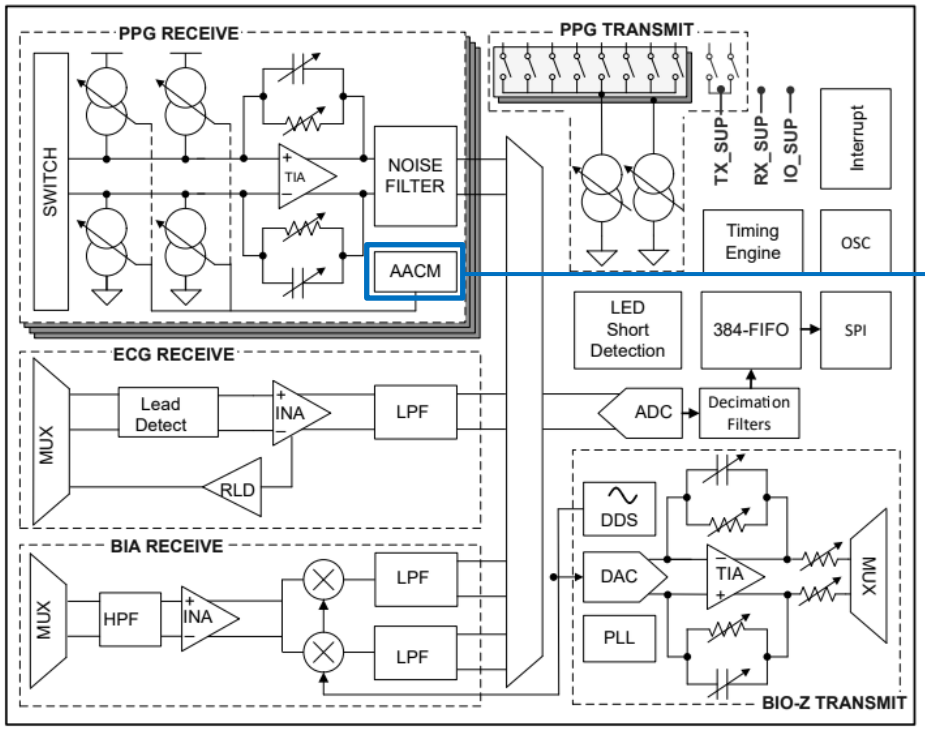
Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

A technical paper authored by Samsung engineers further explains a PPG signal detection system for use in wearable devices configured to operate in an Ambient and LED phase:

'455 Patent Claim	Samsung Accused System[1]
	B. Ambient Light Cancellation (ALC) The ambient light component in the detected PPG signal can be removed in the ALC block, which is shown in Fig. 2. When the LED light turns on, the measured signal corresponding to both the LED light and the ambient light is sampled at the charge reservoir Cr, and when the LED light turns off, the measured signal corresponding to only the ambient light is sampled at an another charge reservoir Ca. Then, the charge redistribution occurs to cancel the ambient  Figure 1. Top block diagram of LED driving and PD detection circuit for PPG application.

'455 Patent Claim	Samsung Accused System[1]
	 Figure 2. Detailed architecture of the ambient light cancellation (ALC) block. Source: J. Kim et al., "Ambient light cancellation in photoplethysmogram application using alternating sampling and charge redistribution technique," 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), at 6441-42.
1[m] increase the signal-to-noise ratio by comparing the	The detection system in the Accused Smartwatch is configured to **increase the signal-to-noise ratio by comparing the first signal and the second signal**, either literally or under the doctrine of equivalents.

’455 Patent Claim	Samsung Accused System[1]
first signal and the second signal; and	For example, ambient light is considered as noise in PPG sensors. Therefore, the presence of ambient light decreases the SNR of PPG sensors. Ambient light cancellation is performed to cancel out the ambient light noise, thereby increasing the SNR. The BioActive Sensor of the Galaxy Watch Ultra performs ambient light cancellation (also referred to as “Digital Ambient Subtraction”), to increase the SNR, by comparing the measured signal when the LED sources are off (“first signal”) and the measured signal when the LED sources are on (“second signal”).  Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw.

’455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic**

'455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy **PPG Receiver:** – Supports 5 PDs, 4 parallel receive paths – Noise filtering with programmable bandwidth – Trans-impedance Gain: 3.7kΩ to 1MΩ – 8-bit Ambient Offset Subtraction DAC up to 256µA – 9-bit LED Offset Subtraction DAC up to 64µA – Digital Ambient Subtraction at ADC Output Source: Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf. "To save power, the LED is pulsed at the PRF rate, turning on for a short window in each PRF cycle. Each turning on of the LED results in one sample in the digital data stream. . . . **Input offset cancellation DAC cancels DC from both ambient** and **LED**, and allows a high TIA gain setting for the best noise performance." Texas Instruments, Application Brief, "Optical Heart Rate Monitoring (OHRM) on Wearables," SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

’455 Patent Claim	Samsung Accused System[1]

Table 1. Specifications for OHRM on Wearables

System Specifications	AFE4432	Comments
Multi-sensor support	4 LEDs, 3 PDs	Combining signals from multiple PDs and LEDs helps mitigate motion artifacts
Sampling rate	1 Hz–1 kHz	A sampling rate of 25 Hz to100 Hz is typically used for continuous HRM
Current consumption	12 µA	For the receiver at 25 Hz PRF
Peak SNR	115 dB over 10-Hz bandwidth	Important consideration to achieve good accuracy in low perfusion cases.
Ambient rejection	> 70 dB up to 160 Hz	Good ambient rejection helps remove the spurious tones caused by ambient light from sources such as indoor lighting

Figure 3 shows the PPG signal chain in AFE4432.

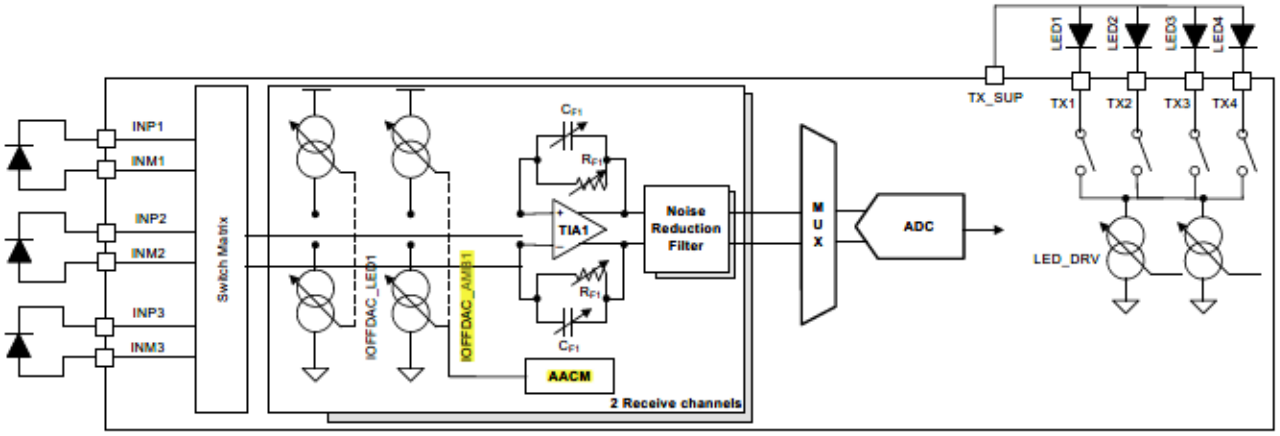


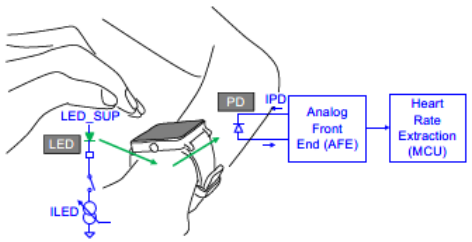
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

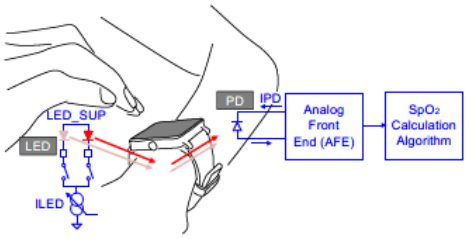
’455 Patent Claim	Samsung Accused System[1]
	Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

TEXAS INSTRUMENTS

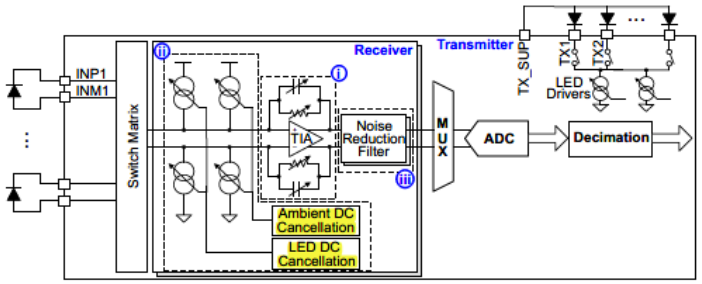
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI's signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.



Heart Rate Monitoring

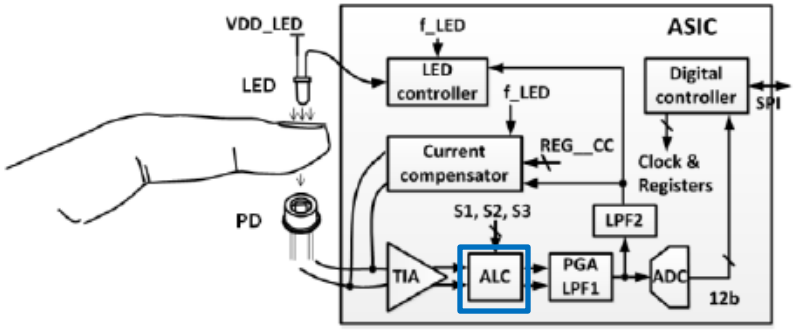


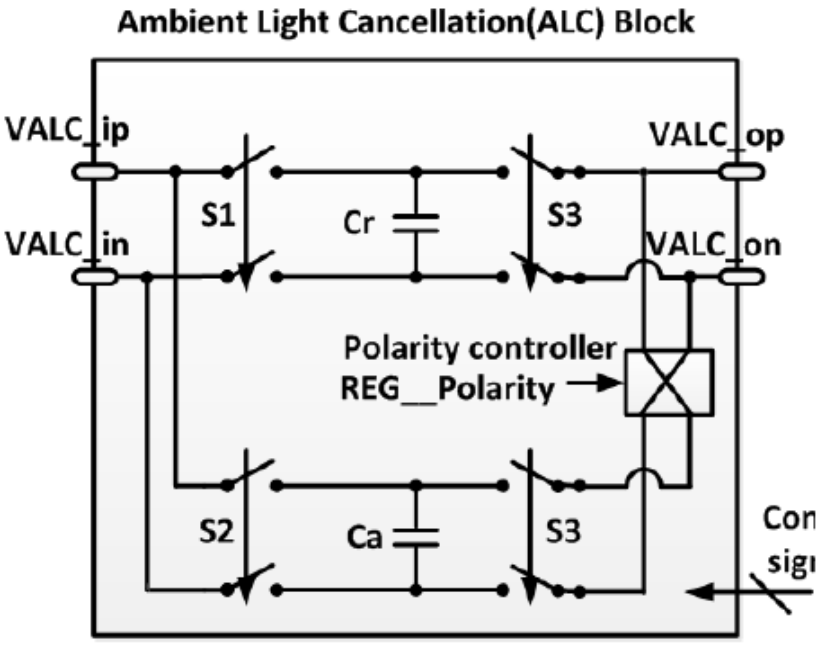
SpO_2 Monitoring



Block Diagram

’455 Patent Claim	Samsung Accused System[1]
	Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F. **5 AFE4500 Register Generation Excel** The AFE4500_Register_Generation_v*.xlsm will be given by TI. This configuration file will be in the EVM software installation directory. Default file location: ***C:\Program Files\Texas Instruments\Bio-Sensing\AFE4500EVM\Register config\AFE4500_Register_Generation_v*.xlsm*** By default the EVM ships in LDO enable mode with following configuration • Clocking : Internal oscillator • PPG configuration – PPG output data rate: 50 Hz – 3 Phases (Phase1, Phase2, Phase3) are defined for PPG: AMB1, LED, AMB2 – PPG Phases are sampled from Green PD of sensor board – TX1 (connected to Green LED on sensor board) is used to LED Phase. – TIA Gain (i.e. Rf): 250 kΩ – Sampling width: 117 µS – Noise reduction filter: 2.5 KHz – ANA AACM: Enabled to cancel ambient signal from all Phases – DIG AACM: Enabled to cancel the DC in LED Phase. • ECG Configuration – ECG output data rate: 500 Hz – ECG INA Gain: 21 Source: Texas Instruments, AFE4500 EVM User Guide, SBAU370 – April 2021, at 23, *available at* https://www.manualslib.com/download/2652772/Texas-Instruments-Afe4500evm.html.

'455 Patent Claim	Samsung Accused System[1]
	Samsung engineers authored a technical paper further describing ambient light cancellation in PPG applications for wearable devices: *B. Ambient Light Cancellation (ALC)* The ambient light component in the detected PPG signal can be removed in the ALC block, which is shown in Fig. 2. When the LED light turns on, the measured signal corresponding to both the LED light and the ambient light is sampled at the charge reservoir Cr, and when the LED light turns off, the measured signal corresponding to only the ambient light is sampled at an another charge reservoir Ca. Then, the charge redistribution occurs to cancel the ambient  Figure 1. Top block diagram of LED driving and PD detection circuit for PPG application. light component out by reconnecting the two charge reservoirs in a manner of reversed polarity.

'455 Patent Claim	Samsung Accused System[1]
	 Figure 2. Detailed architecture of the ambient light cancellation (ALC) block. Source: J. Kim et al., "Ambient light cancellation in photoplethysmogram application using alternating sampling and charge redistribution technique," 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), at 6441-42.
1[n] wherein the plurality of optical wavelengths comprises three optical wavelengths	In the Accused Smartwatch, the plurality of semiconductor sources are configured to generate an output optical light having a plurality of optical wavelengths, **wherein the plurality of optical wavelengths comprises three optical wavelengths for measuring at least a portion of the one or more of the physiological parameters**, either literally or under the doctrine of equivalents.

'455 Patent Claim	Samsung Accused System[1]
for measuring at least a portion of the one or more of the physiological parameters	Samsung states that "[t]he optimal allocation of **Green, Red and Infrared LEDs** sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. **This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels.** Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor The SDK supports an **improved health tracking capability to allow your applications to track the user's health data accurately with the accelerometer, raw ECG (Electrocardiogram), PPG (Photoplethysmogram)**, and heart rate including inter-beat interval. In addition, it provides more advanced health features such as the body composition measurement, to enable compelling use cases for health and fitness applications. **The blood oxygen level** and sweat loss after a running workout are also useful data to check a user's health status." Samsung Developer, "Samsung Privileged Health SDK," *available at* https://developer.samsung.com/health/privileged/overview.html LEDs outputting light at different colors do so at different optical wavelengths. For example, a green LED, a red LED, and an infrared LED all output light at different optical wavelengths:

'455 Patent Claim	Samsung Accused System[1]

Table 1. LEDs – Wavelengths and Applications	
LED Wavelength (Color)	**LED Applications**
410–420 nm (Violet)	Skin therapy
430–470 nm (Blue)	Dental curing instruments
470 nm (Blue)	White LEDs using phosphor
520–530 nm (Green)	Green traffic signal lights
580–590 nm (Amber)	Amber traffic signal lights
630–640 nm (Red)	Red signal lights
660 nm (Deep Red)	Blood oximetry
680 nm (Deep Red)	Blood analysis
800–850 nm (Near-IR)	Night-vision illuminators and beacons for use with night-vision goggles or CCDs
850–940 nm (Near-IR)	Photoelectric controls
940 nm (Near-IR)	Covert illumination CCD-based systems

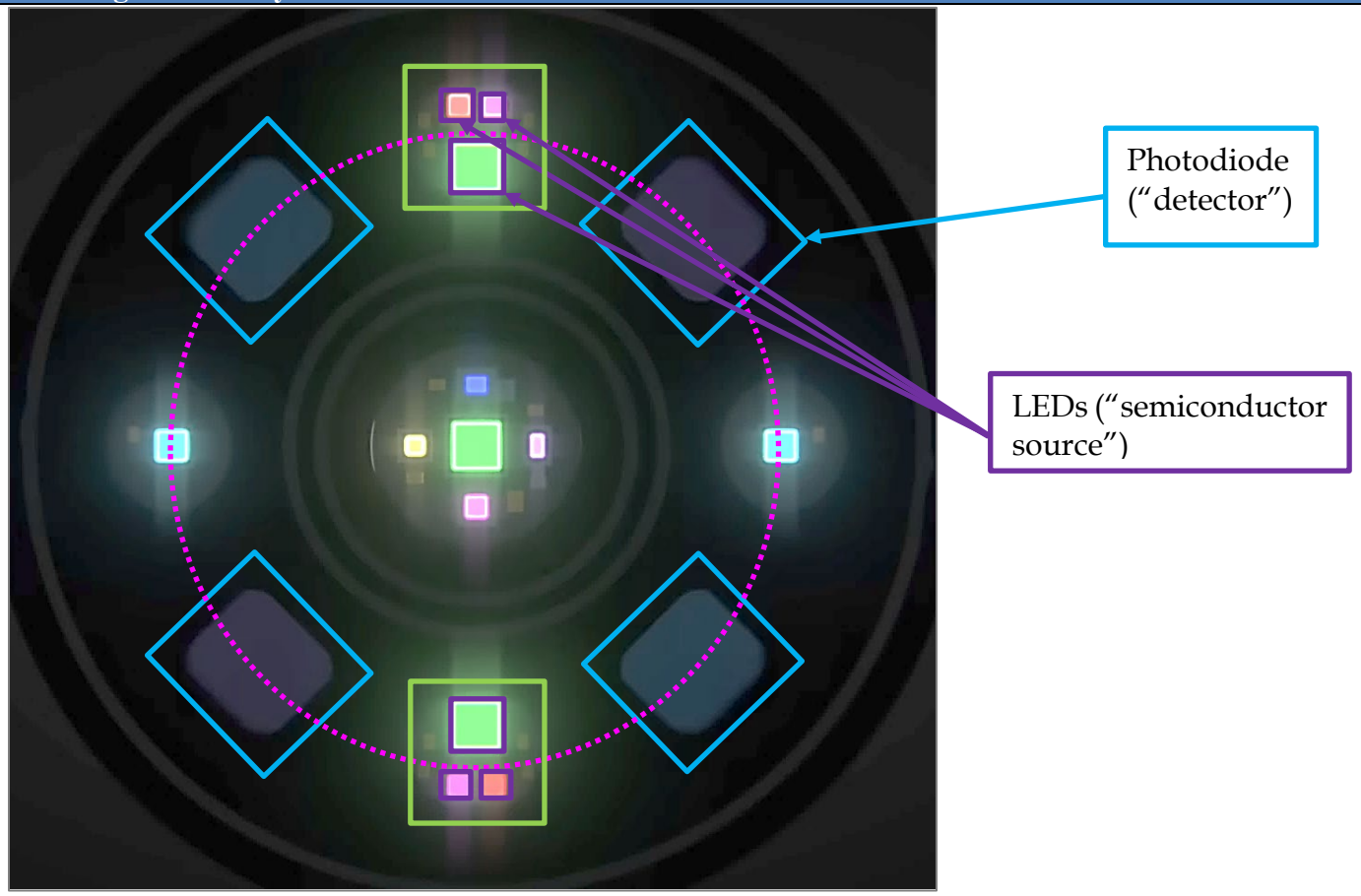
Source: https://www.photonics.com/Articles/Light-Emitting_Diodes_A_Primer/a36706

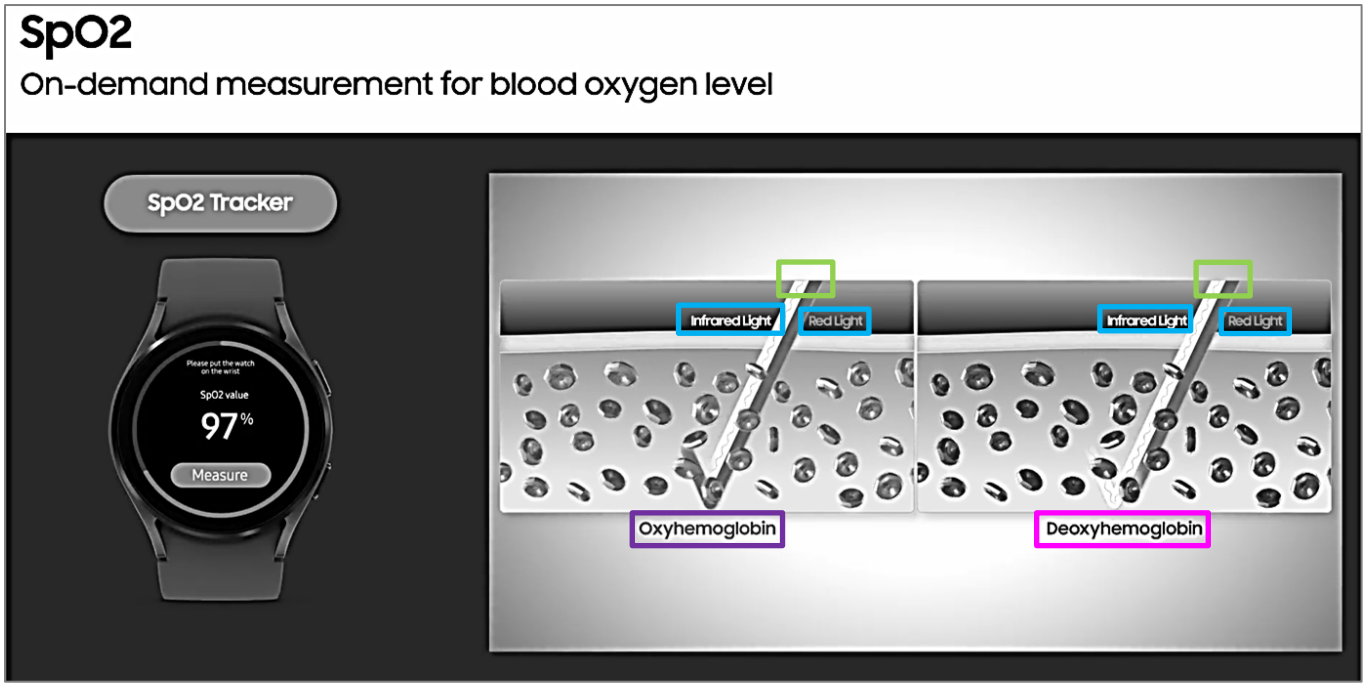
System Specifications	AFE4432	Comments
Multi-sensor support for SpO_2, heart rate monitoring	4 LEDs, 3 photodiodes (PDs)	A typical SpO_2 system can use a green LED in addition to red and infrared (IR) LEDs. The red and IR wavelengths share the same PD, whereas the green wavelength can use a different PD.

Texas Instruments, Application Brief, "Measuring Oxygen Saturation (SpO2) on Wearables," SBAA566, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa566/sbaa566.pdf.

'455 Patent Claim	Samsung Accused System[1]
1[o] wherein the optical wavelengths comprise near infrared or visible wavelengths.	In the Accused Smartwatch, the plurality of semiconductor sources are configured to generate an output optical light having a plurality of optical wavelengths, wherein the optical wavelengths comprise near infrared or **visible wavelengths**, either literally or under the doctrine of equivalents. For example, the green and red light lie in the visible spectrum of light. Samsung states that "[t]he optimal allocation of **Green, Red,** and Infrared LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	The Visible Light Spectrum **Color** / **Wavelength (nm)** Red — 625 - 740 Orange — 590 - 625 Yellow — 565 - 590 Green — 520 - 565 Cyan — 500 - 520 Blue — 435 - 500 Violet — 380 - 435 Source: https://www.thoughtco.com/the-visible-light-spectrum-2699036
2. The system of claim 1, wherein the plurality of semiconductor sources comprises six light emitting diodes, and wherein the plurality of	The Accused Smartwatch comprises a **plurality of semiconductor sources** which **comprises six light emitting diodes, and wherein the plurality of semiconductor sources and the plurality of spatially separated detectors are located on one or more arcs**, either literally or under the doctrine of equivalents.

'455 Patent Claim	Samsung Accused System[1]
semiconductor sources and the plurality of spatially separated detectors are located on one or more arcs.	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor
3. The system of claim 2, wherein the output optical light comprises	In the Accused System, **the output optical light comprises wavelengths between 600 nm and 1000 nm to measure a level of oxy-hemoglobin and deoxy-hemoglobin**, either literally or under the doctrine of equivalents.

'455 Patent Claim	Samsung Accused System[1]
wavelengths between 600 nm and 1000 nm to measure a level of oxy-hemoglobin and deoxy-hemoglobin.	For example, the output optical light (from the LEDs), for measuring oxy-hemoglobin and deoxy-hemoglobin levels (during SpO_2 measurement/measuring blood oxygen level) includes red and infrared light, which have wavelengths between 600 nm and 1000 nm.  Source: https://developer.samsung.com/conference/sdc22/sessions/expand-health-experiences-with-galaxy-watch

’455 Patent Claim	Samsung Accused System[1]

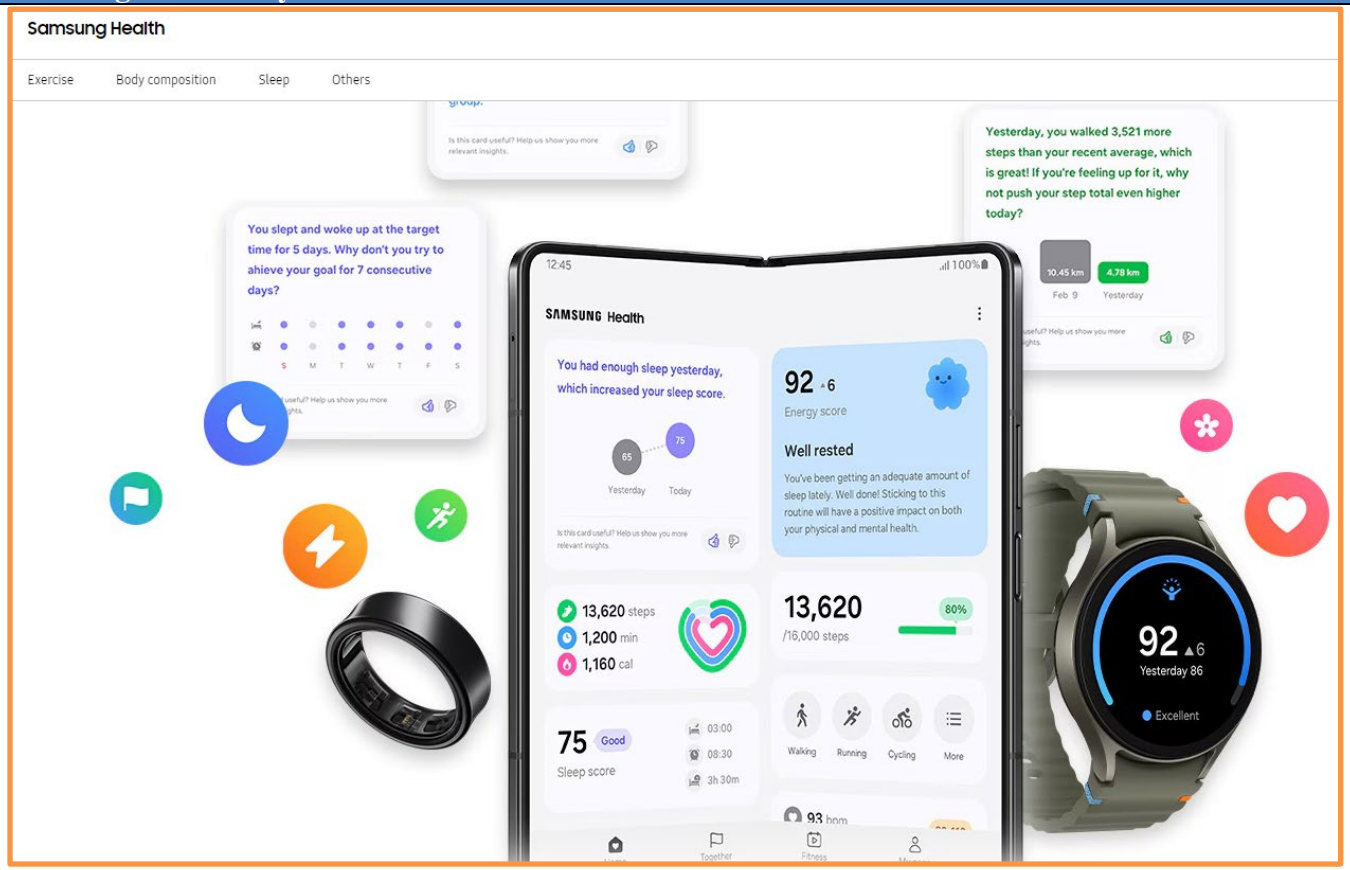
Table 1. LEDs – Wavelengths and Applications

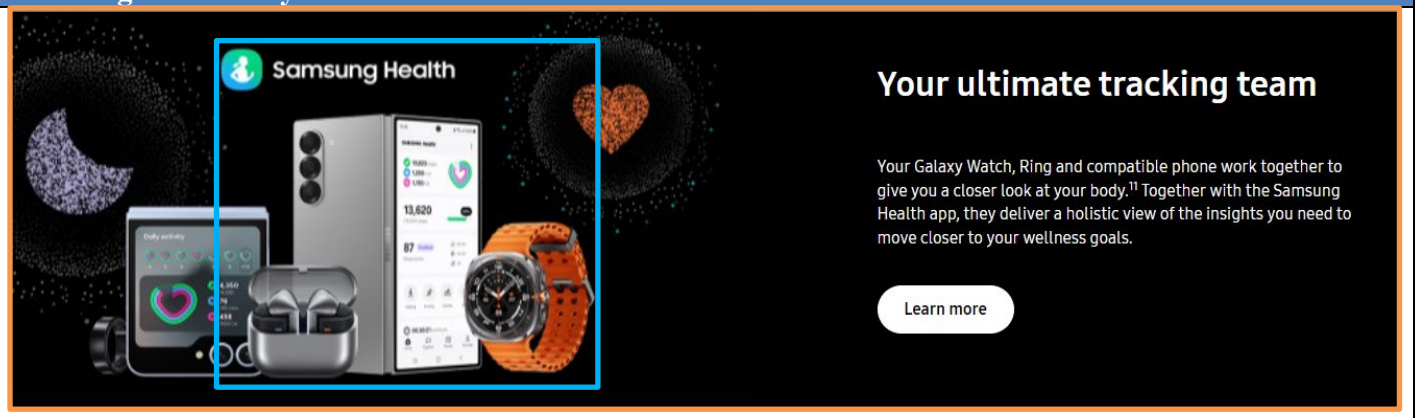
LED Wavelength (Color)	LED Applications
410–420 nm (Violet)	Skin therapy
430–470 nm (Blue)	Dental curing instruments
470 nm (Blue)	White LEDs using phosphor
520–530 nm (Green)	Green traffic signal lights
580–590 nm (Amber)	Amber traffic signal lights
630–640 nm (Red)	Red signal lights
660 nm (Deep Red)	Blood oximetry
680 nm (Deep Red)	Blood analysis
800–850 nm (Near-IR)	Night-vision illuminators and beacons for use with night-vision goggles or CCDs
850–940 nm (Near-IR)	Photoelectric controls
940 nm (Near-IR)	Covert illumination CCD-based systems

Source: https://www.photonics.com/Articles/Light-Emitting_Diodes_A_Primer/a36706

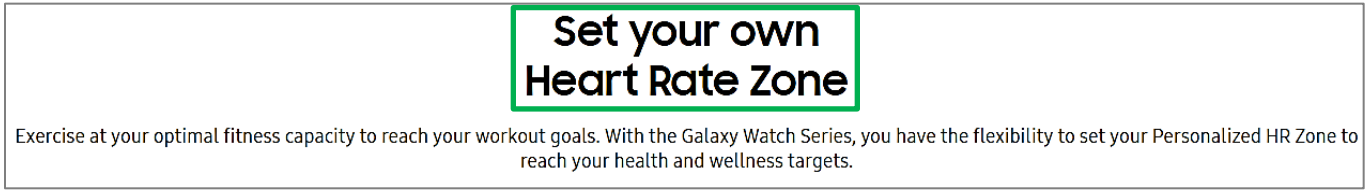
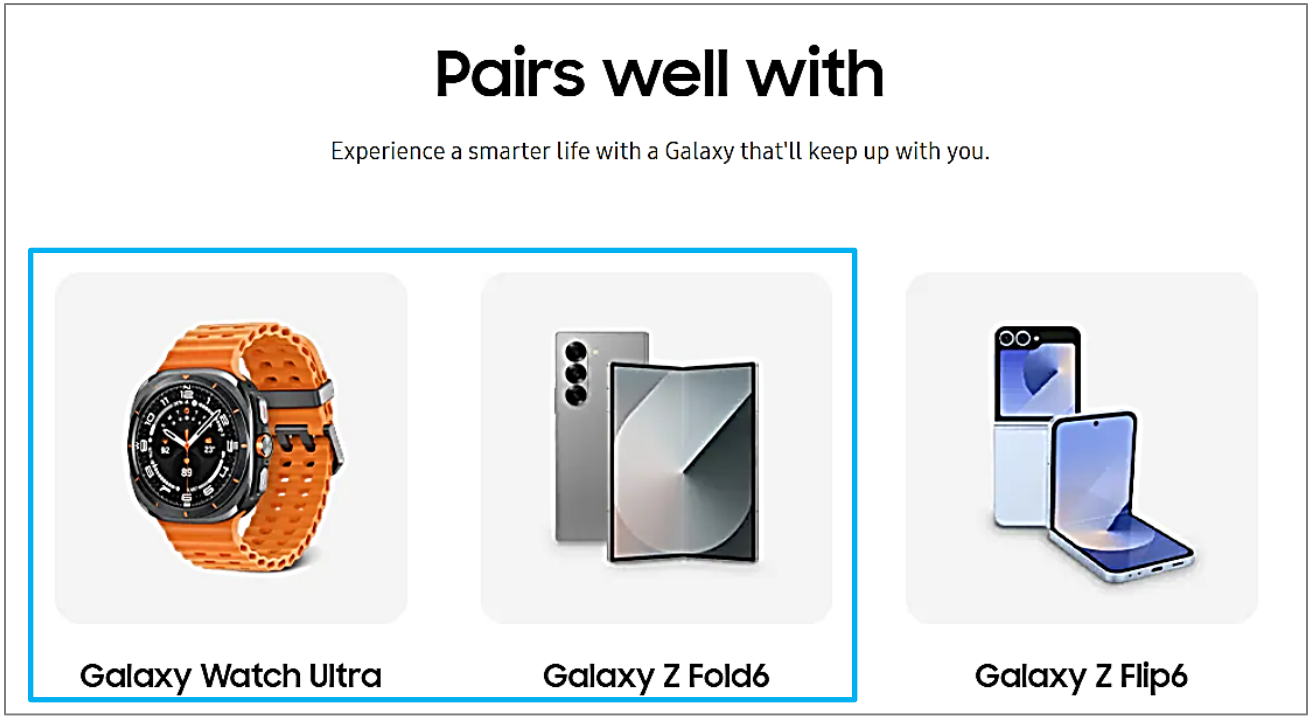
“Infrared radiation (IR), also known as thermal radiation, is that band in the electromagnetic radiation spectrum with **wavelengths above red visible light between 780 nm and 1 mm.”**
Source: https://www.icnirp.org/en/frequencies/infrared/index.html

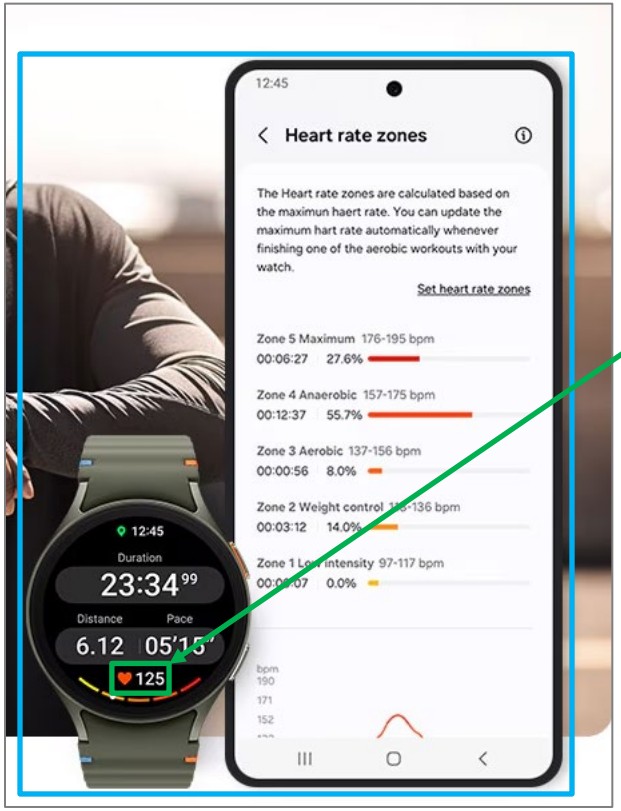
'455 Patent Claim	Samsung Accused System[1]
8[Pre]. A system for measuring one or more physiological parameters and for use with a smart phone or tablet, the system comprising:	Without conceding that the preamble of Claim 8 is limiting, Samsung has made, used, offered to sell, sold in the United States, and/or has imported into the United States, and/or, continues to make, use, offer to sell, and sell within the United States, and/or import into the United States, Accused Systems for measuring one or more physiological parameters and for use with a smart phone or tablet, either literally or under the doctrine of equivalents. For example, Samsung provides a system, including a Galaxy Watch Ultra, a Samsung smartphone or tablet, and Samsung Cloud ("system") for measuring "one or more physiological parameters" of a user, such as heart rate, blood oxygen level, and electrocardiogram. When the user wears a Galaxy Watch Ultra on their wrist, the watch measures physiological parameters using various hardware components, such as Samsung's "BioActive sensor," and transfers the information related to these parameters to an Accused Phone/Tablet and to the Accused Cloud.

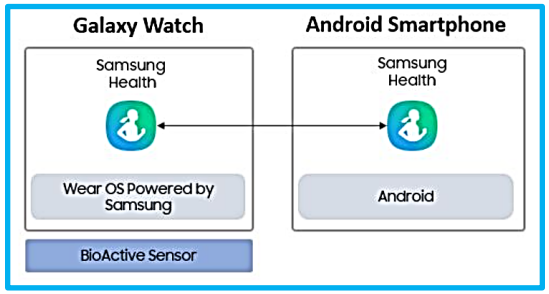
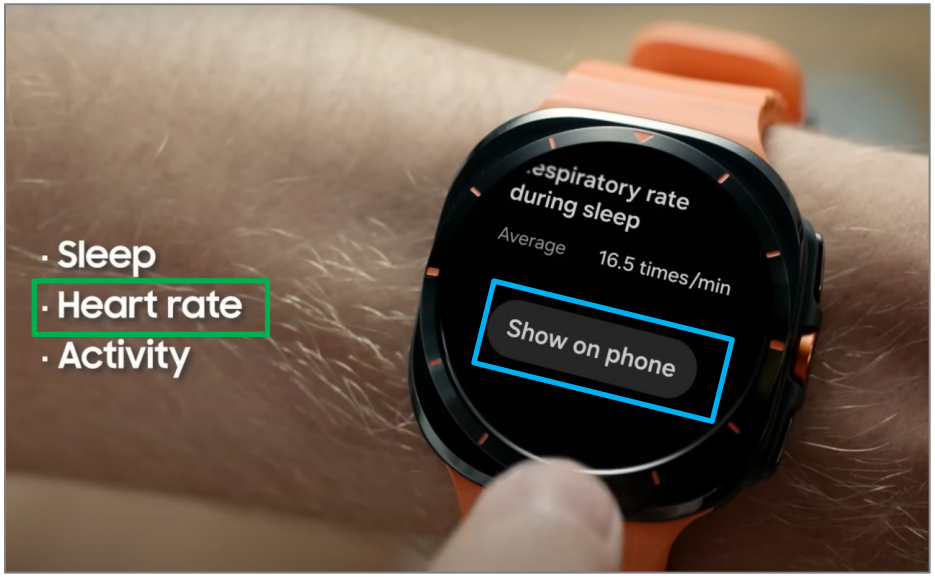
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

'455 Patent Claim	Samsung Accused System[1]
	 **More precise Heart Rate Tracking** Zero in on more precise readings during workouts using Heart Rate Tracking[3, 4, 5] with Galaxy AI[2] that filters out the physical movements of your body. Insights are collected by your Watch and analyzed on your phone. Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/buy/galaxy-watch-ultra-47mm-titanium-gray-sm-l705udaaxaa/

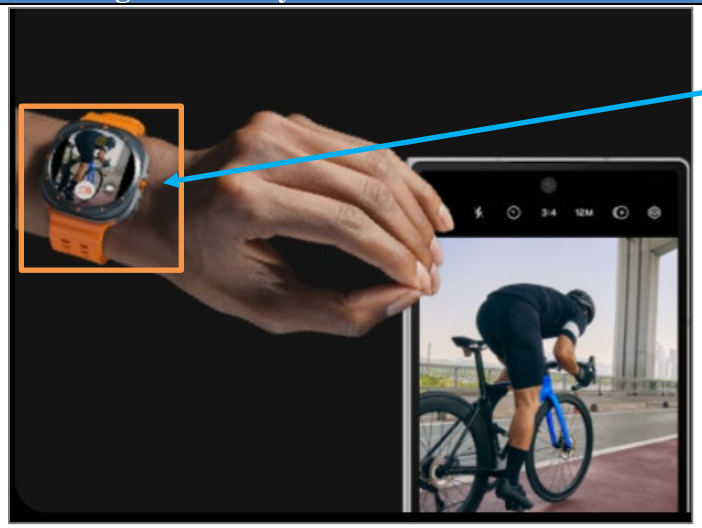
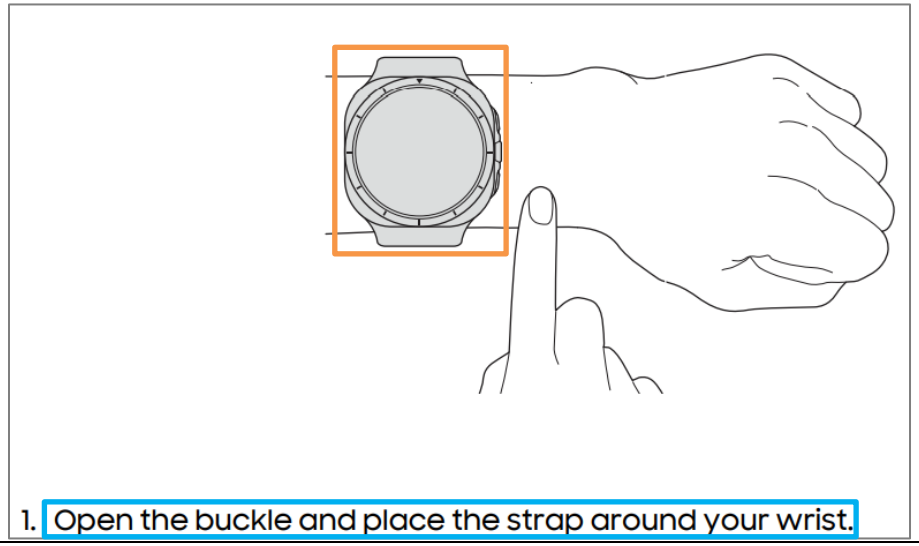
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/#Improve_your_life  Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/#Improve_your_life

'455 Patent Claim	Samsung Accused System[1]
	The Samsung Health application is installed on both the Galaxy Watch and a smartphone. The application synchronizes the measurements between both devices and manages the user's health data securely on them.  Figure 1: Samsung Health on Galaxy Watch and Android smartphone Source: https://developer.samsung.com/health/blog/en/health/blog/accessing-samsung-health-data-through-health-connect 

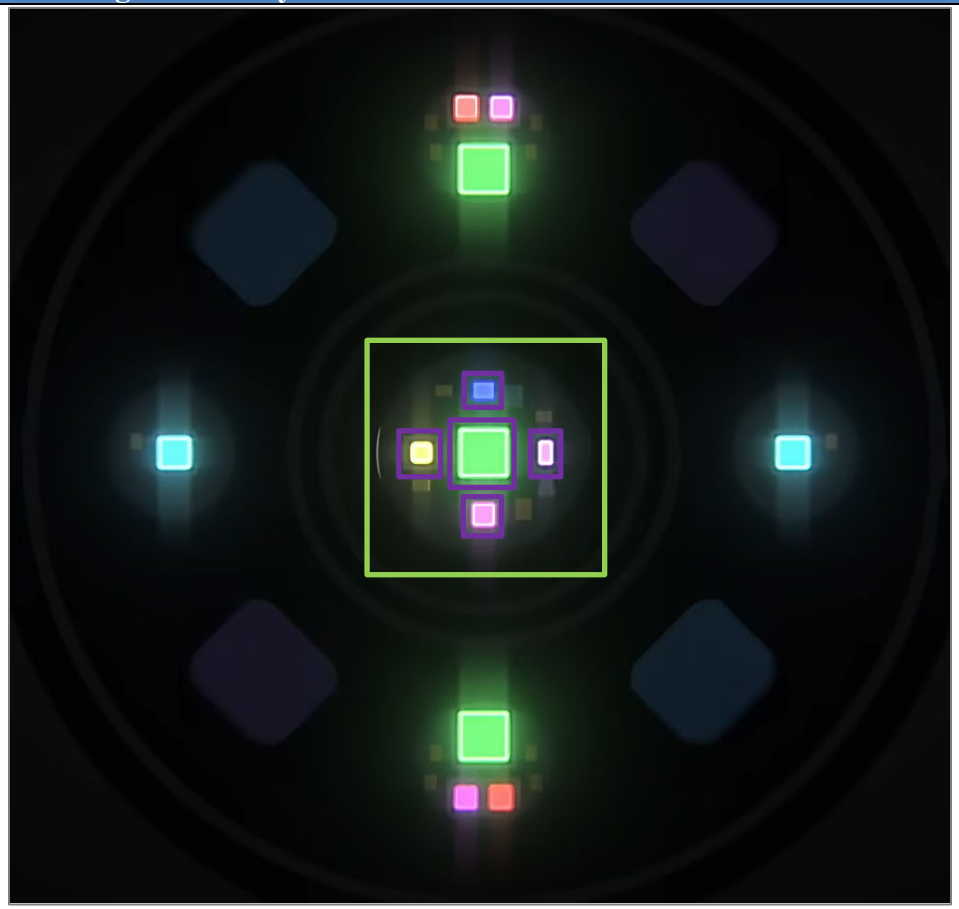
’455 Patent Claim	Samsung Accused System[1]
	Source: https://www.youtube.com/watch?v=VQW-ZpdAm5M  Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/
8[a] a wearable device adapted to be placed on a wrist or an ear of a user, including a light source comprising a driver and a plurality	The Accused System comprises a wearable device adapted to be placed on a wrist or an ear of a user, including a light source comprising a driver and a plurality of semiconductor sources that are light emitting diodes, the light emitting diodes configured to generate an output optical light having one or more optical wavelengths, either literally or under the doctrine of equivalents. For example, the Accused Smartwatch (“wearable device”) is worn on the wrist of the user.

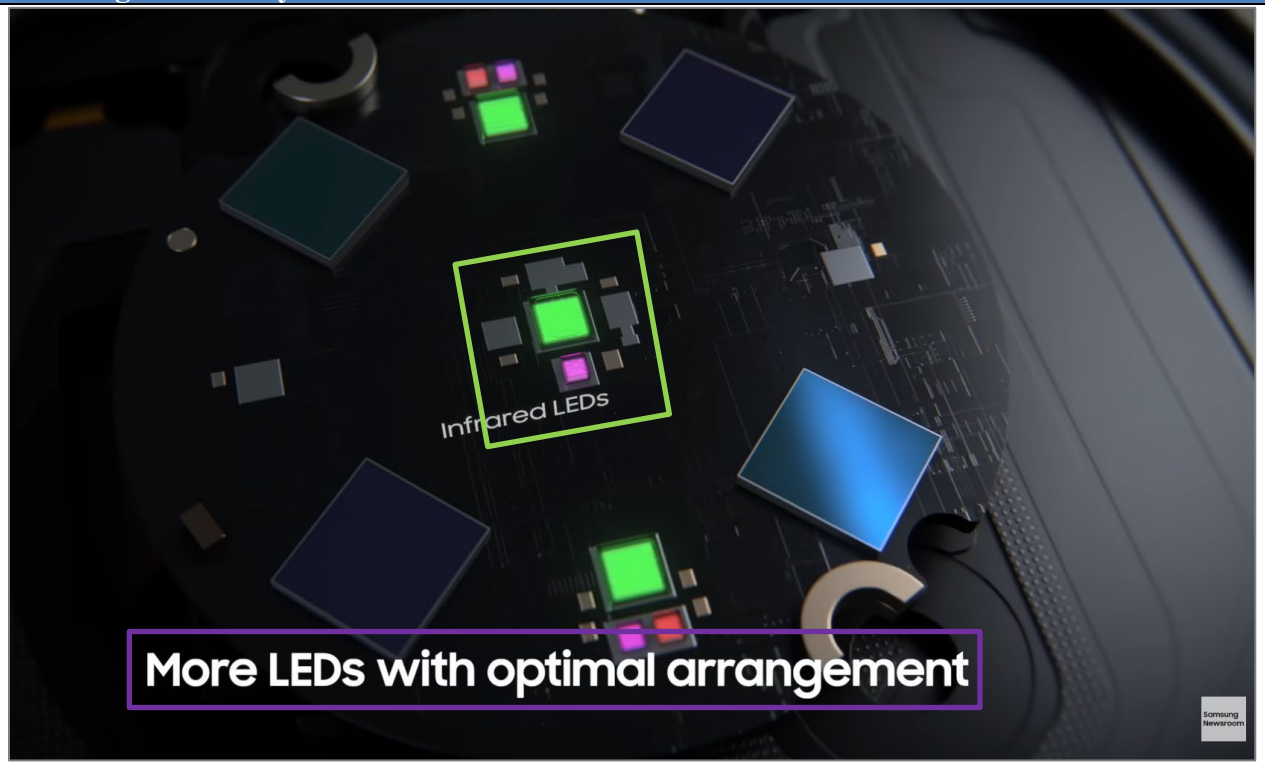
’455 Patent Claim	Samsung Accused System[1]
of semiconductor sources that are light emitting diodes, the light emitting diodes configured to generate an output optical light having one or more optical wavelengths;	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/buy/galaxy-watch-ultra-47mm-titanium-gray-sm-l705udaaxaa/

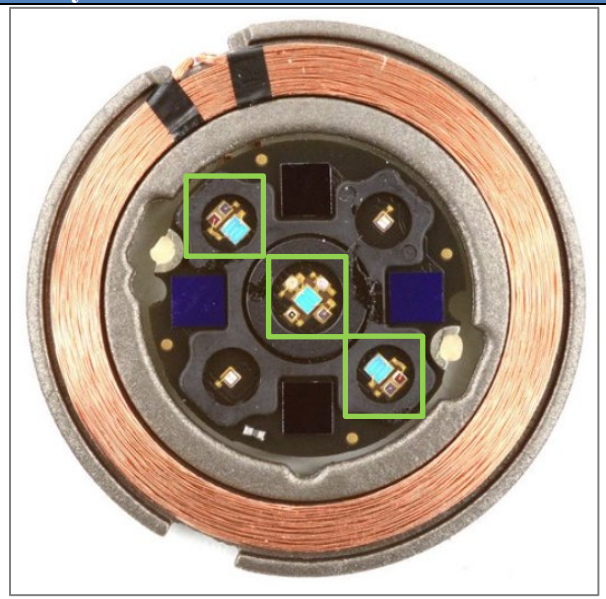
’455 Patent Claim	Samsung Accused System[1]
	 Accused Smartwatch is adapted to be placed on a wrist of a user. Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/  1. Open the buckle and place the strap around your wrist.

'455 Patent Claim	Samsung Accused System[1]
	Source: Samsung Galaxy Watch7 | Watch Ultra User Guide at p. 10, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240717003704208/WEA_L30X_L31X_L70X_EN_UG_XF3_070324_FINAL.pdf. The Accused Smartwatch includes a light source comprising multiple light emitting diodes ("LEDs"), such as a green LED, a red LED, and an infrared LED, each of which includes a "semiconductor source." Samsung states, for example, that its "BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of light-receiving photodiodes, **adding additional colors of light-emitting diodes (LEDs)** and arranging them optimally across the sensor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor Samsung further states that "[**t]he optimal allocation of Green, Red and Infrared LEDs** sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

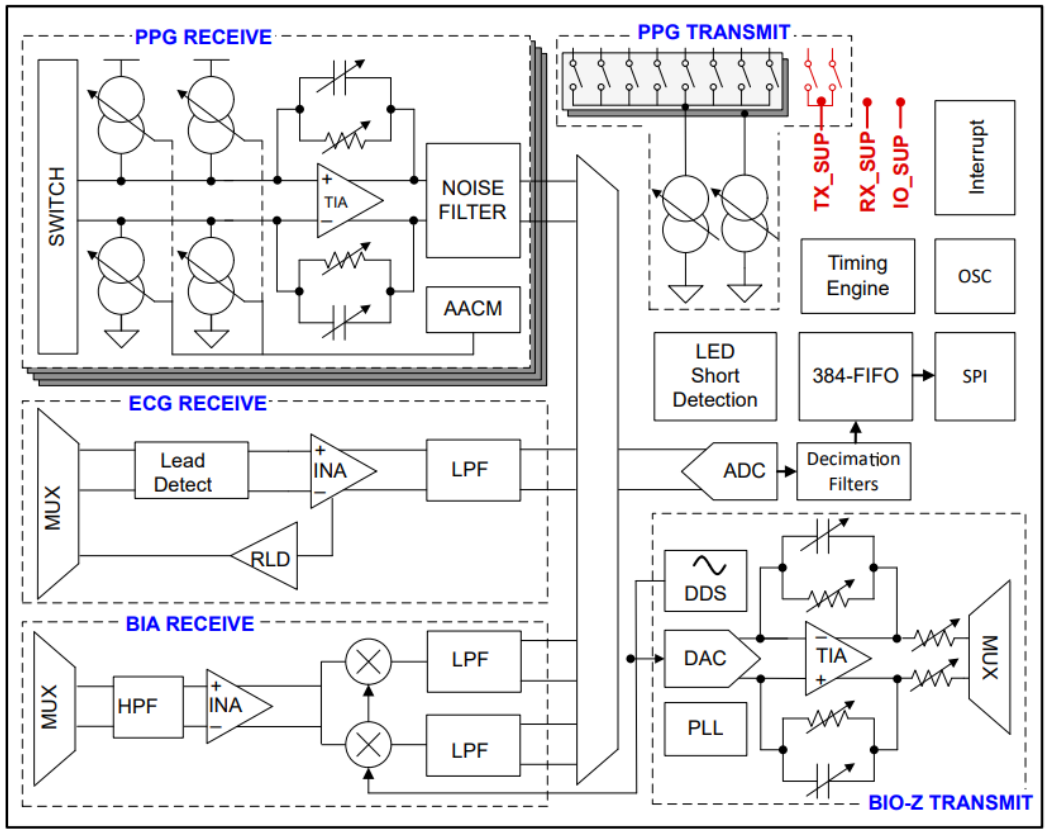
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

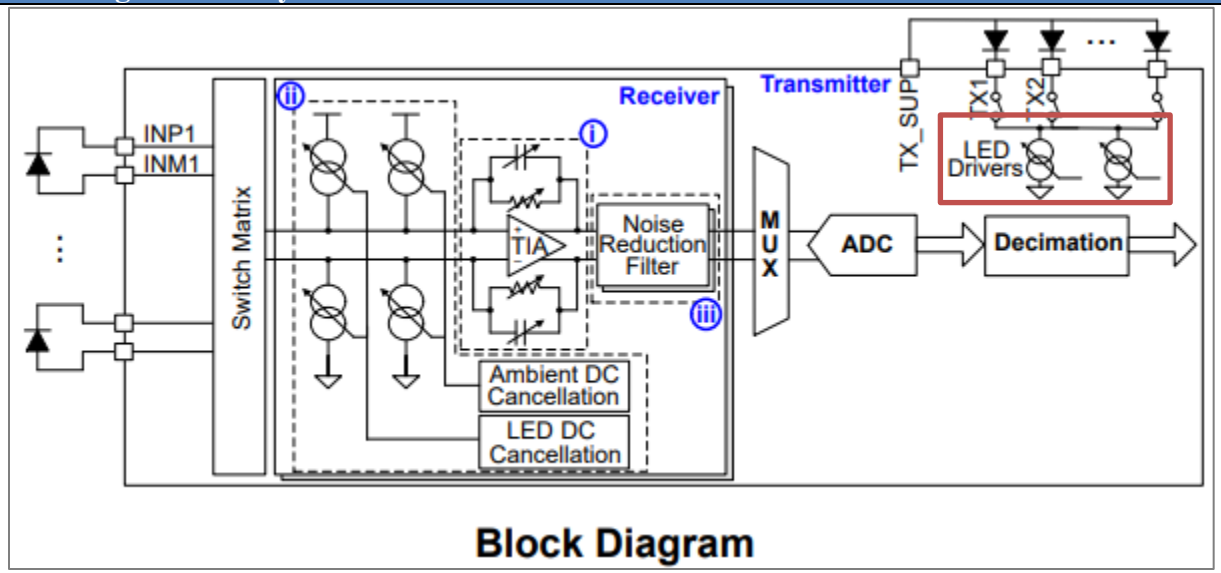
’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 “The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. A PPG signal chain comprises **a current driver for LEDs** and a receiver that senses the signal from PDs. An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.” Texas Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]

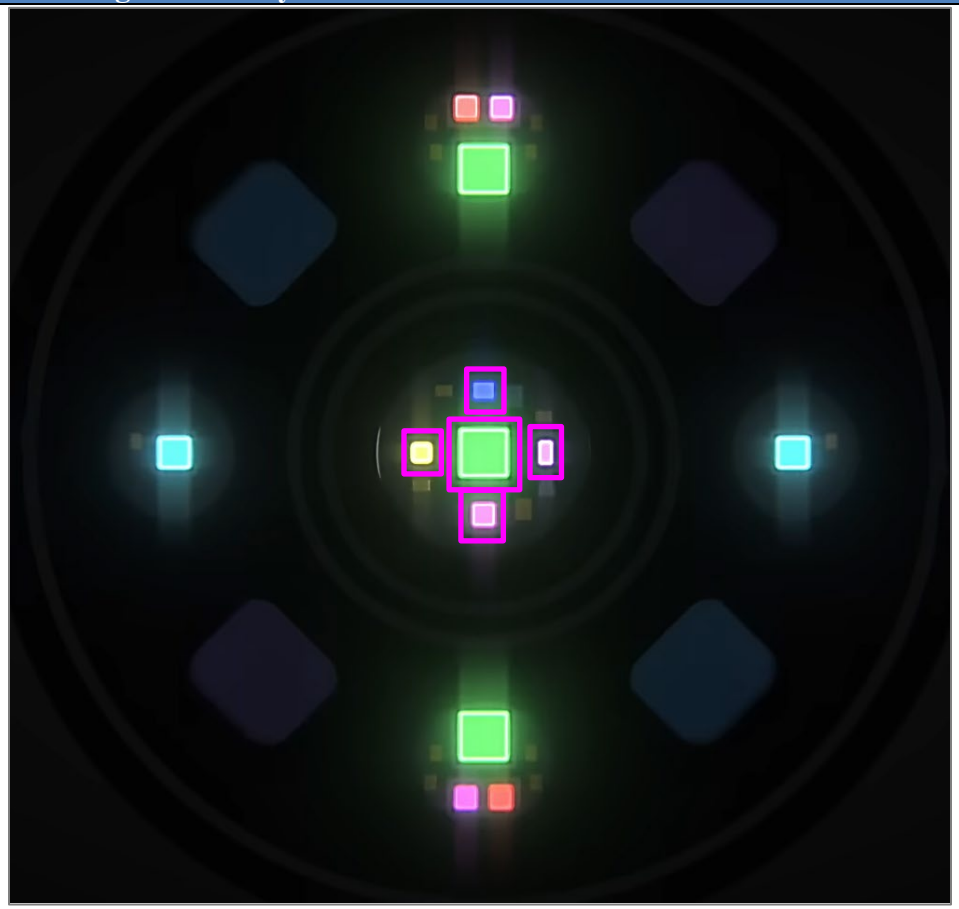


Simplified Schematic

Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

'455 Patent Claim	Samsung Accused System[1]
	 Source: Texas Instruments, Product Overview, "Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing," Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F. For example, the Accused Smartwatch includes multiple LEDs ("semiconductor sources"), such as a green LED, a red LED, and an infrared LED. Different color LEDs and infrared LEDs each generate output optical light having different optical wavelengths. Samsung states that "[t]he optimal allocation of **Green, Red and Infrared** LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of

’455 Patent Claim	Samsung Accused System[1]
	heart rate during intensive workouts is 30% more accurate compared to its predecessor.” Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor The following data types are supported by the Samsung Privileged Health SDK: **PPG green** — Raw data from PPG green LED. Provided as a batching event. **PPG IR** — Raw data from PPG infrared LED. Provided as an on-demand event. **PPG red** — Raw data from PPG red LED. Provided as an on-demand event. Source: Samsung Developer, Samsung Privileged Health SDK, *available at* https://developer.samsung.com/health/privileged/overview.html

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327

<table>
<tr><th>’455 Patent Claim</th><th>Samsung Accused System[1]</th></tr>
<tr><td></td><td>LEDs outputting light at different colors do so at different optical wavelengths. For example, a green LED, a red LED, and an infrared LED all output light at different optical wavelengths:

<table>
<tr><th colspan="2">Table 1. LEDs – Wavelengths and Applications</th></tr>
<tr><th>LED Wavelength (Color)</th><th>LED Applications</th></tr>
<tr><td>410–420 nm (Violet)</td><td>Skin therapy</td></tr>
<tr><td>430–470 nm (Blue)</td><td>Dental curing instruments</td></tr>
<tr><td>470 nm (Blue)</td><td>White LEDs using phosphor</td></tr>
<tr><td>520–530 nm (Green)</td><td>Green traffic signal lights</td></tr>
<tr><td>580–590 nm (Amber)</td><td>Amber traffic signal lights</td></tr>
<tr><td>630–640 nm (Red)</td><td>Red signal lights</td></tr>
<tr><td>660 nm (Deep Red)</td><td>Blood oximetry</td></tr>
<tr><td>680 nm (Deep Red)</td><td>Blood analysis</td></tr>
<tr><td>800–850 nm (Near-IR)</td><td>Night-vision illuminators and beacons for use with night-vision goggles or CCDs</td></tr>
<tr><td>850–940 nm (Near-IR)</td><td>Photoelectric controls</td></tr>
<tr><td>940 nm (Near-IR)</td><td>Covert illumination CCD-based systems</td></tr>
</table>
Source: https://www.photonics.com/Articles/Light-Emitting_Diodes_A_Primer/a36706</td></tr>
<tr><td><u>8[b]</u> the wearable device comprising one or more lenses</td><td>The Accused System comprises wearable device comprising one or more lenses configured to receive at least a portion of the output optical light and to deliver a lens output light to tissue, either literally or under the doctrine of equivalents.</td></tr>
</table>

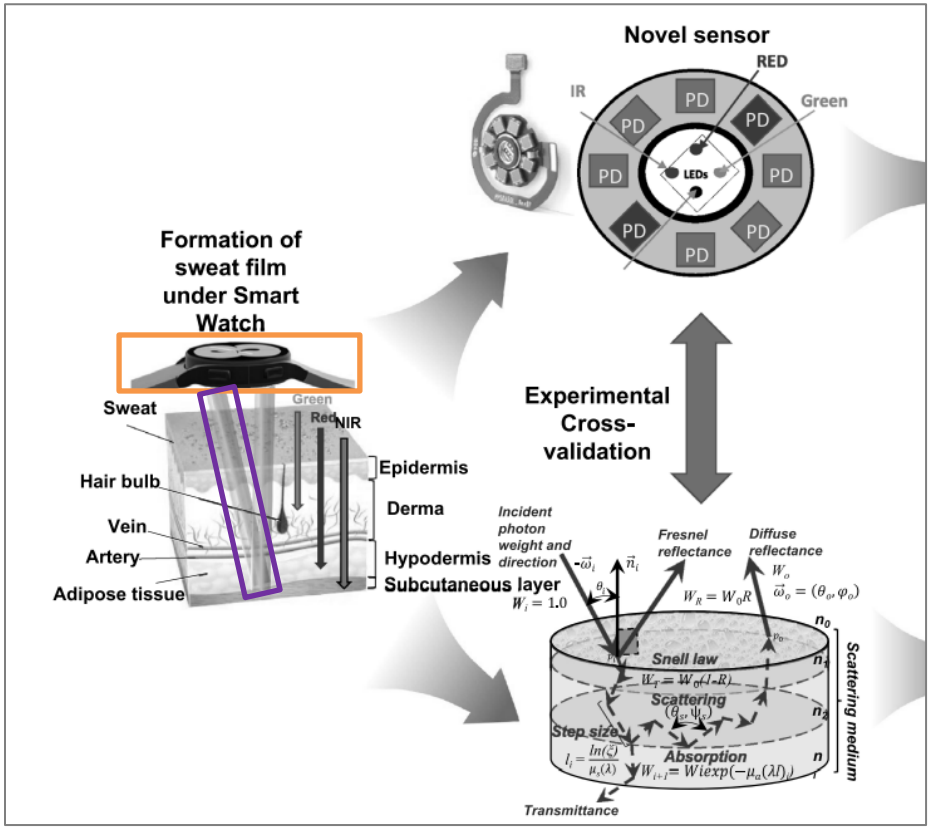
'455 Patent Claim	Samsung Accused System[1]
configured to receive at least a portion of the output optical light and to deliver a lens output light to tissue;	For example, the Accused Smartwatch ("wearable device") comprises one or more lenses positioned between LEDs and the wrist of a user when worn by the user. The lenses receive output optical light from the LEDs and deliver the light to tissue of the user (*e.g.*, skin, blood vessels, veins).  Source: https://www.youtube.com/watch?v=lZ6Q7JqtiA0 Samsung states that "[t]he **Galaxy Watch** uses light sensors that operate within the limits set by the IEC62471 safety regulations. However, **people with photosensitive skin may have adverse reactions to light,** such as skin discoloration or a rash." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor. Thus, the one or more lenses in the Accused Smartwatch delivers light that is output from the LEDs to skin of the user ("lens output light to tissue").

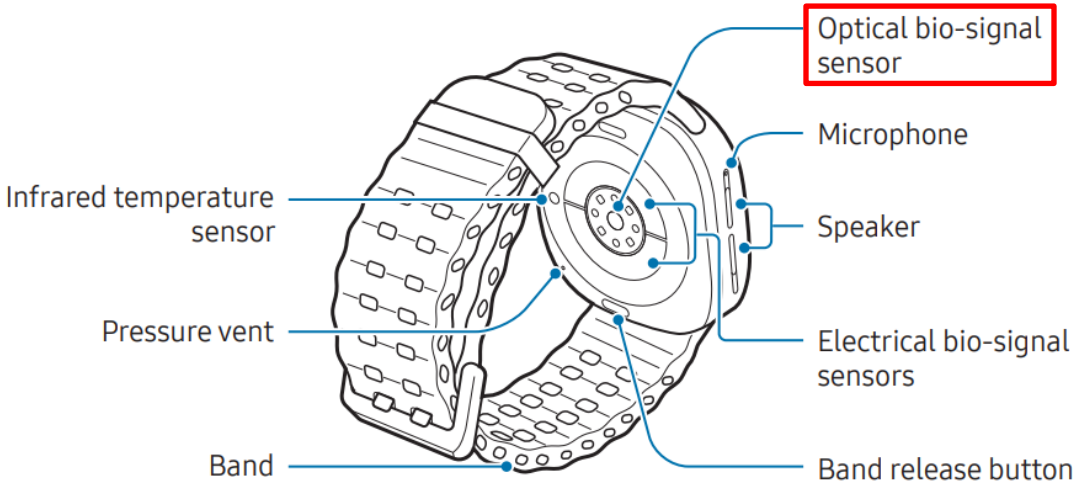
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=lZ6Q7JqtiA0 

'455 Patent Claim	Samsung Accused System[1]
	Source: https://www.youtube.com/watch?v=jlW0i7u4FVk Additionally, in a technical paper, Samsung engineers and pixel designers for photoplethysmography ("PPG") sensors explained "**applying micro lenses**" and using "**micro lens** focusing" techniques to enhance the delivery of infrared ("IR") light sources. J. Lim et al., "A single chip PPG sensor with enhanced IR sensitivity for low power and small size," 2021 IS&T Int'l Symp. Elec. Imaging, at 2-3, *available at* https://library.imaging.org/admin/apis/public/api/ist/website/downloadArticle/ei/33/7/art00002. Samsung's Galaxy Watch7 and Watch Ultra user guide also states the following: "The accuracy of the information and data provided by this device and its related software, including heart rate readings, may be affected by factors such as environmental conditions, **skin condition**, specific activity performed while using/wearing the device, settings of the device, user configuration/user-provided information, **placement of the sensor on the body**, and other end-user interactions." Samsung Galaxy Watch7 | Watch Ultra User Guide, at p. 42, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240717003704208/WEA_L30X_L31X_L70X_EN_UG_XF3_070324_FINAL.pdf. The Accused Smartwatch ("wearable device") utilizes a biosensor manufactured by Texas Instruments ("TI")—*e.g.*, an analog front end ("AFE") integrated circuit component for PPG, electrocardiography ("ECG") and other biosensing applications.

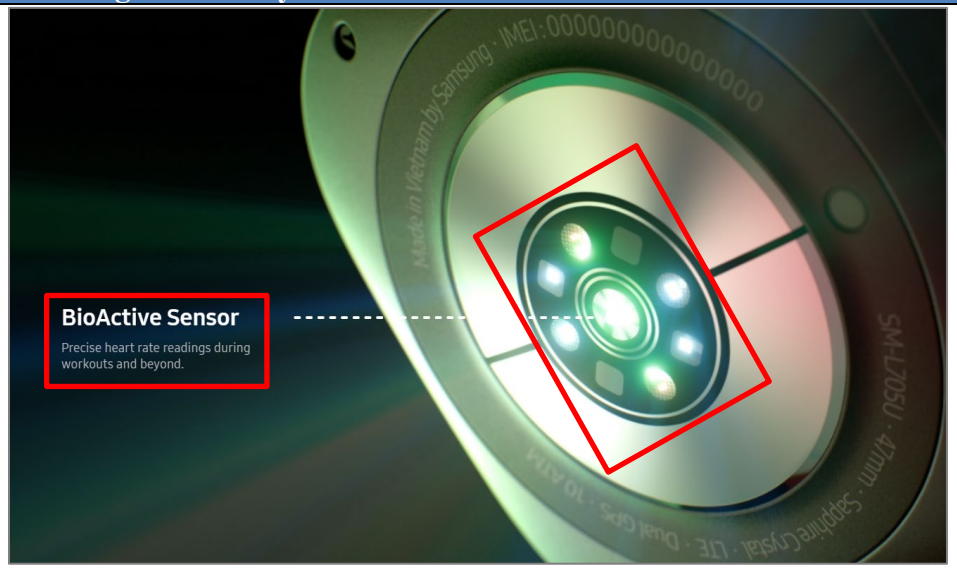
’455 Patent Claim	Samsung Accused System[1]
	Step 6 Bio Sensor Assembly   • Texas Instruments AFE4510 biosensing analog front-end Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw. Such AFEs from TI include AFE44S30, AFE4432, AFE44I30, AFE4460, AFE49I30, AFE4950, AFE4500. *See* Texas Instruments, Biosensing AFEs, https://www.ti.com/data-converters/integrated-special-function/medical-afes/biosensing-afes/overview.html. TI’s AFEs enable wearable devices to perform multiple optical biosensing applications. For example, TI explains in a technical paper:

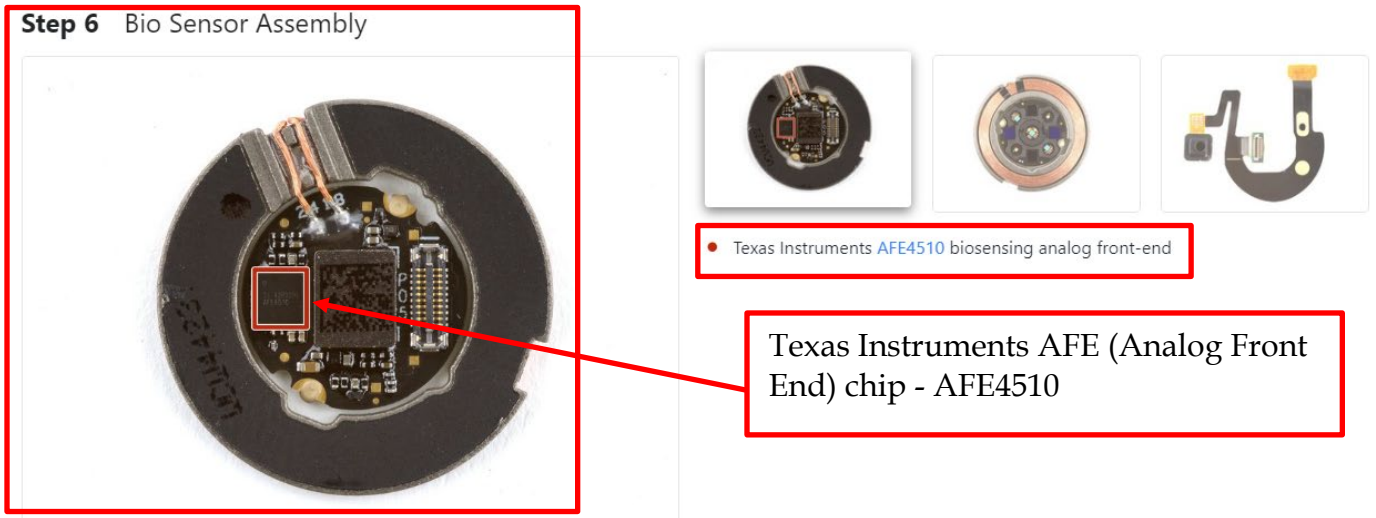
'455 Patent Claim	Samsung Accused System[1]
	Application *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR). In a device like a smartwatch, the LED and PD both face the wrist. The light from the LED is incident on the skin, and the reflection of the light from the artery results in a pulsating component. Typically, green LEDs are used, and the signal from multiple spatially-separated PDs are combined to mitigate effects such as motion. Texas Instruments, Application Brief, "Optical Heart Rate Monitoring (OHRM) on Wearables," SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

’455 Patent Claim	Samsung Accused System[1]
	Additionally, the following scientific report authored by multiple Samsung engineers further shows lens output light being delivered to tissue of the user:  Source: E. Volkova et al., “Multispectral sensor fusion in SmartWatch for in situ continuous monitoring of human skin hydration and body sweat loss,” Scientific Reports (2023), at 3, *available at* https://www.nature.com/articles/s41598-023-40339-7.pdf.

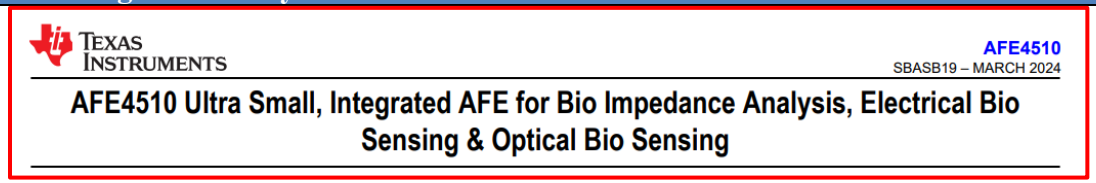
'455 Patent Claim	Samsung Accused System[1]
8[c] the wearable device further comprising a detection system configured to receive at least a portion of the lens output light reflected from the tissue and to generate an output signal having a signal-to-noise ratio,	The **wearable device** of the Accused System further comprises **a detection system configured to receive at least a portion of the lens output light reflected from the tissue and to generate an output signal having a signal-to-noise ratio**, literally or under the doctrine of equivalents. For example, the BioActive Sensor in the Accused Smartwatch ("wearable device") comprises a detection system that: (a) receives light initially output from LEDs and then reflected from tissue of a user, and (b) generates an output PPG signal having a signal-to-noise ratio.  Source: Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 8, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf; *see also* Samsung Developer, Samsung Privileged Health SDK, *available at* https://developer.samsung.com/health/privileged/overview.html.

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 The AFE4510 specification (excerpts shown below) describes a PPG signal receiver, a PPG signal transmitter, and PPG signal acquisition functionality for receiving light output by LEDs that is reflected from skin and body tissue of the user (*e.g.*, by photodiodes (“PDs”)), and for converting the received light into—*i.e.*, generating—a PPG output signal having some signal-to-noise ratio (“SNR”).

’455 Patent Claim	Samsung Accused System[1]



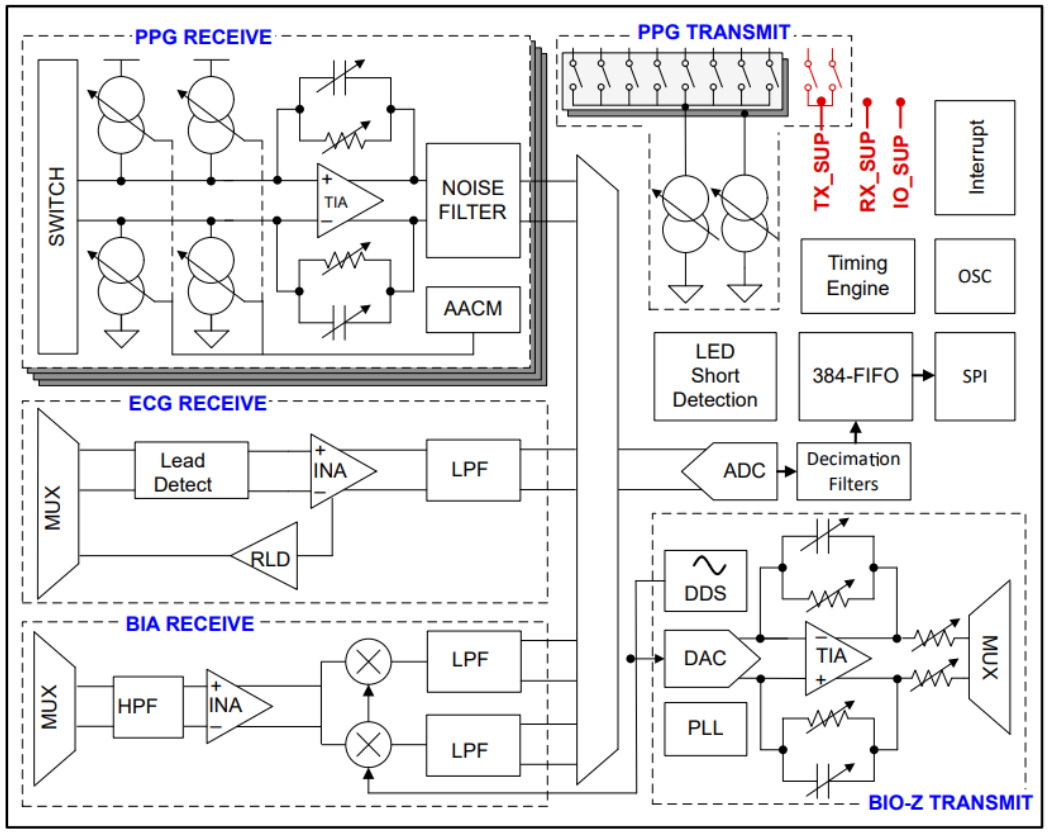
TEXAS INSTRUMENTS

AFE4510
SBASB19 – MARCH 2024

AFE4510 Ultra Small, Integrated AFE for Bio Impedance Analysis, Electrical Bio Sensing & Optical Bio Sensing

- **PPG signal acquisition:**
  - Acquisition of 24 PPG signal sets (LED, AMB)
  - Supports PPG sensors at different data rates
  - Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement
  - Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver
- **PPG Transmitter:**
  - 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA
  - LED Short Detection
  - Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy
- **PPG Receiver:**
  - Supports 5 PDs, 4 parallel receive paths
  - Noise filtering with programmable bandwidth
  - Trans-impedance Gain: 3.7kΩ to 1MΩ
  - 8-bit Ambient Offset Subtraction DAC up to 256µA
  - 9-bit LED Offset Subtraction DAC up to 64µA
  - Digital Ambient Subtraction at ADC Output

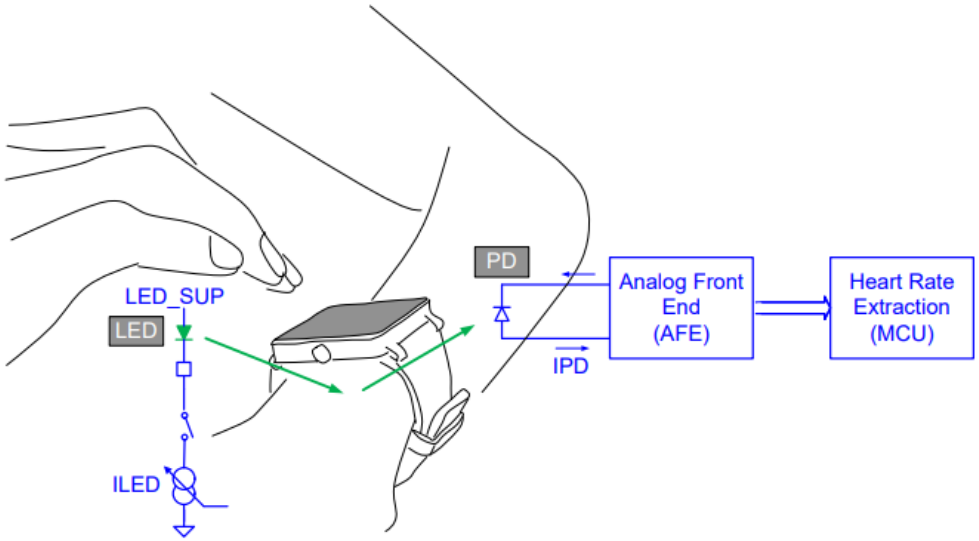
’455 Patent Claim	Samsung Accused System[1]



Simplified Schematic

Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

'455 Patent Claim	Samsung Accused System[1]
	The BioActive Sensor ("detection system") in the Accused Smartwatch is configured to receive lens output light that is reflected from body tissue of the user and to generate and output PPG signal to enable multiple biosensing applications, including optical heart rate monitoring ("OHRM"). For example, TI explains OHRM using its AFE biosensors as follows: *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR). In a device like a smartwatch, the LED and PD both face the wrist. The light from the LED is incident on the skin, and the reflection of the light from the artery results in a pulsating component. Typically, green LEDs are used, and the signal from multiple spatially-separated PDs are combined to mitigate effects such as motion.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 1. Heart Rate Monitoring on a Wearable Device** Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf. An exemplary “PPG signal chain” for a TI AFE biosensor (shown below) further illustrates how the BioActive Sensor (“detection system”) of the Accused Smartwatch is configured to receive a lens output light reflected from tissue of a user and generate a PPG output signal.

’455 Patent Claim	Samsung Accused System[1]

Figure 3 shows the PPG signal chain in AFE4432.

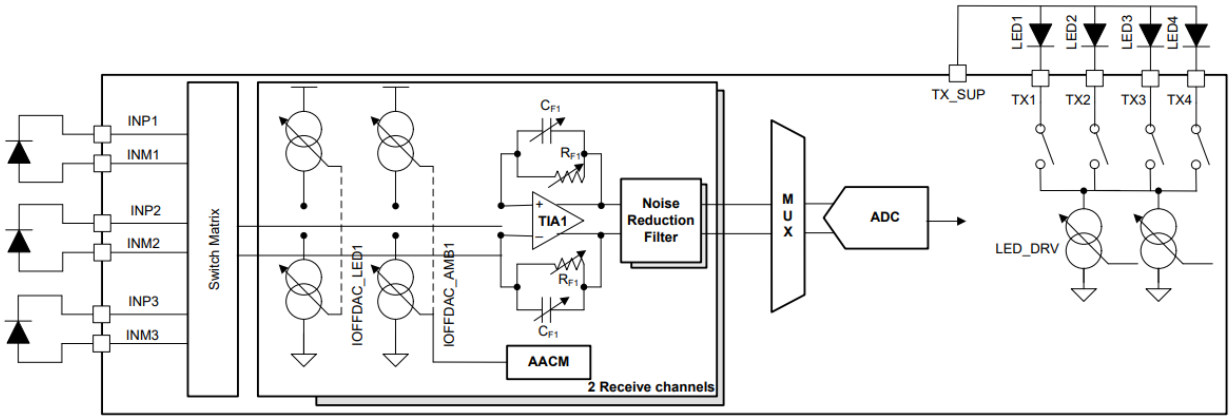


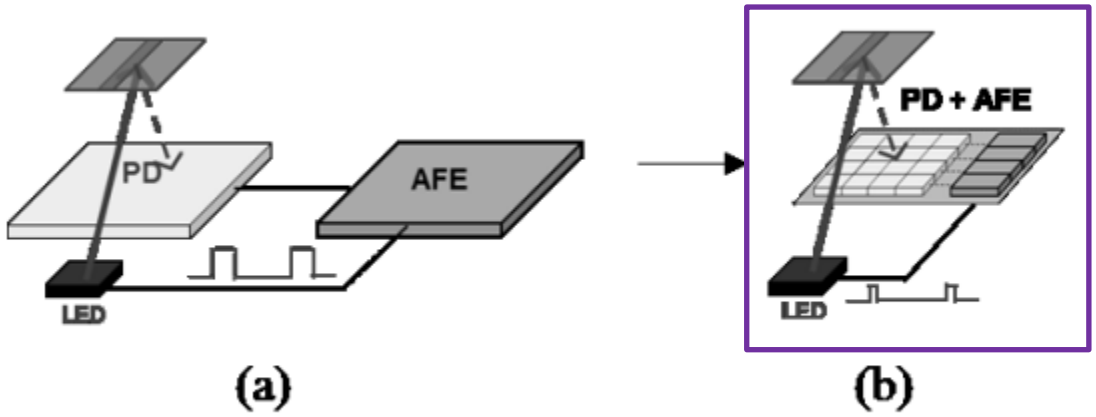
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

Samsung engineers further explain in technical papers a detection system configured to receive light reflected from tissue of a user and to generate an output PPG signal.

For example: “Recently, the technology is migrated to wearable devices such as wrist-worn smart watch or a wireless ear set. Among them, PPG sensor is a health sensor that measures the change in blood flow to be modulated by the heart rate. When a separate light source (LED) is irradiated to the skin, the light absorption by the blood vessel is changed in synchronization with the heart rate. **A sensor measures,**

’455 Patent Claim	Samsung Accused System[1]
	transmitted or **reflected signal** represented in Amplitude Modulation It has been used for a long time as a medical tool to measure oxygen saturation (SpO2) in a patient's finger in an emergency status [1]. For the use of PPG sensors as various health care products, features of low power and smaller size are essentially required.”  *Figure 1. (a) Separated chip PPG sensor and (b) Single chip PPG sensor* Source: J. Lim et al., “A single chip PPG sensor with enhanced IR sensitivity for low power and small size,” 2021 IS&T Int’l Symp. Elec. Imaging, at 2-3, *available at* https://library.imaging.org/admin/apis/public/api/ist/website/downloadArticle/ei/33/7/art00002. For example: “Nowadays, our Smart watches are equipped with Samsung’s BioActive Sensor which has evolved to become far more advanced and miniature technology and not only able to ‘just’ count HR, steps and calories, but also can monitor sleep, measure blood pressure and more. . . . At present, wearable devices, including smart watches and fitness trackers, routinely monitor/analyze the PPG signal and provide non-invasive information of the aforementioned human health indicators with recent additions of temperature, blood oxygen level (SpO2), etc. monitoring capabilities.”

’455 Patent Claim	Samsung Accused System[1]

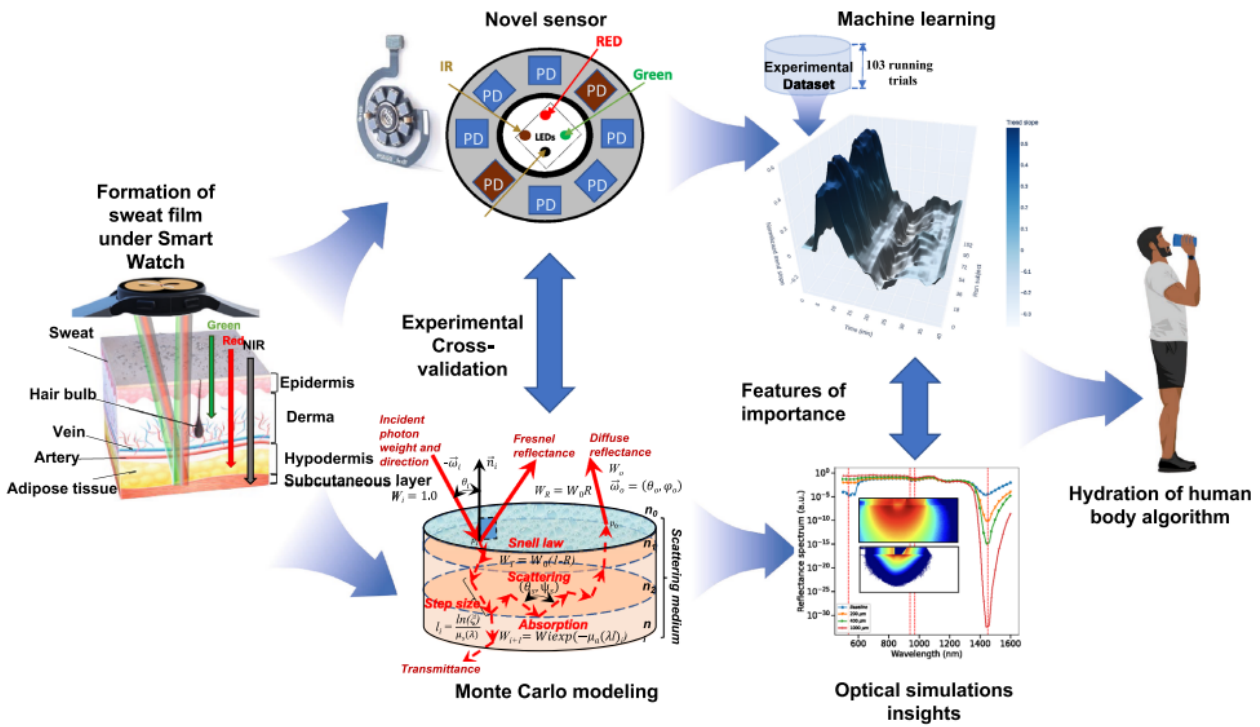
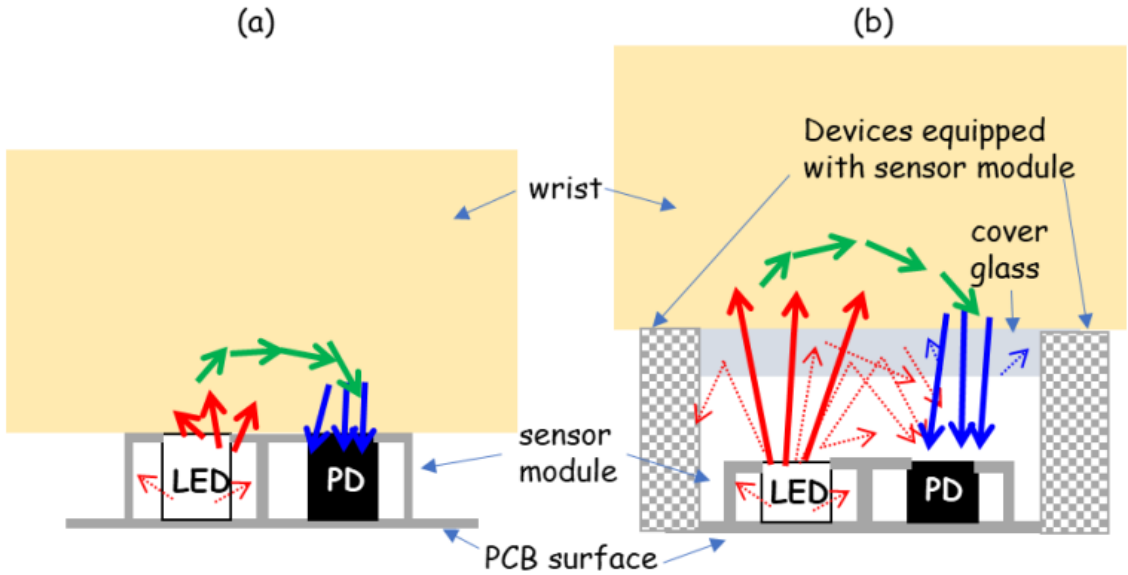
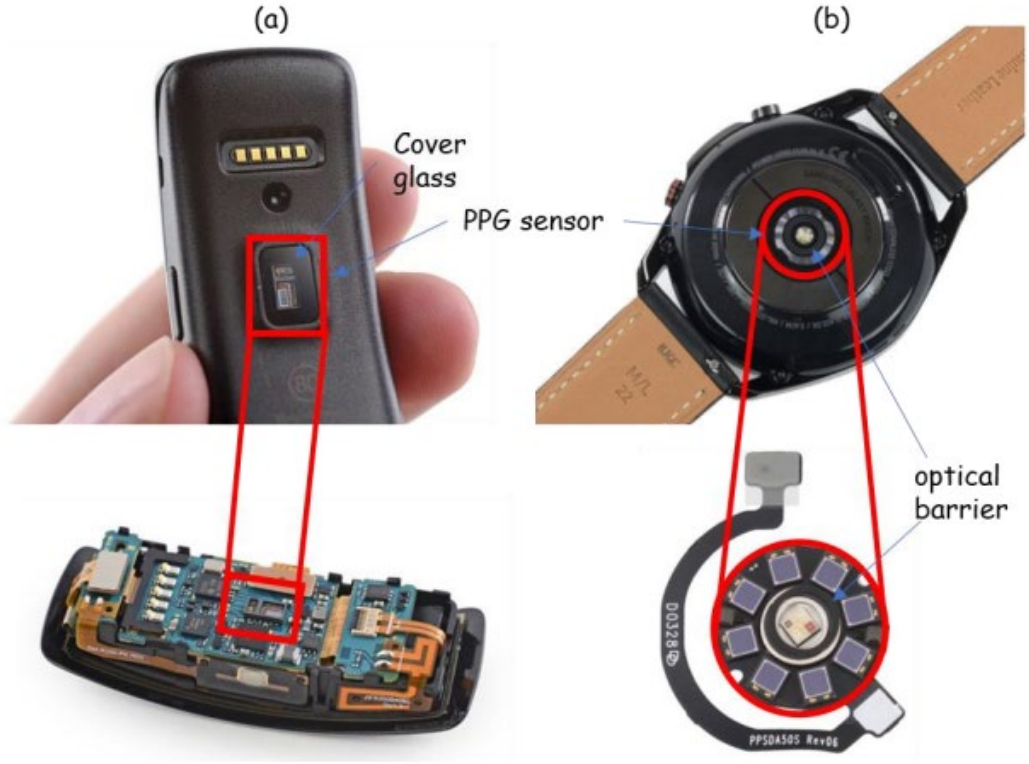


Figure 2. Our capture-to-sensing pipeline. Here: a sweat film is formed under the SmartWatch prototype; Custom-made sensor evaluates change in PPG signal at a range of wavelengths and distances; The trends in the signal are investigated using experimentally validated numerical algorithms of light transport in skin; Particular features of importance due to fluctuations of wet/dry skin optical properties are extracted based on their significance and a ML method is trained to readily detect them; Finally, sweat loss is quantitatively accessed and recommendations to consumer are made.

Source: E. Volkova et al., “Multispectral sensor fusion in SmartWatch for in situ continuous monitoring of human skin hydration and body sweat loss,” Scientific Reports (2023), at 1-3, *available at* https://www.nature.com/articles/s41598-023-40339-7.pdf.

’455 Patent Claim	Samsung Accused System[1]
	The detection system of the Accused Smartwatch has been detailed in other technical documents as well. For example:

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 3.** Conceptual diagram of a PPG sensor module with an embedded LED–PD pair. The diagram illustrates two scenarios: (**a**) when the integrated sensor module is in direct contact with the wrist and (**b**) when the sensor module is embedded in a device and covered with a glass surface. In the diagram, the red solid line represents incident light from the LED entering skin tissue, while the green solid line indicates light causing various reactions inside the tissue. The blue solid line represents light entering the PD from skin tissue and being detected. Additionally, the red dotted line in the diagram illustrates light reflected inside the sensor module that does not enter the skin, some of which directly enters the light-receiving unit. The blue dotted line represents the light that is reflected back by the cover glass among the light entering towards the PD.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 4.** Representative examples of PPG sensor systems applied to commercial wrist-worn wearable devices: (**a**) the Samsung Galaxy Gear Fit, released in 2014, utilizes a sensor module with an embedded LED–PD optopair, and (**b**) the Samsung Galaxy Watch 3, released in 2020, uses separate LEDs and PDs as a sensor. An analog front end (AFE) is employed in both devices to measure the PD output as a PPG signal.

’455 Patent Claim	Samsung Accused System[1]

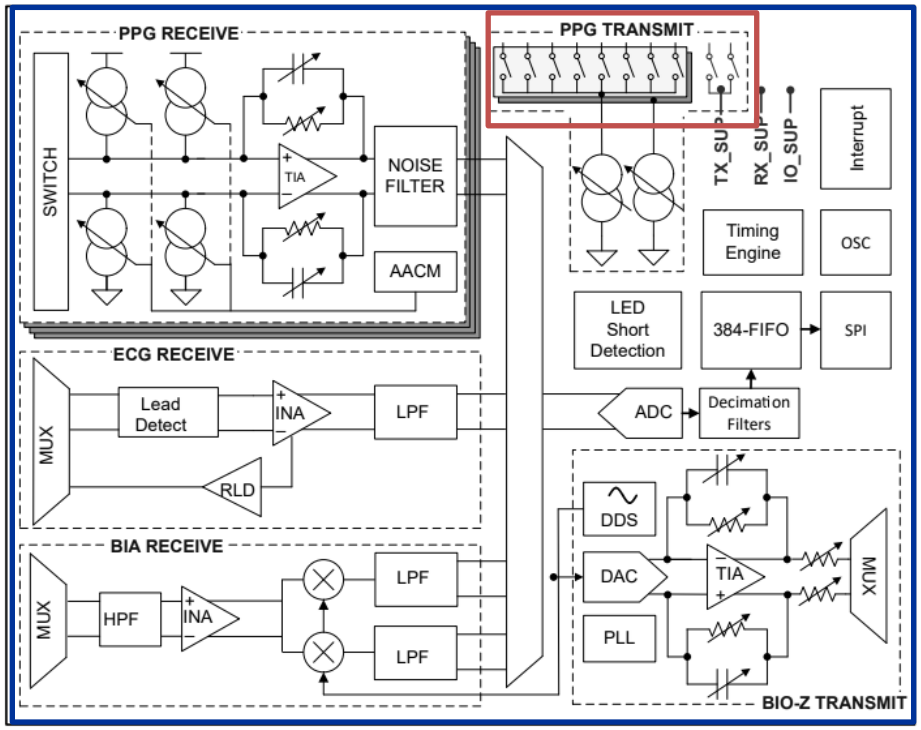


Figure 5. Examples of PPG sensor configurations that use multiple LEDs and PDs, and their application to commercial smartwatches. (**a**–**d**) illustrate different PPG sensor structures, while (**e**) through (**h**) present examples of these structures in use: (**e**) structure (**a**) applied to the Samsung Galaxy Gear s3; (**f**) structure (**d**) applied to the Samsung Galaxy Watch; (**g**) shows the sensor structure of the Garmin Fenix 5 with three LEDs and one PD in the center, and (**h**) shows the sensor structure of the Apple Watch with two LEDs and two PDs.

Source: Kim, K.B. et al., “Photoplethysmography in Wearable Devices: A Comprehensive Review of Technological Advances, Current Challenges, and Future Directions,” Electronics 2023, 12, 2923, at 7-9, *available at* https://www.mdpi.com/2079-9292/12/13/2923.

'455 Patent Claim	Samsung Accused System[1]
8[d] wherein the detection system is configured to be synchronized to the light source;	The **detection system** in the Accused Smartwatch **is configured to be synchronized to the light source**, literally or under the doctrine of equivalents. For example, the BioActive Sensor ("detection system") is connected to the light source containing multiple LEDs. It is configured to synchronize with the light source by controlling the LED current (light intensity) and the pulse rate of the LEDs using LED drivers. To measure heart rate, for example, green LEDs are used with a pre-determined intensity and pulse rate. Different LEDs are used to measure other parameters, such as blood oxygen levels. Green LEDs ("light source") blink when measuring heart rate, and both green and red LEDs ("light source") blink alternately when measuring blood oxygen levels. This, among other evidence below, shows that the BioActive Sensor ("detection system") is synchronized with the light source. The BioActive Sensor in the Accused Smartwatch features a biosensing AFE manufactured by TI (*e.g.*, AFE 4510). The AFE component used in the BioActive Sensor has a detection system that is synchronized to programmable LEDs (light source). **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy

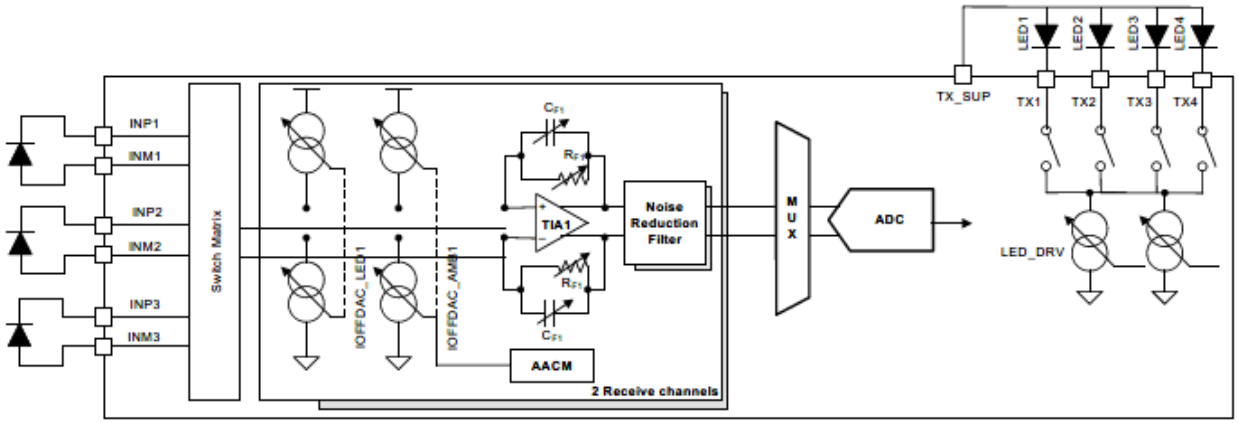
’455 Patent Claim	Samsung Accused System[1]



Simplified Schematic

“**The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. A PPG signal chain comprises a current driver for LEDs** and a receiver that senses the signal from PDs. An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.”

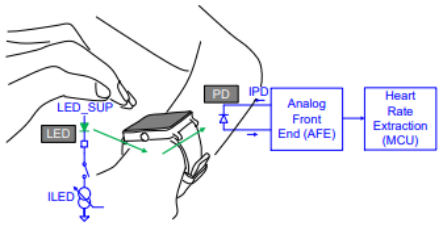
Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 3. PPG Signal Chain in AFE4432** The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices. Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

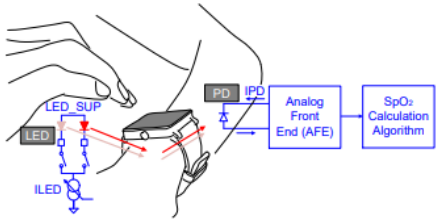
’455 Patent Claim	Samsung Accused System[1]

TEXAS INSTRUMENTS

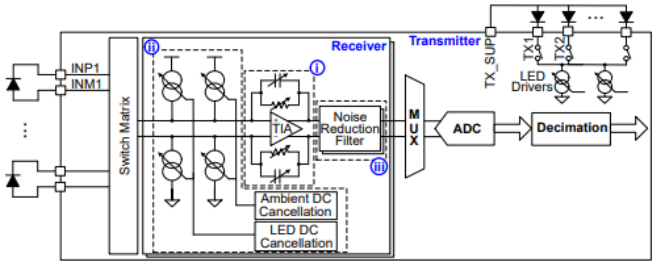
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI's signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.



Heart Rate Monitoring



SpO_2 Monitoring

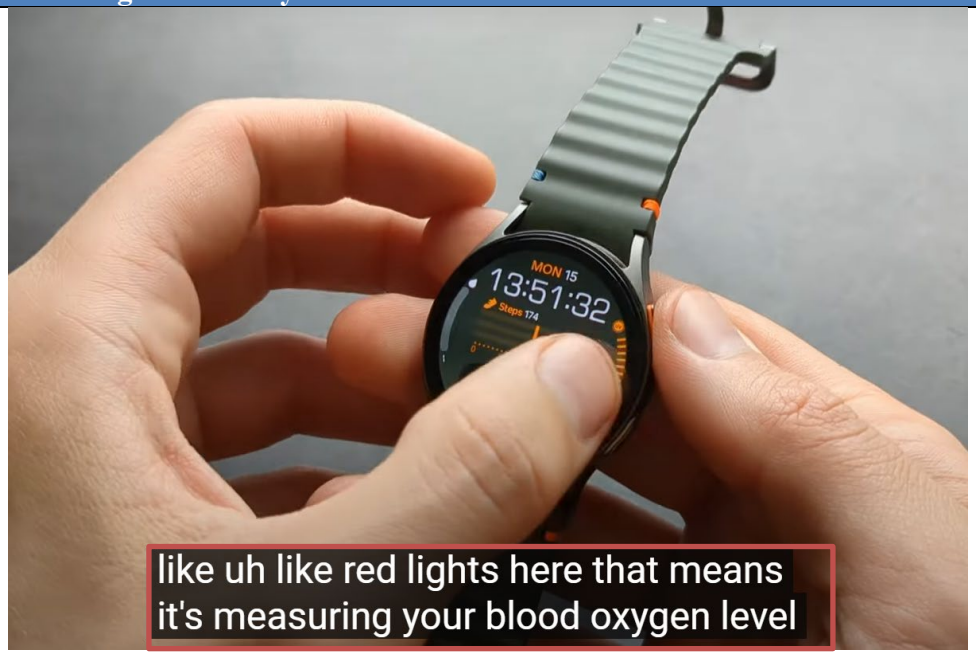


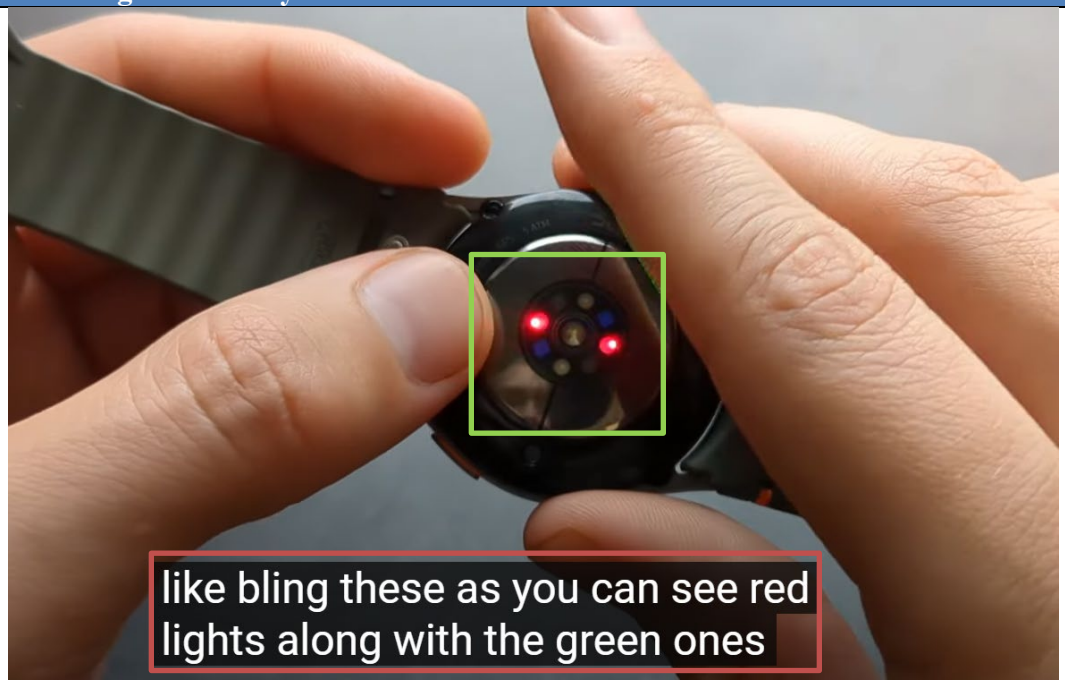
Block Diagram

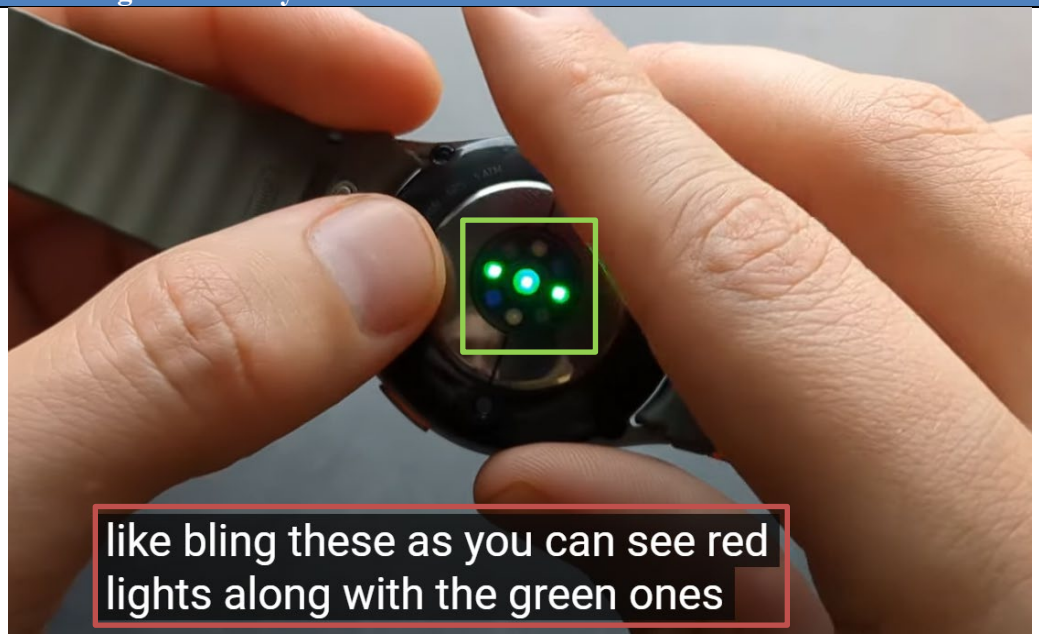
Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

’455 Patent Claim	Samsung Accused System[1]
	“The BioActive sensor has three sensors integrated inside. Apart from body composition, it can measure heart rate, ECG, and blood pressure. . . . It is one of the common uses of the BioActive sensor on your Galaxy Watch. **The sensor relies on built-in green LEDs and infrared lights to calculate heart rate.** These green LEDs are slotted between the BioActive sensor chips.” P. Shah, “What is Samsung BioActive sensor?” Android Police, July 17, 2024, https://www.androidpolice.com/samsung-bioactive-sensor-guide/. “The **diverse colors of LEDs and new photodiodes enable the sensor** to unlock new possibilities in **health monitoring**. One of the new features is the advanced glycation end products (AGEs) index, which is an indicator of metabolic health and biological aging.” “Samsung details BioActive Sensor ahead of Galaxy Unpacked,” fonearena, July 9, 2024, https://www.fonearena.com/blog/428320/samsung-bioactive-sensor-galaxy-unpacked-2024.html. A product video further explains functionalities of the light source (LEDs) and detection system, including how the detection system is configured to synchronize to differing flashing LED colors on the Accused Smartwatch to facilitate calculating different physiological parameters.

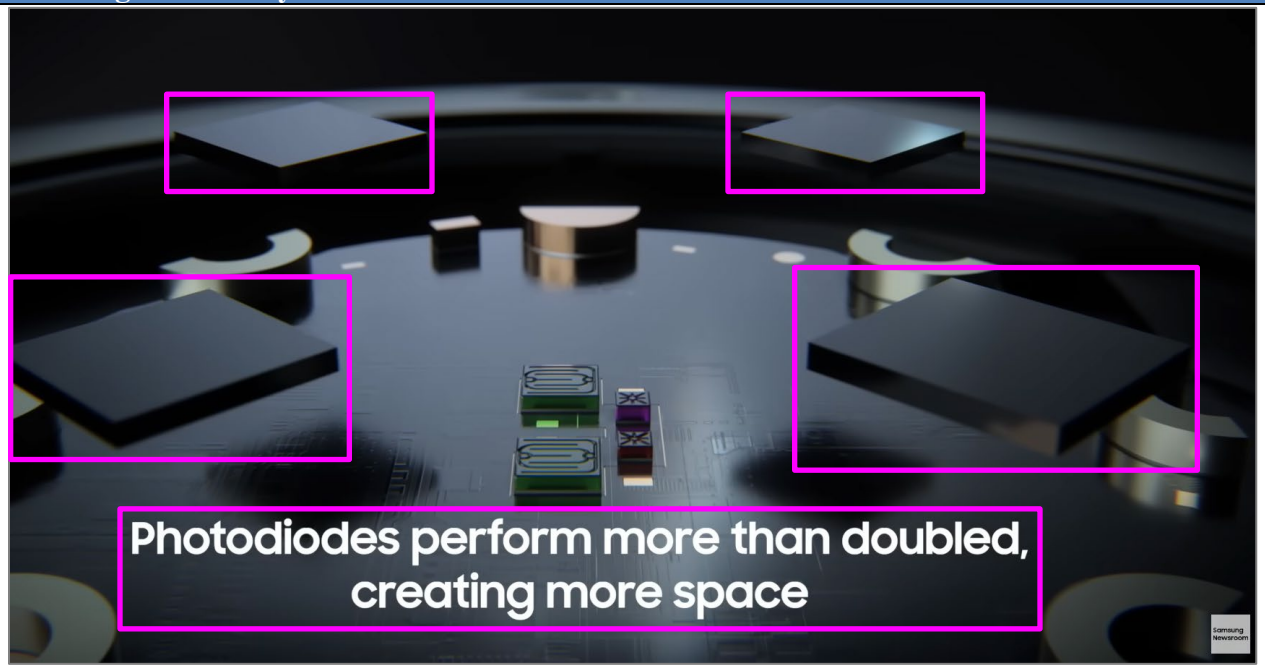
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:24, https://www.youtube.com/watch?v=JG9pGlqmges&t=23s.

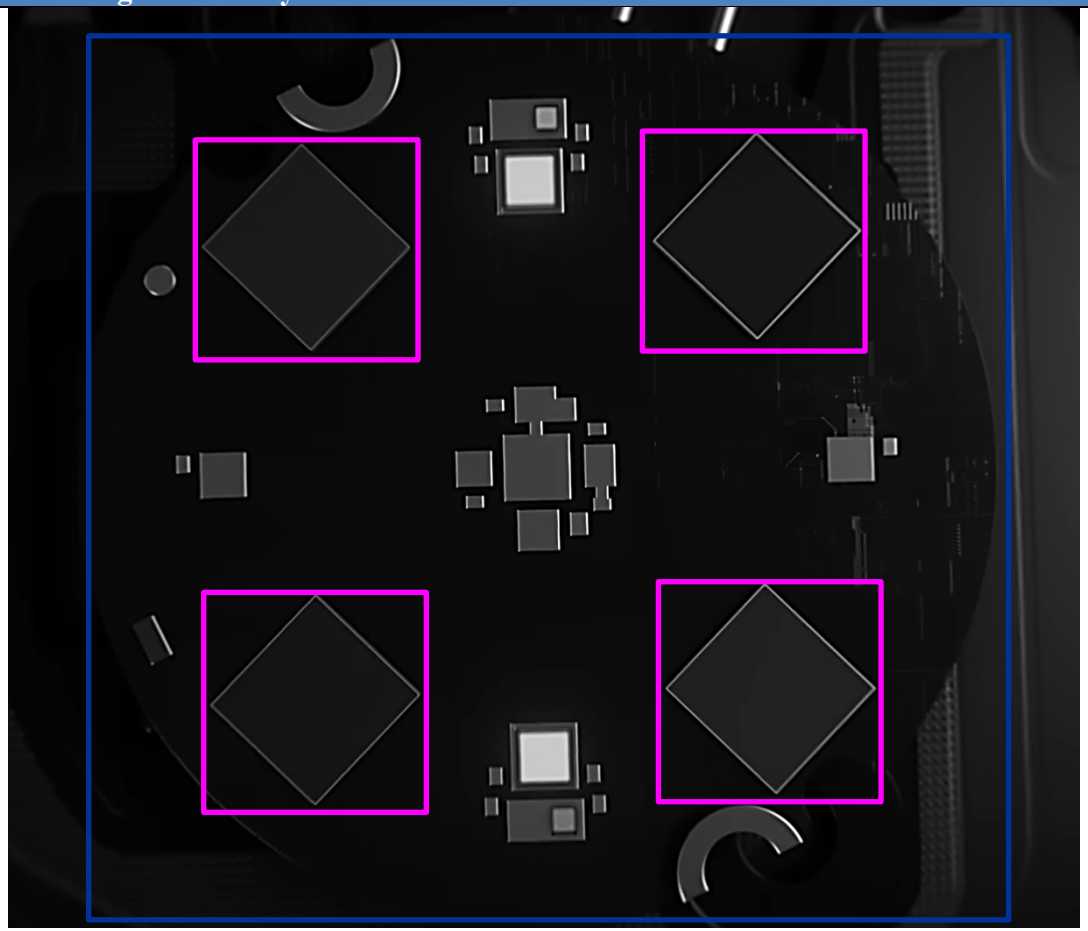
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:37, https://youtu.be/JG9pGlqmges?si=IrcplcEOdHE3cB3l&t=37

’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:53, https://youtu.be/JG9pGlqmges?si=xMBhD11dBJQoADTO&t=53

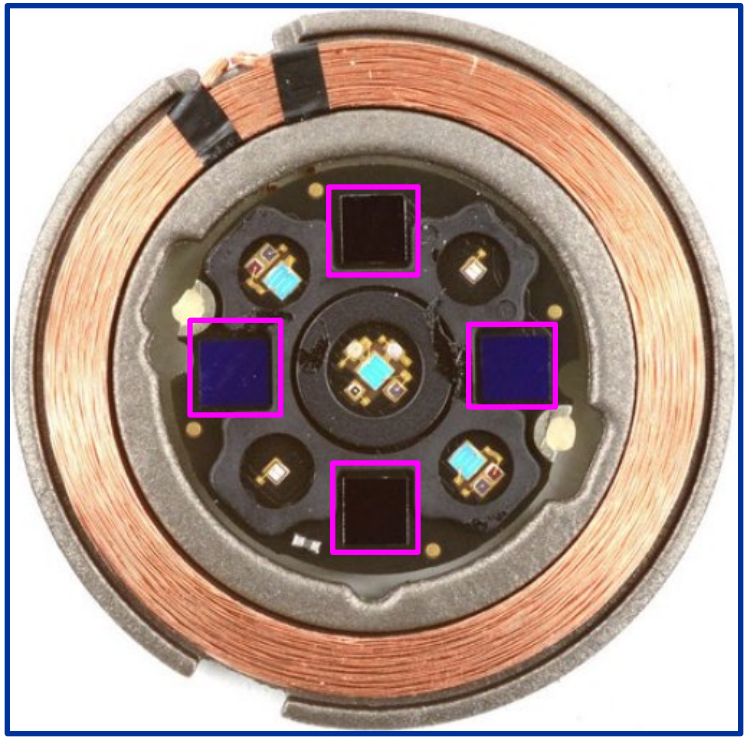
'455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, "Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off," July 21, 2024, at 0:53, https://youtu.be/JG9pGlqmges?si=YV8CQ6yVqkvL7ITZ&t=53
8[e] wherein the detection system comprises a plurality of detectors that are spatially separated from each other, and wherein at least one analog to digital converter is coupled	The **detection system** in the Accused Smartwatch comprises **a plurality of detectors that are spatially separated from each other** and wherein at least one analog to digital converter is coupled to at least one of the spatially separated detectors, literally or under the doctrine of equivalents. For example, the BioActive Sensor ("detection system") includes multiple photodiodes/PDs ("detectors") that are spatially separated from each other. "**The all-new BioActive Sensor** is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung

'455 Patent Claim	Samsung Accused System[1]
to at least one of the spatially separated detectors;	engineers focused on three upgrades to the new sensor: enhancing the performance of **light-receiving photodiodes,** adding additional colors of light-emitting diodes (LEDs) and arranging them optimally across the sensor." **Samsung more than doubled the performance of each photodiode, successfully decreasing the number needed to maintain capacity from eight to four.** This redesign freed up additional space for the integration of a larger number and variety of LEDs and ensured their optimal placement across the sensor. The new sensor now includes Blue, Yellow, Violet and Ultraviolet LEDs in addition to an increased number of Green, Red and Infrared LEDs. With the integration and arrangement of these LEDs, photodiodes and specially designed photodiode, Samsung is taking innovation one step further and is now able to pursue unexplored aspects of health monitoring on wearables. . . . The more diverse colors of LEDs and **newly designed photodiodes** unlock new possibilities and empower you to better predict trends and take proactive steps for preventative care. The first of these features will be an advanced glycation end products (AGEs) index — an indicator of metabolic health and biological aging strongly influenced by overall lifestyle and dietary habits. Used as an insightful biomarker, this index provides a snapshot of your biological age to help you make more informed decisions about your wellness journey and work towards a healthier future. The addition of an AGEs index is just one of the many new advanced features planned for the next Galaxy Watch." Samsung Newsroom, "Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor," Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor.

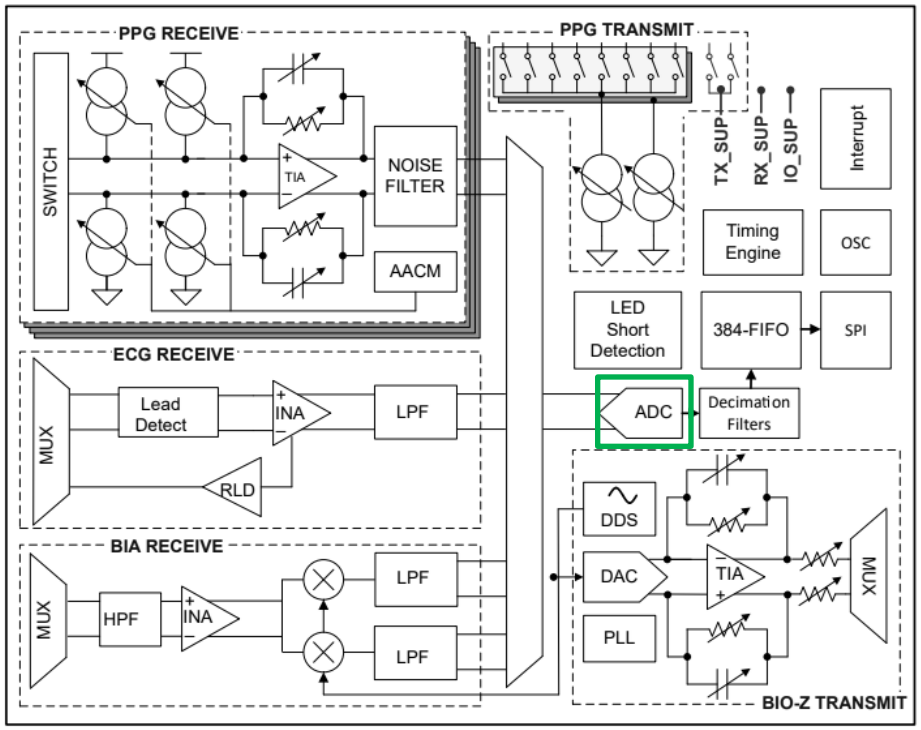
’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung Newsroom, “Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor,” Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor; Samsung Newsroom, “Introducing Samsung’s New BioActive Sensor,” July 8, 2024, https://www.youtube.com/watch?v=snMLajaf0tc&t=7s.

’455 Patent Claim	Samsung Accused System[1]
	

Source: Source: Samsung Newsroom, “Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor,” Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor; Samsung Newsroom, “Introducing Samsung’s New BioActive Sensor,” July 8, 2024, https://www.youtube.com/watch?v=snMLajaf0tc&t=7s.

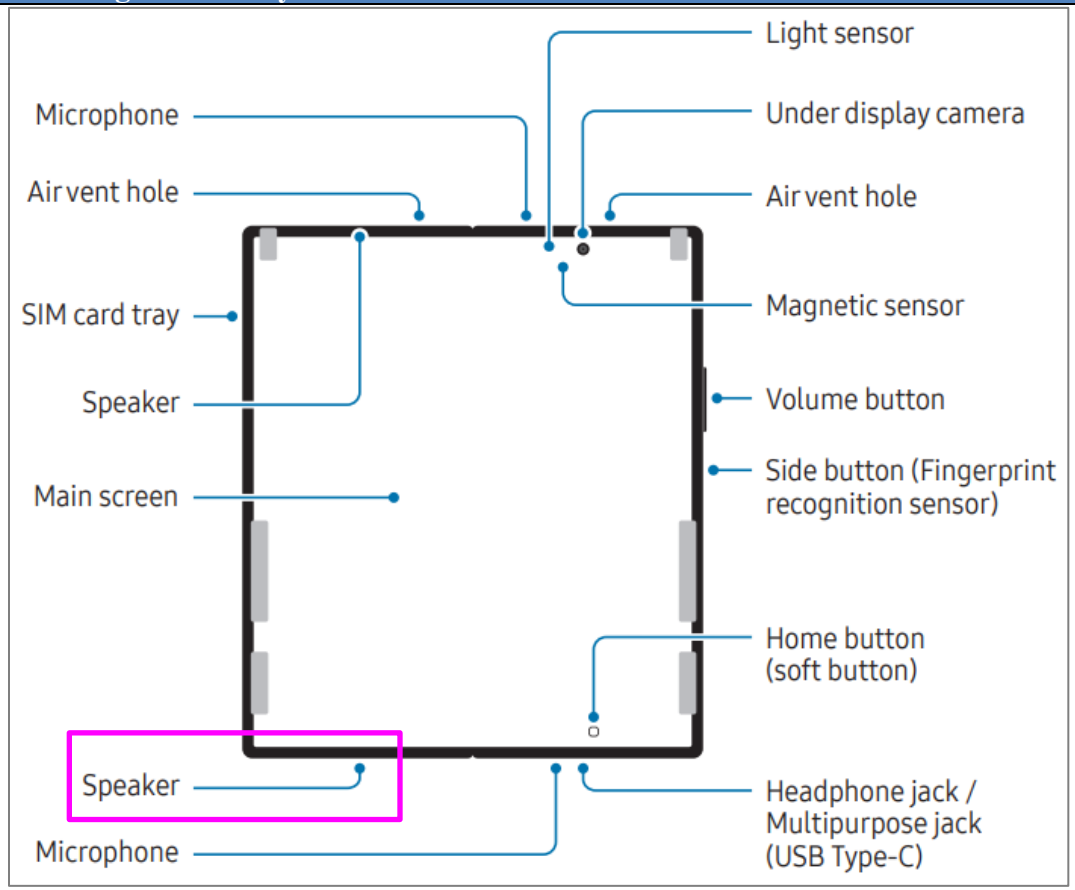
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 “**The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals.** A PPG signal chain comprises a current driver for LEDs and **a receiver that senses the signal from PDs.** An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.” Texas

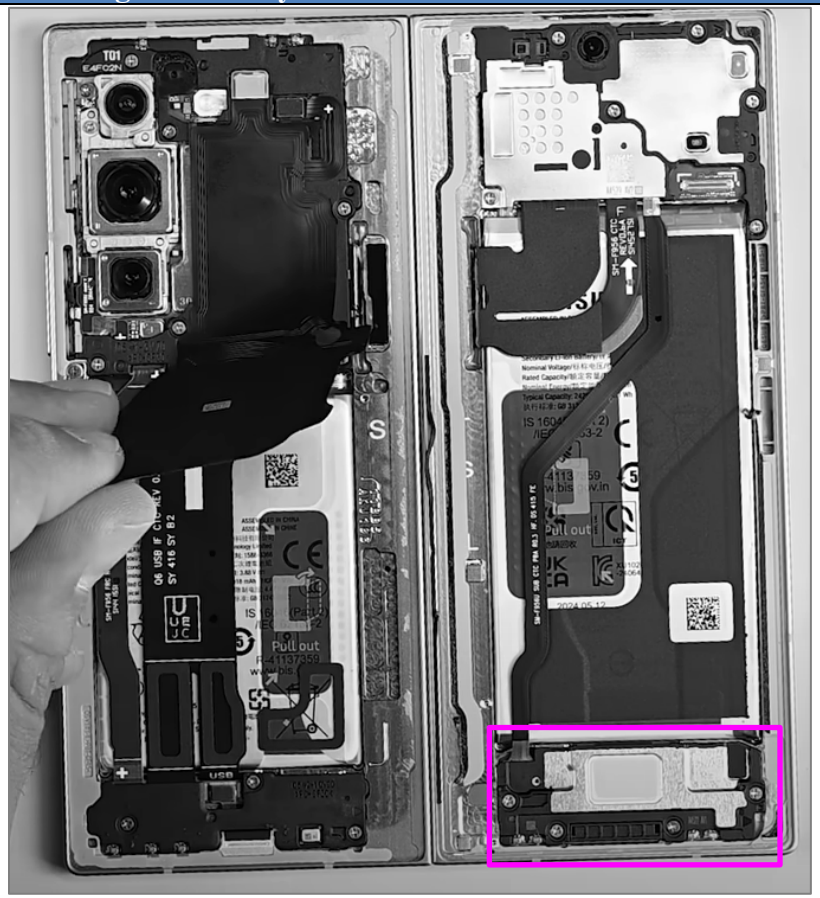
’455 Patent Claim	Samsung Accused System[1]
	Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf. For example, there is at least one analog to digital converter (“ADC”) coupled to at least one of the photodiodes/PDs (“detectors”) in the BioActive Sensor in the Accused Smartwatch. “The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. **A PPG signal chain comprises** a current driver for LEDs and **a receiver that senses the signal from PDs.** An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. **The outputs of the various signal chains are digitized by a common ADC** and stored in a FIFO which can be read out using an SPI interface.” Texas Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

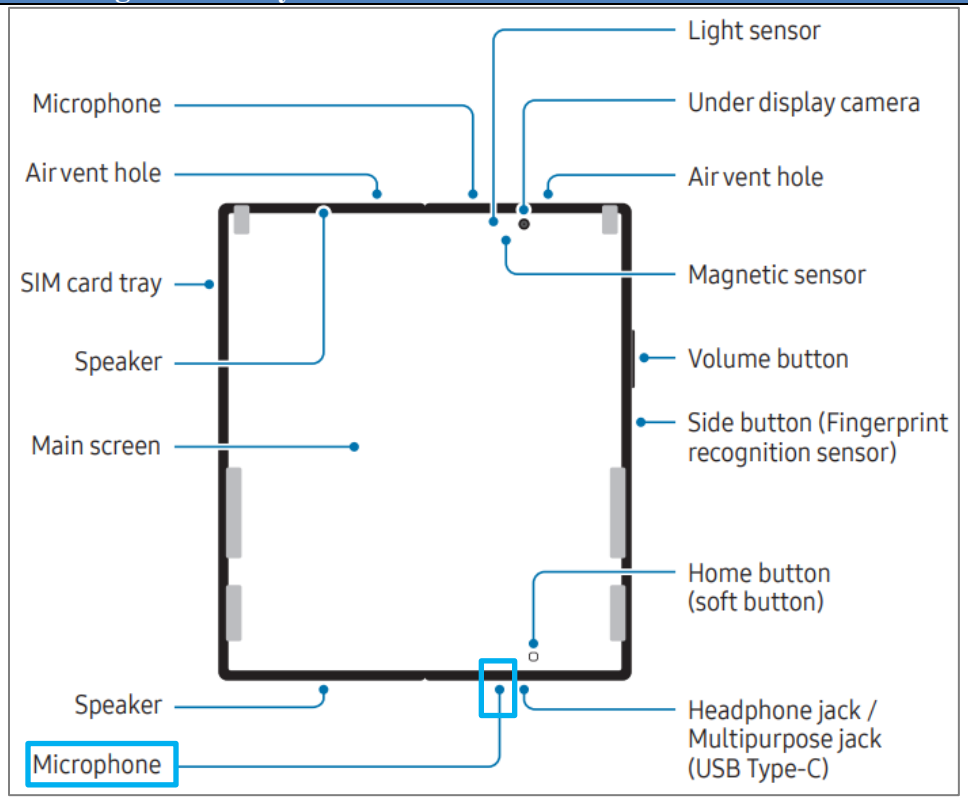
'455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic** Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.
8[f] the smart phone or tablet comprising a wireless receiver, a wireless transmitter, a display, a	The Accused System comprises an **Accused Phone/Tablet** comprising **a wireless receiver, a wireless transmitter, a display, a speaker, a voice input module, a microprocessor** and **a touch screen**, literally of under the doctrine of equivalents.

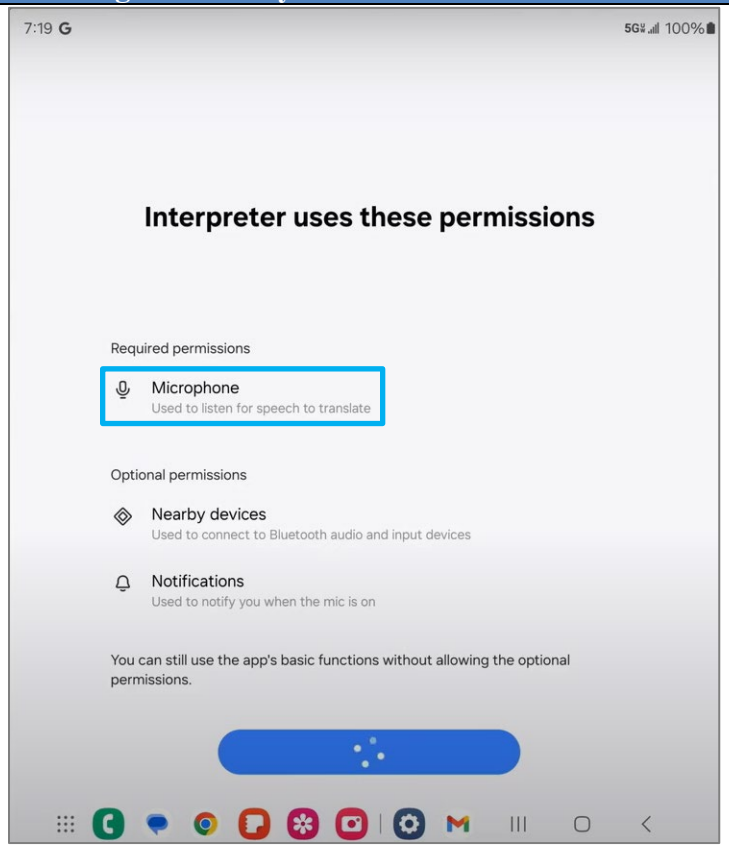
'455 Patent Claim	Samsung Accused System[1]
microphone, a speaker, a microprocessor and a touch screen,	For example, the Galaxy Watch Ultra pairs with the Galaxy Z Fold6 ("smart phone"). The Galaxy Z Fold6 includes Wi-Fi connectivity, which requires the smart phone to include both **a wireless receiver** and **a wireless transmitter**.  Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/

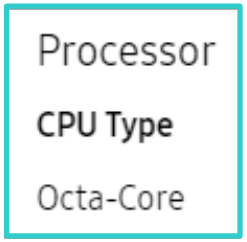
’455 Patent Claim	Samsung Accused System[1]
	Connectivity **Wi-Fi Connectivity** 802.11a/b/g/n/ac/ax 2.4GHz+5GHz+6GHz, HE160, MIMO, 1024-QAM Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/ The Galaxy Z Fold6 (“smart phone”) further includes **a display,** **a speaker,** and a microphone (“**a voice input module**”). Display **Resolution (Main Display)**: 2160 x 1856 (QXGA+) **Main Display Size**: 193.2mm (7.6" full rectangle) / 192.5mm (7.6" rounded corners) **Technology (Main Display)**: Dynamic AMOLED 2X Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/

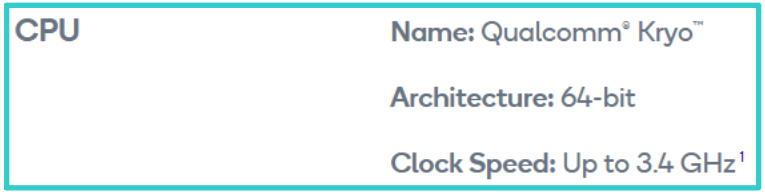
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 5]

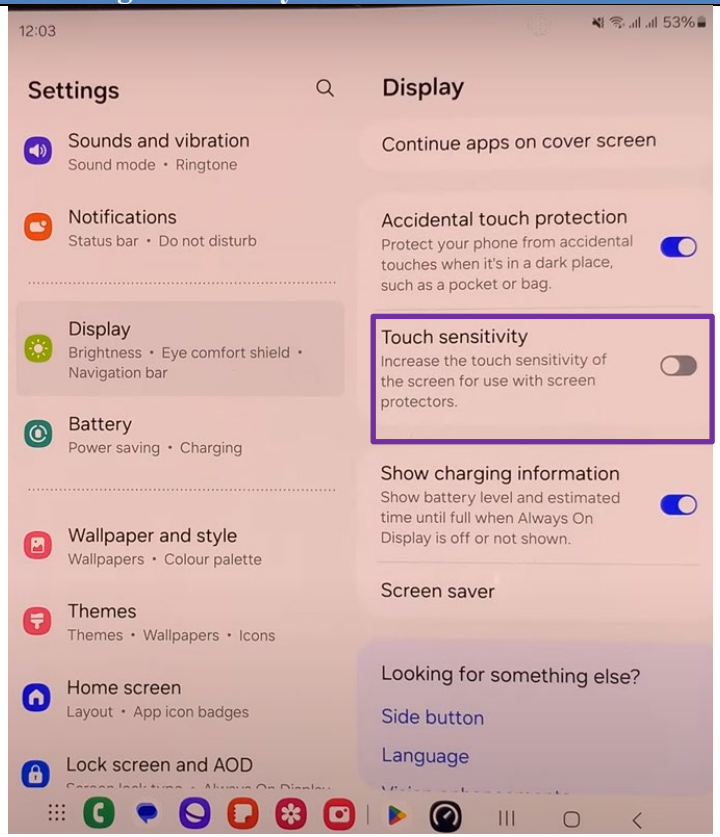
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=xYIe5uDVDWI

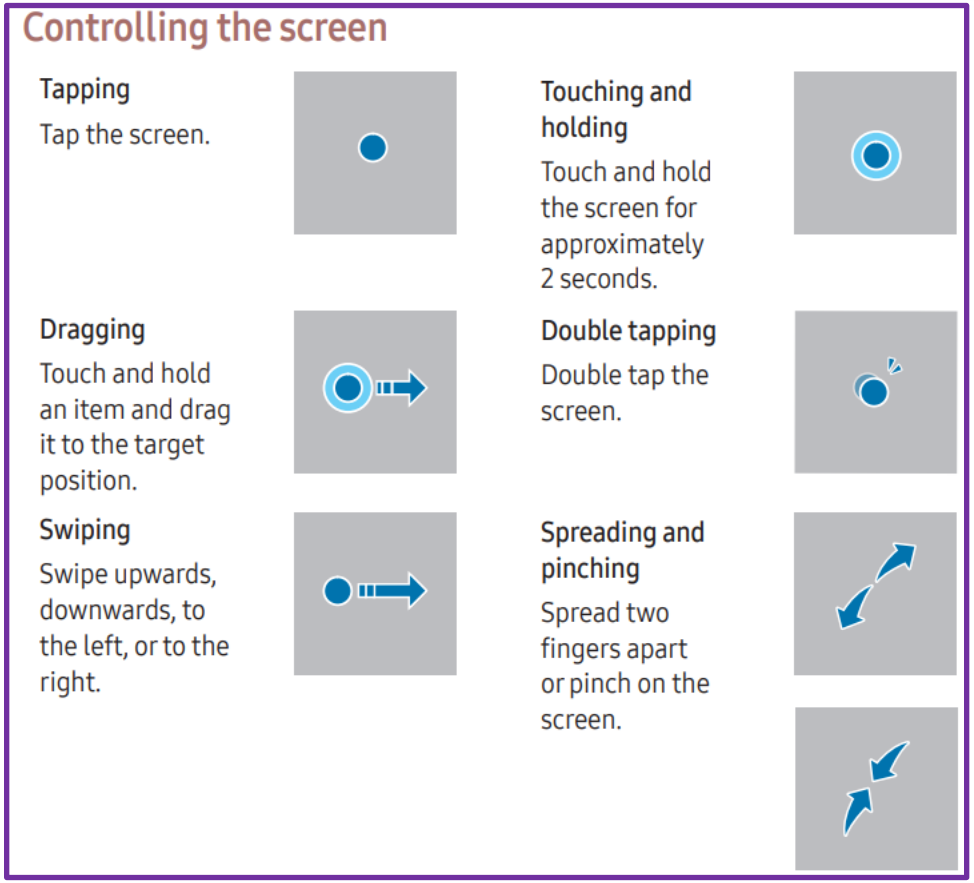
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 5]

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=sPP6NW89Am0 The Galaxy Z Fold6 further includes **a microprocessor** (*e.g.*, Snapdragon 8 Gen 3 SoC (system on chip) having Qualcomm Kryo microprocessor) and **a touch screen**.

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/  Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/

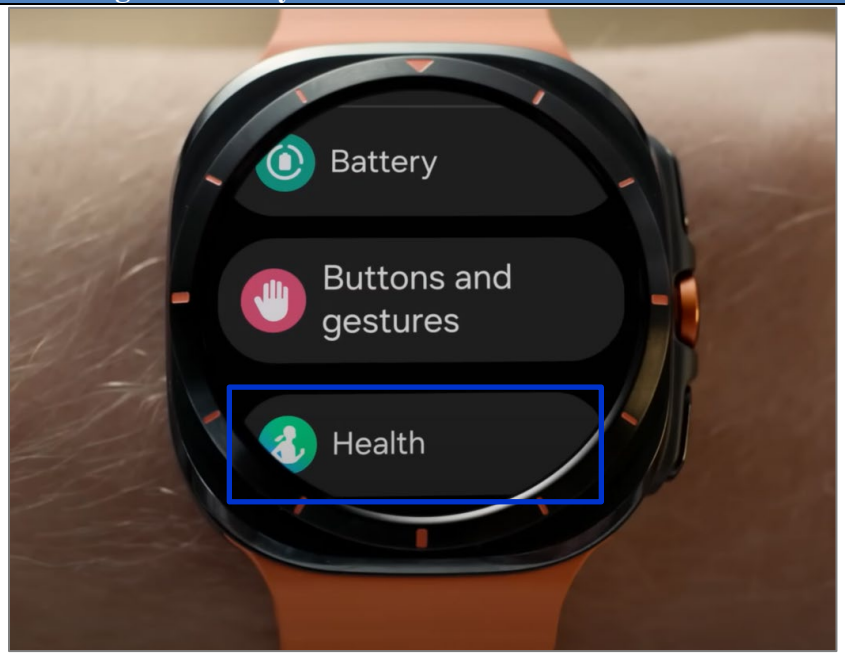
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.qualcomm.com/products/mobile/snapdragon/smartphones/snapdragon-8-series-mobile-platforms/snapdragon-8-gen-3-mobile-platform

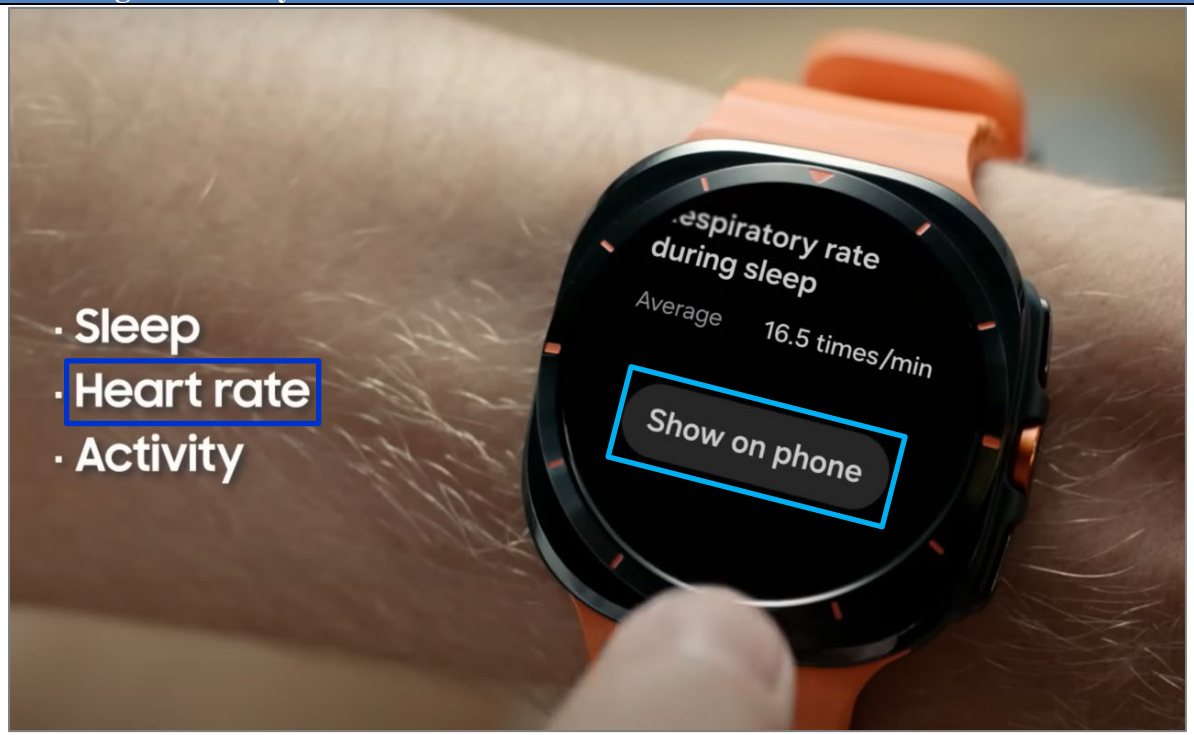
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=cn2UQ6Fr4hM

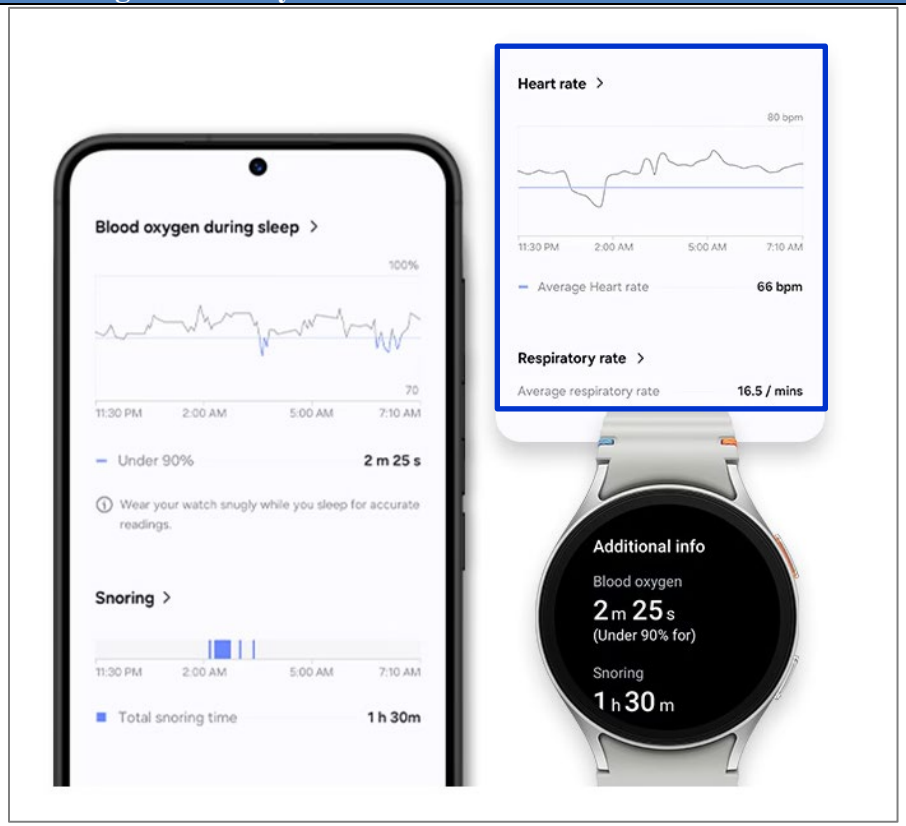
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 26]

'455 Patent Claim	Samsung Accused System[1]
8[g] the smart phone or tablet configured to receive and process at least a portion of the output signal, wherein the smart phone or tablet is configured to store and display the processed output signal, and wherein at least a portion of the processed output signal is configured to be transmitted over a wireless transmission link;	The Accused Phone/Tablet is configured **to receive and process at least a portion of the output signal**, and the Accused Phone/Tablet is configured **to store and display the processed output signal**, wherein **at least a portion of the processed output signal** is configured **to be transmitted over a wireless transmission link**, literally or under the doctrine of equivalents. For example, the Galaxy Z Fold6 ("the **smart phone**") receives the output signal from the BioActive Sensor via the Samsung Health app, processes the signal (*e.g.*, generates Heart Rate Zones, in addition to other health and wellness metrics and reports), and then stores and displays the Heart Rate Zones ("processed signal"). "The Samsung Privileged Health SDK is specialized for Galaxy Watch4 devices or later. **It provides both raw sensor signal data from the Samsung BioActive Sensor** and processed data with our differentiated features. The SDK supports an improved health tracking capability to allow your applications to track the user's health data accurately with the accelerometer, raw ECG (Electrocardiogram), **PPG (Photoplethysmogram), and heart rate including inter-beat interval.**" Samsung Developer, "Samsung Privileged Health SDK," *available at* https://developer.samsung.com/health/privileged/overview.html.

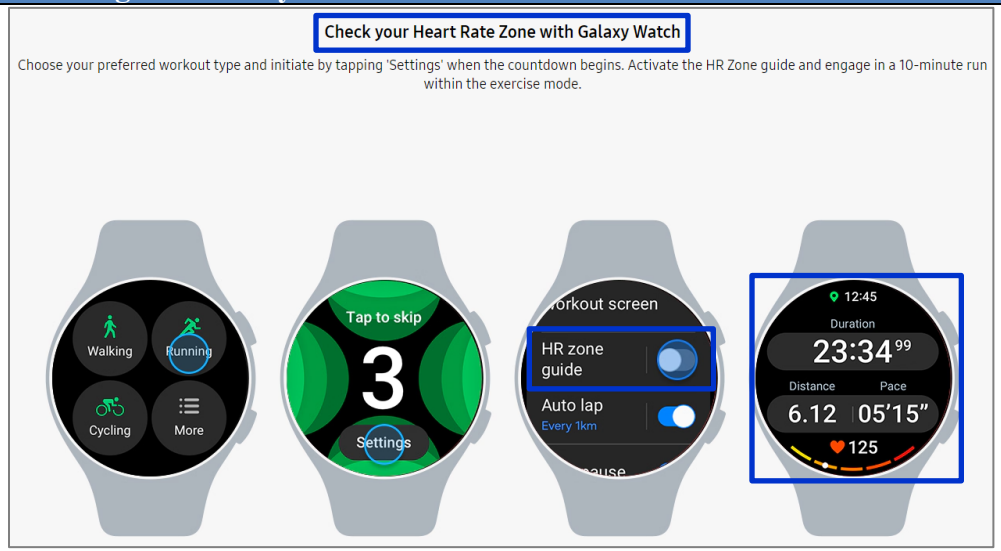
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/.

’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “A friendly guide to Galaxy Watch Ultra, Watch7 and Buds3Pro,” July 24, 2024, https://www.youtube.com/watch?v=VQW-ZpdAm5M.

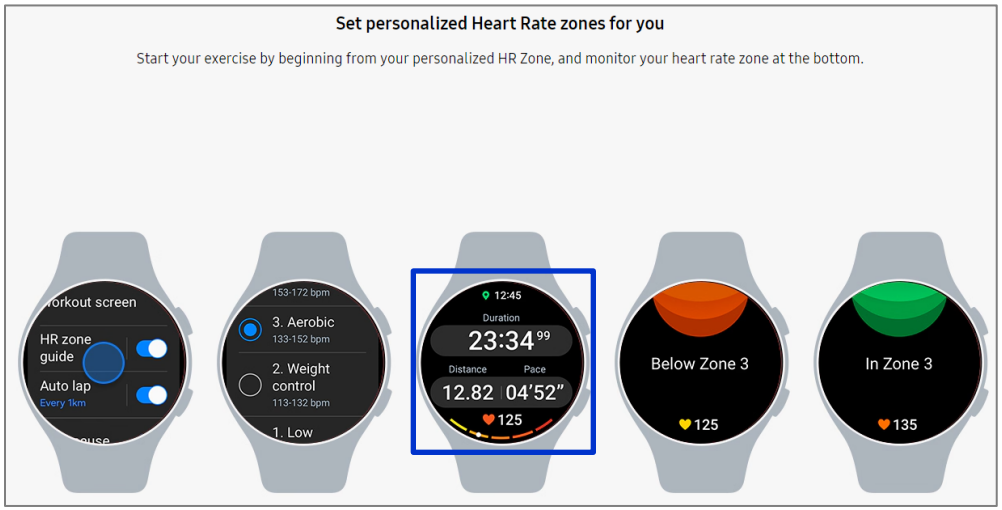
’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “A friendly guide to Galaxy Watch Ultra, Watch7 and Buds3Pro,” July 24, 2024, https://www.youtube.com/watch?v=VQW-ZpdAm5M

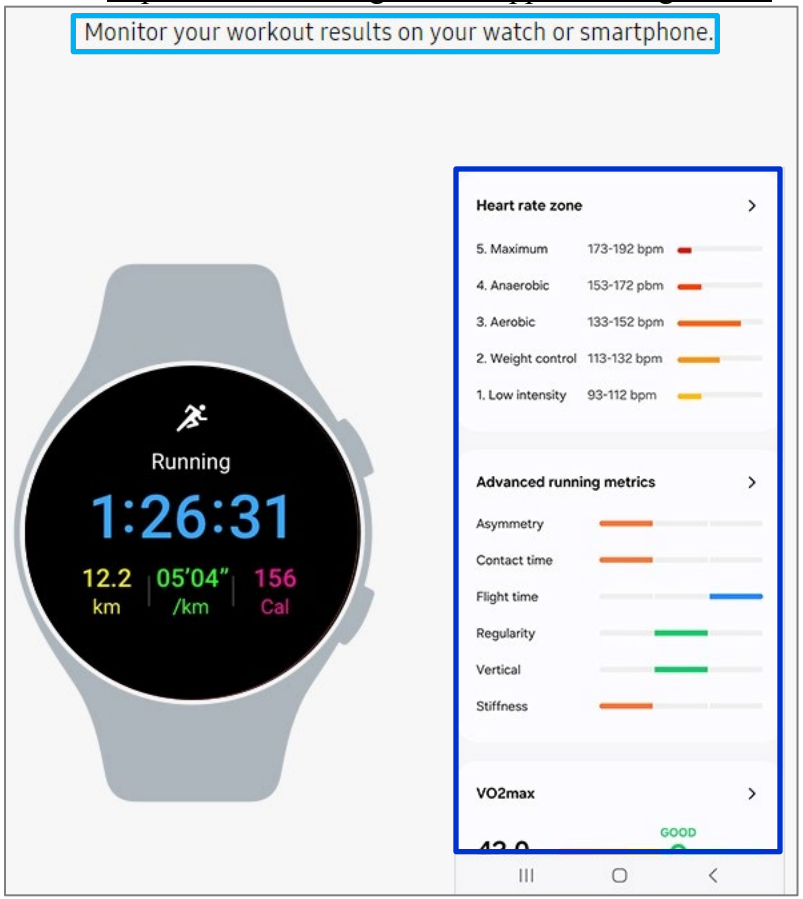
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/

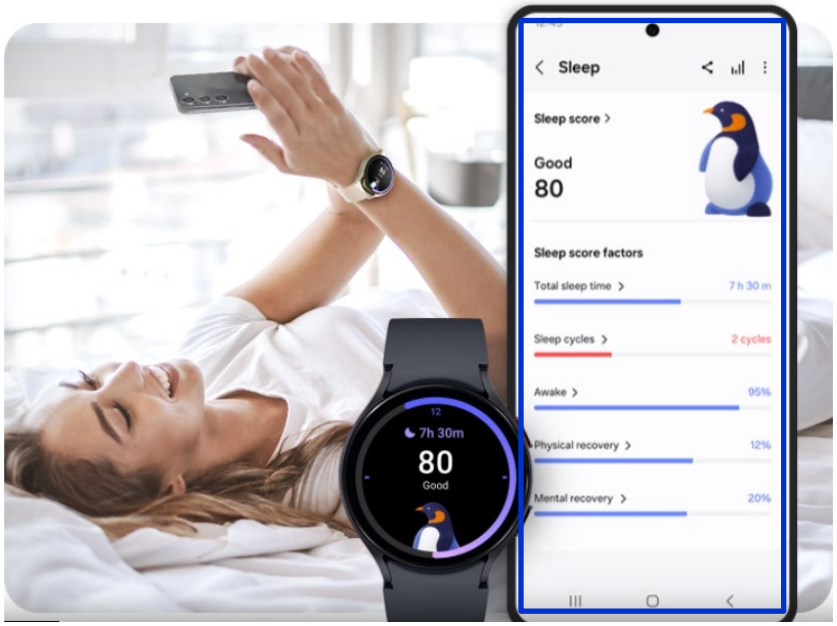
’455 Patent Claim	Samsung Accused System[1]

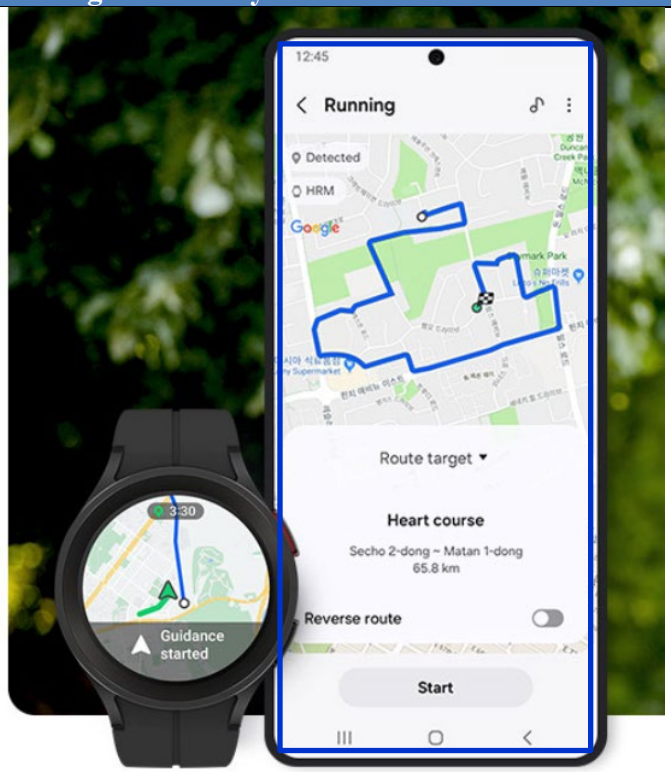


Source: https://www.samsung.com/us/apps/samsung-health/

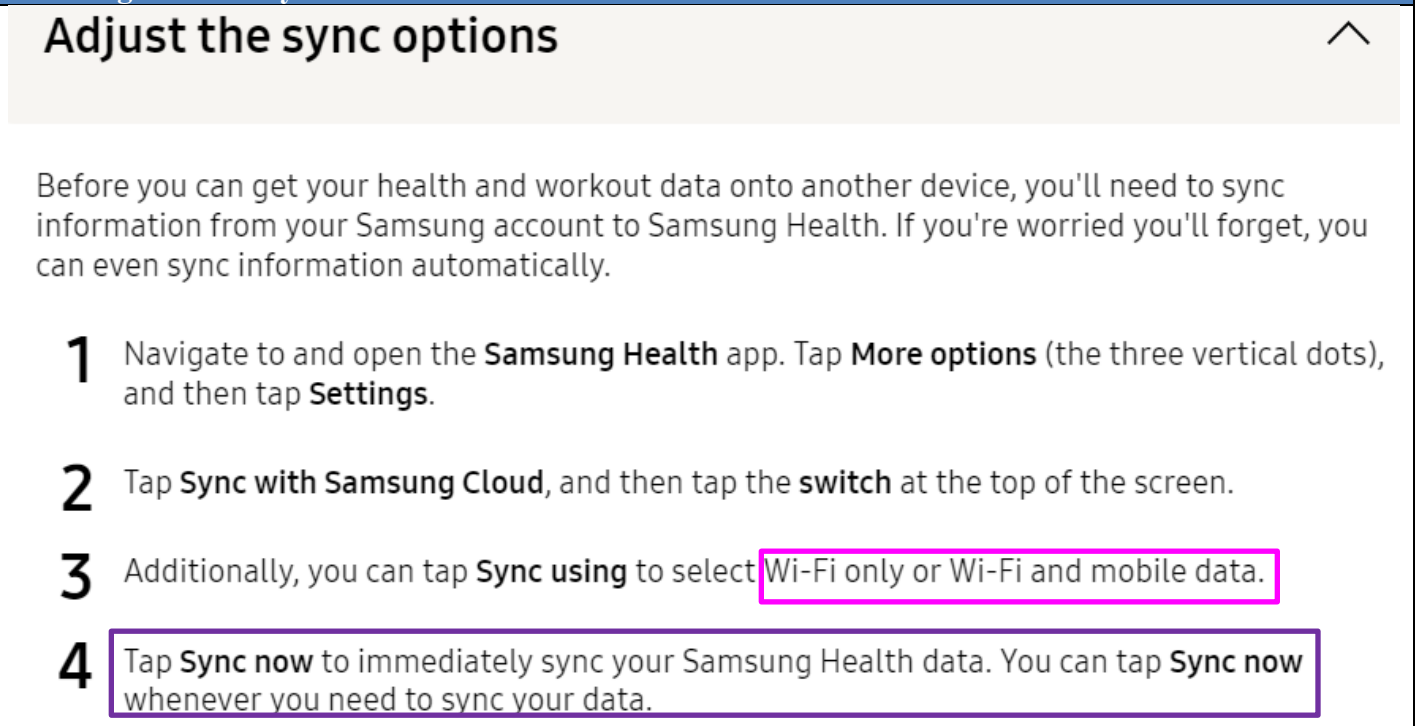


’455 Patent Claim	Samsung Accused System[1]
	Source: https://www.samsung.com/us/apps/samsung-health/  Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/global/galaxy/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/global/galaxy/apps/samsung-health/ “The **Energy score feature** is available **if the connected phone** has version 6.27 or later of the Samsung Health app installed.” Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 53, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf.

’455 Patent Claim	Samsung Accused System[1]
	“The sleep pattern will have its four states (Awake, REM, Light, Deep) analysed by using your movement and changes in your **heart rate** while you are sleeping. **You can check the recommended ranges for each measured sleep state in the graph on your connected phone**.” Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 71, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf. The Samsung Health app data (“a portion of the processed output signal”) is synchronized with Samsung Cloud to enable transmission of data to Samsung Cloud over Wi-Fi (“wireless transmission link”). “If you just got a new phone or tablet, it doesn’t mean you have to lose your hard work in **Samsung Health. Your workout and health information can be transferred to the new device**; you just need to **sync your Samsung Health profile with your Samsung account!** Once your data is synced, you'll be able to access it on a different device.”

'455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, "Sync your data in Samsung Health," https://www.samsung.com/us/support/answer/ANS10001399/.
8[h] wherein the output signal is indicative of one or more of the physiological parameters;	The Accused Smartwatch generates an **output signal** that **is indicative of one or more of the physiological parameters**, either literally or under the doctrine of equivalents. For example, the PPG signal ("output signal") from the BioActive Sensor indicates, among other things, heart rate and blood oxygen levels ("one or more of the physiological parameters").

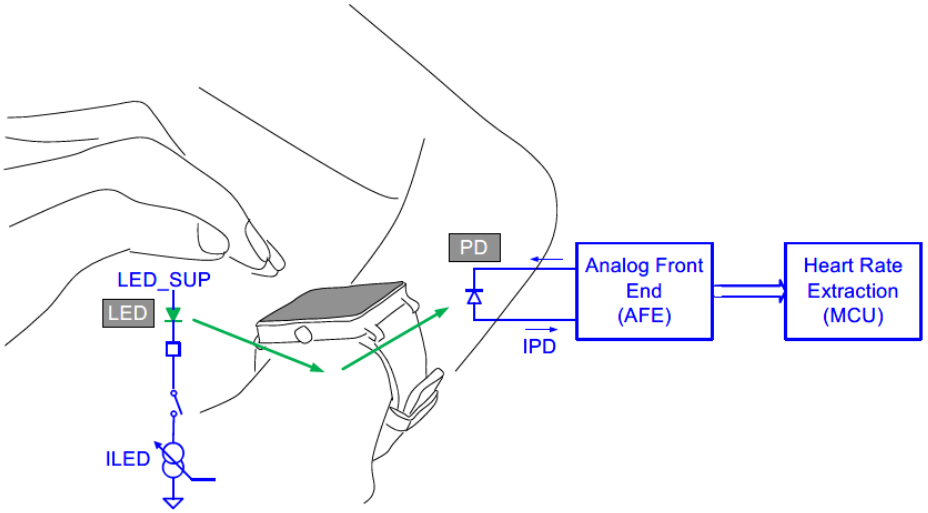
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

'455 Patent Claim	Samsung Accused System[1]
	Introducing Samsung's New BioActive Sensor The all-new BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of light-receiving photodiodes, adding additional colors of light-emitting diodes (LEDs) and arranging them optimally across the sensor. **Bringing Greater Accuracy and New Possibilities for Preventative Wellness** The optimal allocation of Green, Red and Infrared LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure,[2] blood oxygen levels and stress levels.[3] Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor. The more diverse colors of LEDs and newly designed photodiodes unlock new possibilities and empower you to better predict trends and take proactive steps for preventative care. The first of these features will be an advanced glycation end products (AGEs) index[4] – an indicator of metabolic health and biological aging strongly influenced by overall lifestyle and dietary habits. Used as an insightful biomarker, this index provides a snapshot of your biological age to help you make more informed decisions about your wellness journey and work towards a healthier future. The addition of an AGEs index is just one of the many new advanced features planned for the next Galaxy Watch. Source: Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	3 Description The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bio-impedance signals. A PPG signal chain comprises a current driver for LEDs and a receiver that senses the signal from PDs. An ECG receiver with a Right-leg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface

'455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy **OHRM**: Optical Heart-rate monitoring Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-4, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]
	Application *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR).

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 1. Heart Rate Monitoring on a Wearable Device** Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

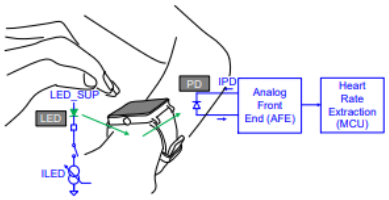
'455 Patent Claim	Samsung Accused System[1]

Product Overview

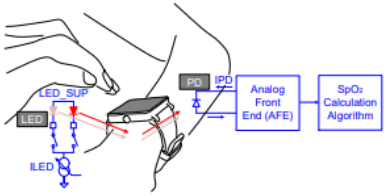
Photoplethysmography (PPG) With Integrated AFE for Optical Biosensing

TEXAS INSTRUMENTS

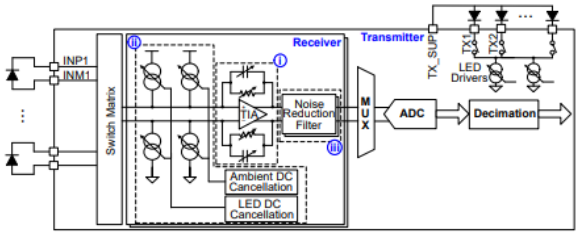
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI's signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.



Heart Rate Monitoring

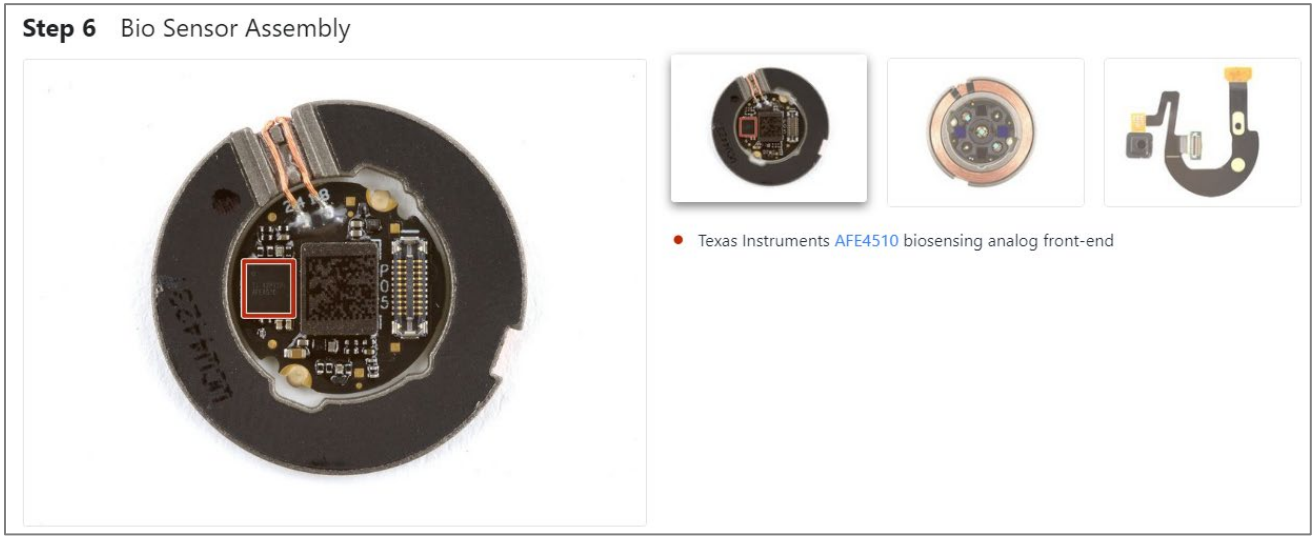


SpO_2 Monitoring



Block Diagram

Source: Texas Instruments, Product Overview, "Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing," Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

’455 Patent Claim	Samsung Accused System[1]
	See also https://www.samsung.com/us/apps/samsung-health/; https://www.samsung.com/sg/apps/samsung-health-monitor/; https://www.youtube.com/watch?v=snMLajaf0tc&t=7s; https://news.samsung.com/global/samsung-leads-holistic-health-innovation-with-galaxy-watch5-and-galaxy-watch5-pro.
8[i] the wearable device configured to increase the signal-to-noise ratio by increasing light intensity of at least one of the plurality of semiconductor sources from an initial light intensity; and	The Accused Smartwatch is **configured to increase the signal-to-noise ratio by increasing light intensity of at least one of the semiconductor sources from an initial light intensity**, either literally or under the doctrine of equivalents. For example, the Galaxy Watch Ultra increases the signal-to-noise ratio (“SNR”) of the PPG signal received from the BioActive Sensor. The BioActive Sensor has a peak system SNR of 115 dB, which indicates that the general output SNR is lower than this peak value. To achieve the peak SNR, the sensor is configured to increase the LED current (“light intensity”) of the LEDs (“semiconductor sources”). 

’455 Patent Claim	Samsung Accused System[1]
	Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw. **3 Description** The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bio-impedance signals. A PPG signal chain comprises a current driver for LEDs and a receiver that senses the signal from PDs. An ECG receiver with a Right-leg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface

’455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-4, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]

Figure 3 shows the PPG signal chain in AFE4432.

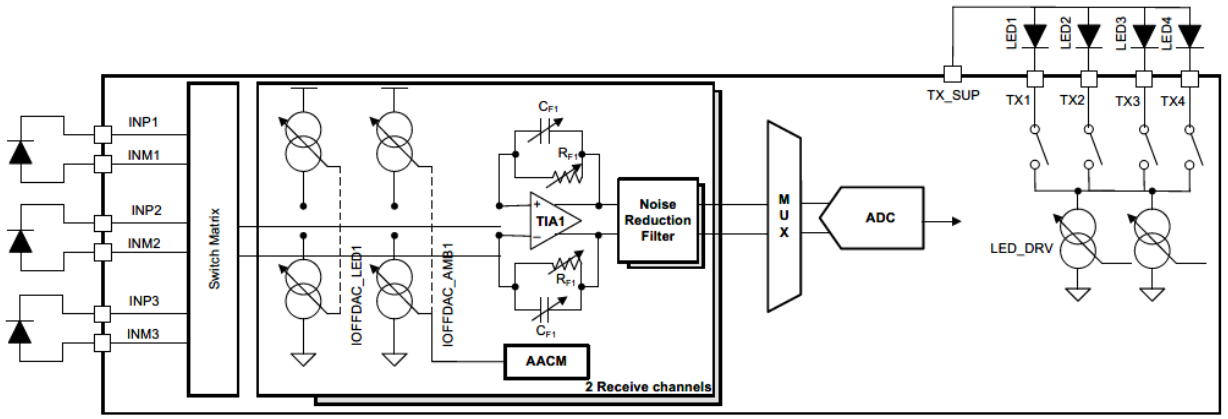
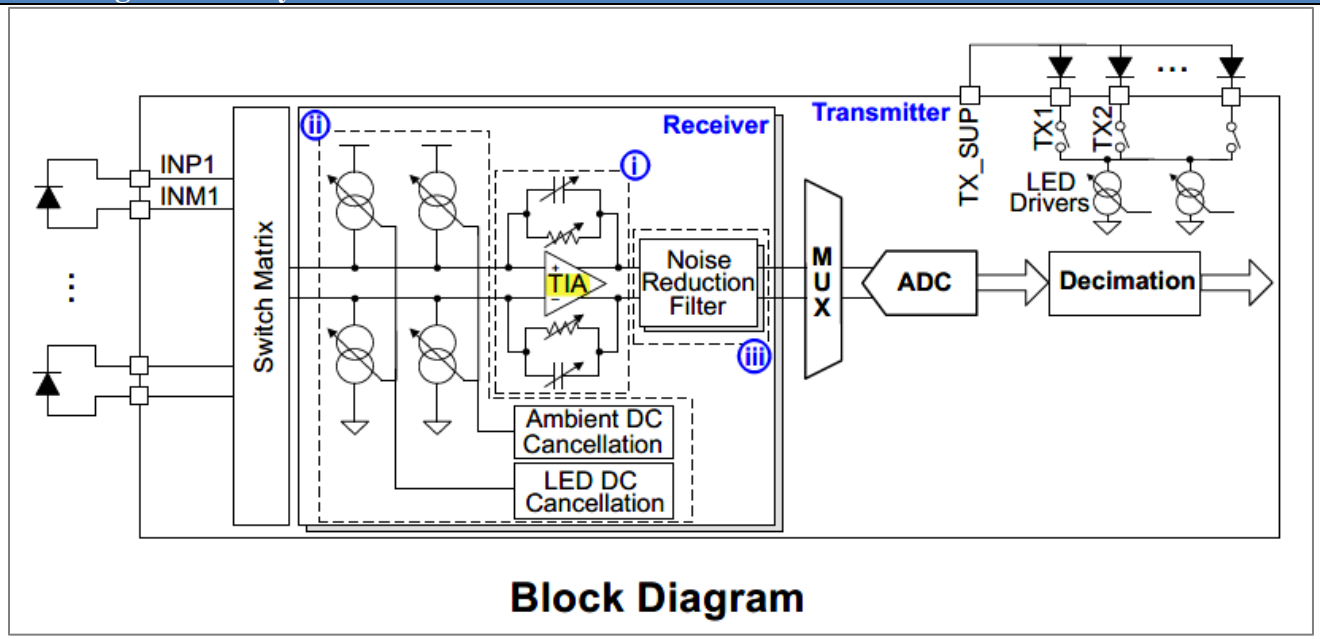


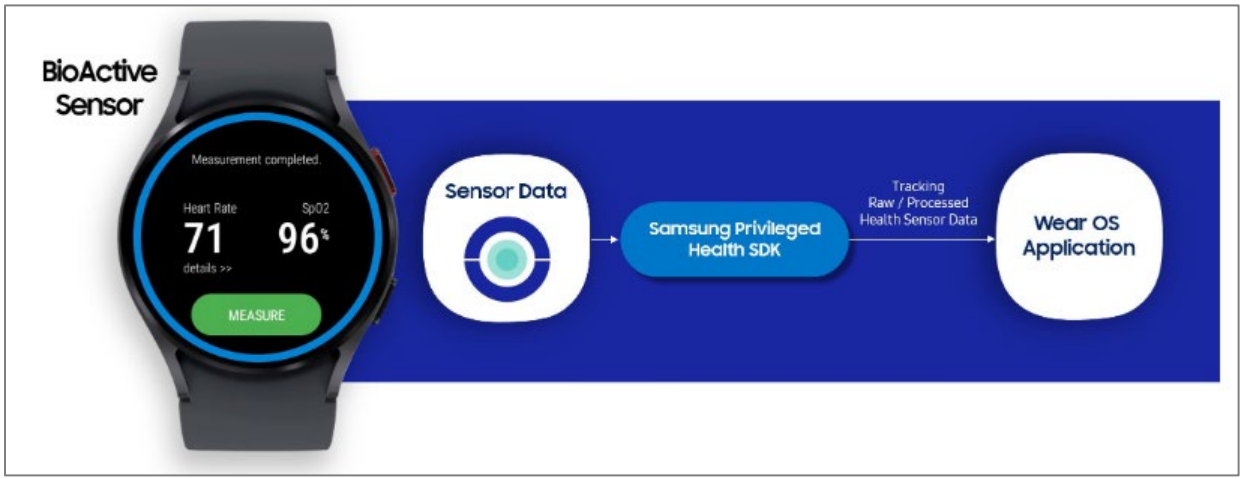
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

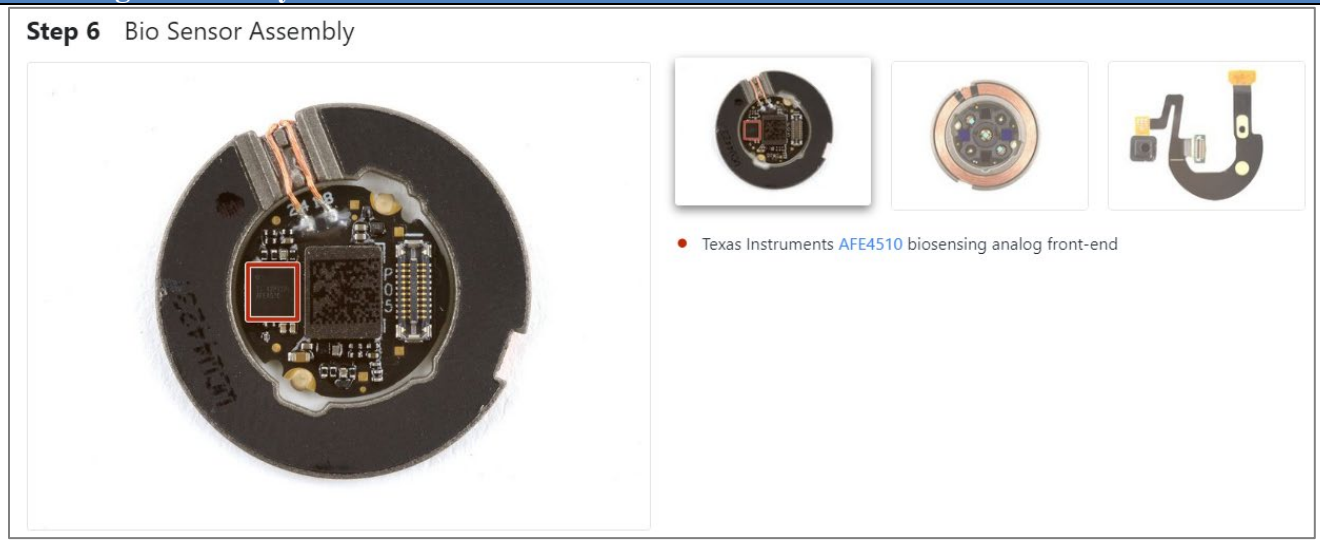
Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

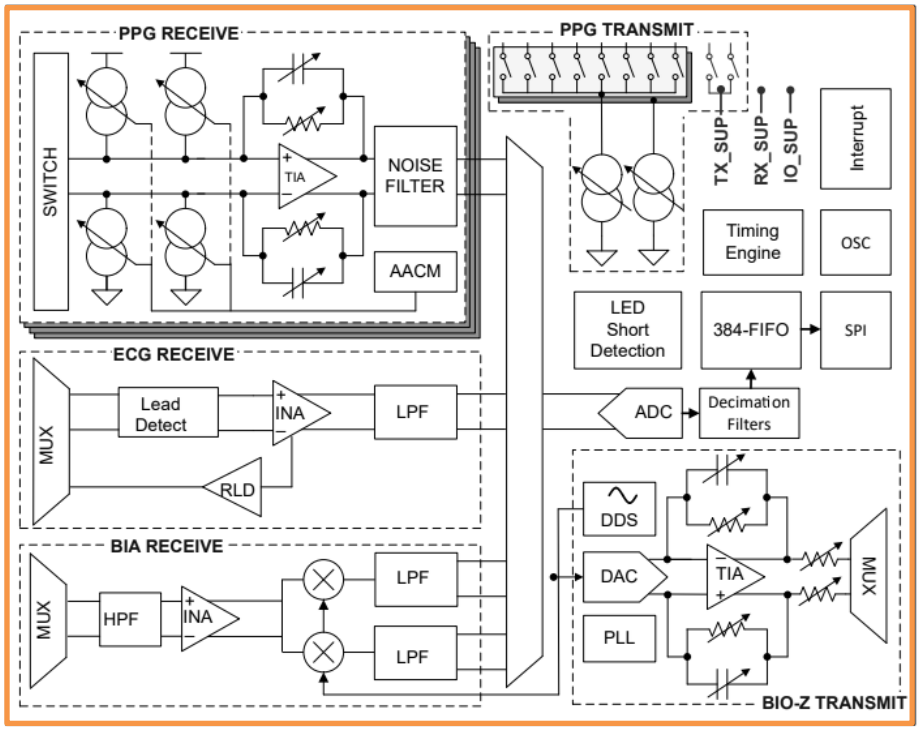
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI’s signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.

’455 Patent Claim	Samsung Accused System[1]
	 Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F. “However, **increasing the LED current gives better signal quality from the SNR perspective.** The optimal AFE configuration settings are completely dependent on the application. This includes the separation of LED and PD, location of the sensor, and other factors.” Texas Instruments, Application Report, “How to Design Peripheral Oxygen Saturation (SpO_2) and Optical Heart Rate Monitoring (OHRM) Systems Using the AFE4403,” SLAA655 – Mar. 2015, at 3, *available at* https://www.ti.com/lit/an/slaa655/slaa655.pdf.

'455 Patent Claim	Samsung Accused System[1]
	"Coming to the next Galaxy Watch, the new sensor will enable advanced predictive and preventative wellness features never before seen on a wearable device — in addition to **more accurate health measurements**. . . . The all-new BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that **enable even more precise health insights**. . . . This allows the new BioActive Sensor to **more accurately measure** health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is **30% more accurate** compared to its predecessor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor  "The SDK supports an improved health tracking capability to **allow your applications to track the user's health data accurately** with the accelerometer, raw ECG (Electrocardiogram), **PPG (Photoplethysmogram)**, and **heart rate including inter-beat interval**. In addition, it provides more advanced health features such as the body composition measurement, to enable compelling use cases for

'455 Patent Claim	Samsung Accused System[1]
	health and fitness applications. The blood oxygen level and sweat loss after a running workout are also useful data to check a user's health status." Source: Samsung Developer, "Samsung Privileged Health SDK," https://developer.samsung.com/health/privileged/overview.html
8[j] the detection system further configured to: generate a first signal responsive to light received while the light emitting diodes are off, generate a second signal responsive to light received while at least one of the light emitting diodes is on, and	The **detection system** in the Accused Smartwatch is further configured to **generate a first signal responsive to light received while the semiconductor sources are off,** and **generate a second signal responsive to light received while at least one of the semiconductor sources is on**, either literally or under the doctrine of equivalents. For example, the BioActive Sensor includes a PPG sensor that operates in multiple phases, including (1) Ambient (when the LEDs, or "semiconductor sources," are off) and (2) LED (when the LEDs, or "semiconductor sources," are on). During the Ambient phase, the sensor receives light with the LEDs off and generates a first signal. In the LED phase, the sensor receives light from the LEDs and generates a second signal.

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw.

’455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic**

’455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy **PPG Receiver:** – Supports 5 PDs, 4 parallel receive paths – Noise filtering with programmable bandwidth – Trans-impedance Gain: 3.7kΩ to 1MΩ – 8-bit Ambient Offset Subtraction DAC up to 256µA – 9-bit LED Offset Subtraction DAC up to 64µA – Digital Ambient Subtraction at ADC Output Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

'455 Patent Claim	Samsung Accused System[1]

5.1 PPG Configuration

5.1.1 Phase Definition

This sheet is used to specify number of phases, timing, signal chain parameters associated with each phase, and the LED/PD association for each phase. The phase type is selected from the drop down menu (Ambient and LED) and the appropriate parameters for the phase type are automatically shaded in blue. Specify only the parameters that show up in the Blue boxes. Manually fill each cell using the drop down boxes (do not cut and paste values across cells). Also, fill only the boxes that show up in blue. Do not modify the cream- colored boxes.

3		tLED_SAMP	0	us (LED ON start to SAMP start)		1	No data written into FIFO							Single or Dual TIA		Single		
4						2	Phase [N] - Phase [N-1]							PPG Decimation Fa	PPG_DEC_FA	2	ble PPG Decim	EN_PPG_DEC
5	Phase parameter table					3	Phase [N-1] - Average(Phase [N], Phase [N-2])							TIA1				
6	Phase	Phase type	LED drv1 connects to	LED drv2 connects to	NUMAV	Stagger LED?	4 Phase[N] - Phase [N-2]	FIFO data word	SAMP time (us)	Filter BW Selection	Connect PD4?	Connect PD3?	Connect PD2?	Connect PD1?	Rf (kOhm)	Cf (pF)	IOFFDAC_ TIA1 (uA)	AACM TYPE
7	1	Ambient			2	0	Never mask	1	115	Set1			1		100	20	0	ANA AACM
17	2	LED	TX5	TX5	2	0	Never mask	1	115	Set1			1		100	20	0	LED_DC Cancel
27	3	Ambient			2	0	Never mask	3	115	Set1			1		100	20	0	ANA AACM
37																		
47																		
57																		
67																		
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Figure 5-1. PPG per-phase configuration

’455 Patent Claim	Samsung Accused System[1]



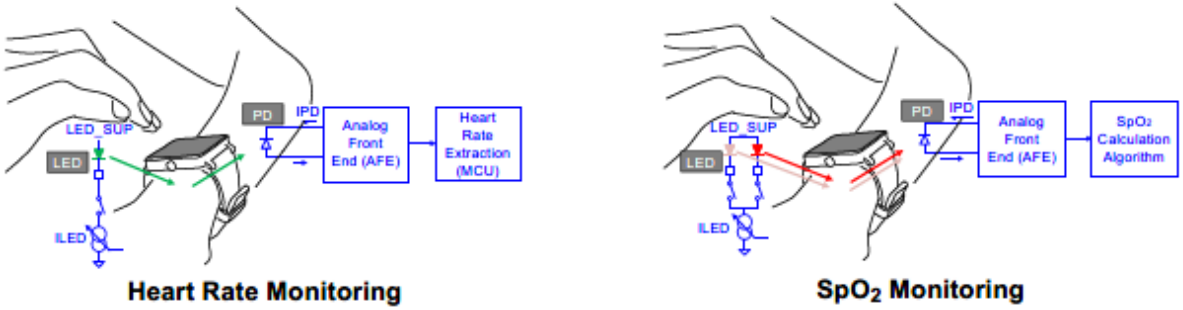
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
3		tLED_SAMP	0	us (LED ON start to SAMP start)			1	No data written into FIFO						Single or Dual TIA		Single		
4							2	Phase [N] - Phase [N-1]						PPG Decimation Fa	PPG_DEC_FA	2	le PPG Decim	EN_PPG_DEC
5	Phase parameter table						3	Phase [N-1] - Average(Phase [N], Phase [N-2])										
							4	Phase[N] - Phase [N-2]			TIA1							
6	Phase	Phase type	LED drv1 connects to	LED drv2 connects to	NUMAV	Stagger LED?	Fractional masking	FIFO data word	SAMP time (us)	Filter BW Selection	Connect PD4?	Connect PD3?	Connect PD2?	Connect PD1?	Rf (kOhm)	Cf (pF)	IOFFDAC_ TIA1 (uA)	AACM TYPE
7	1	Ambient			2	0	Never mask	1	115	Set1			1		100	20	0	ANA AACM
17	2	LED	TX5	TX5	2	0	Never mask	1	115	Set1			1		100	20	0	LED_DC Cancel
27	3	Ambient			2	0	Never mask	3	115	Set1			1		100	20	0	ANA AACM
37																		
47																		
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67																		
77																		
87																		
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107																		
117																		

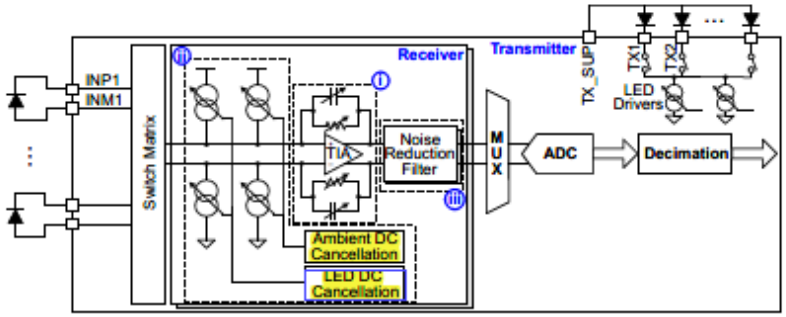
Figure 5-1. PPG per-phase configuration

Source: Texas Instruments, AFE4500 EVM User Guide, SBAU370 – April 2021, at 23, *available at* https://www.manualslib.com/download/2652772/Texas-Instruments-Afe4500evm.html.

“To save power, the LED is pulsed at the PRF rate, turning on for a short window in each PRF cycle. Each turning on of the LED results in one sample in the digital data stream. . . . Input offset cancellation DAC cancels DC from both **ambient** and **LED**, and allows a high TIA gain setting for the best noise performance.” Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

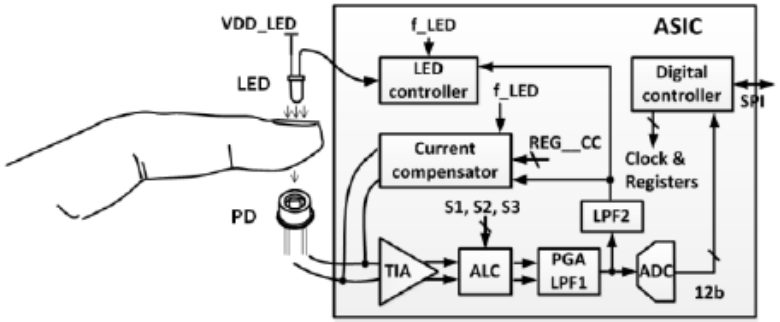
’455 Patent Claim	Samsung Accused System[1]

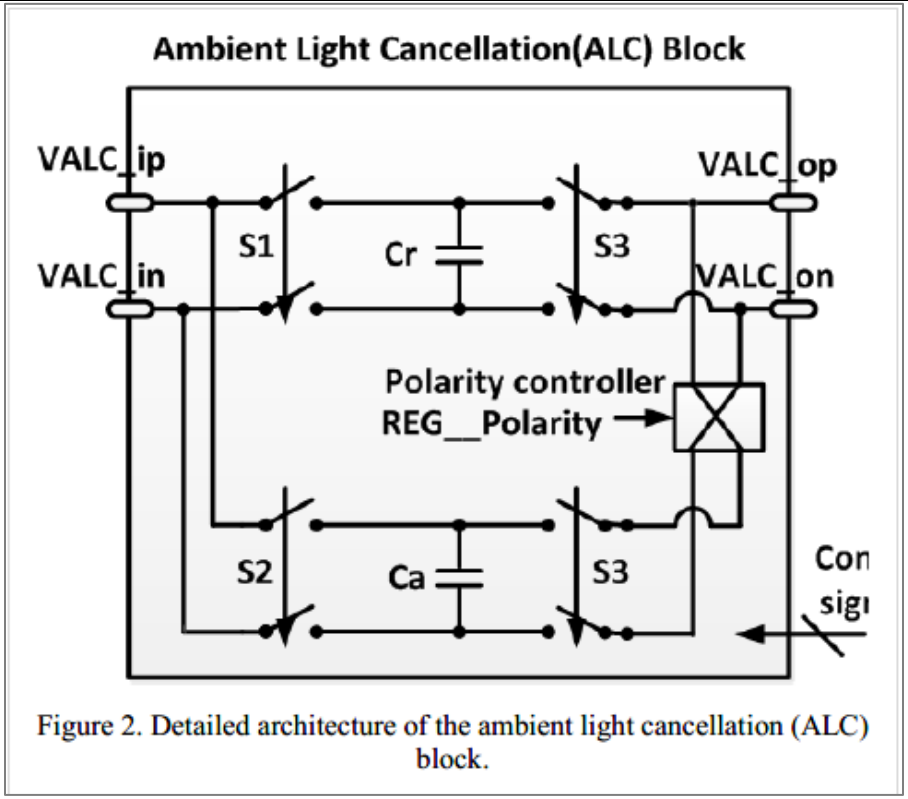


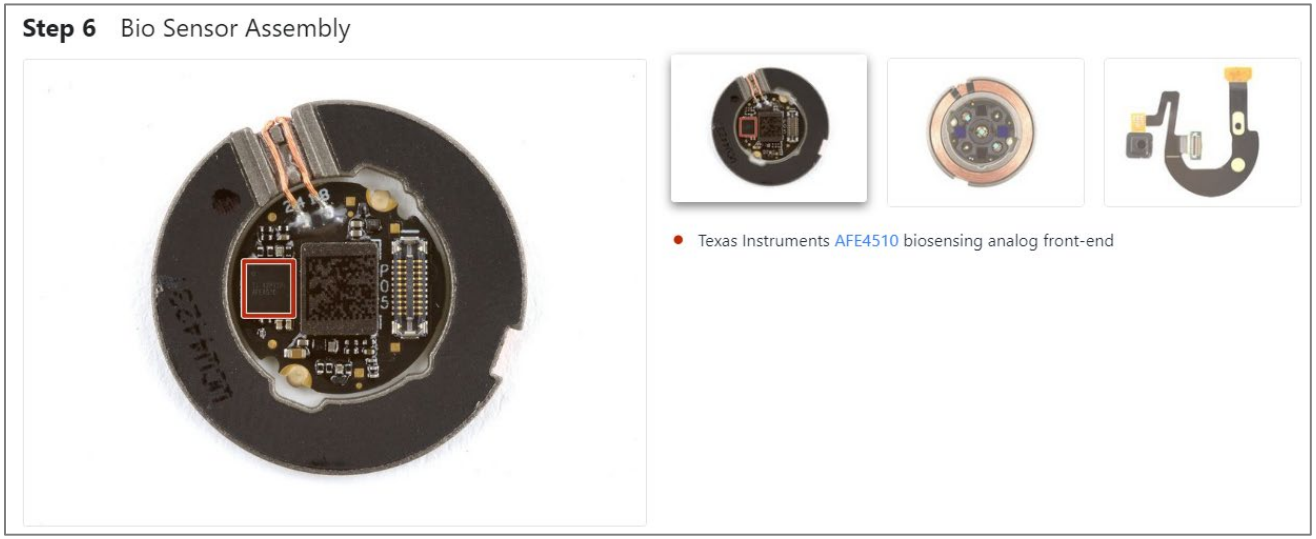


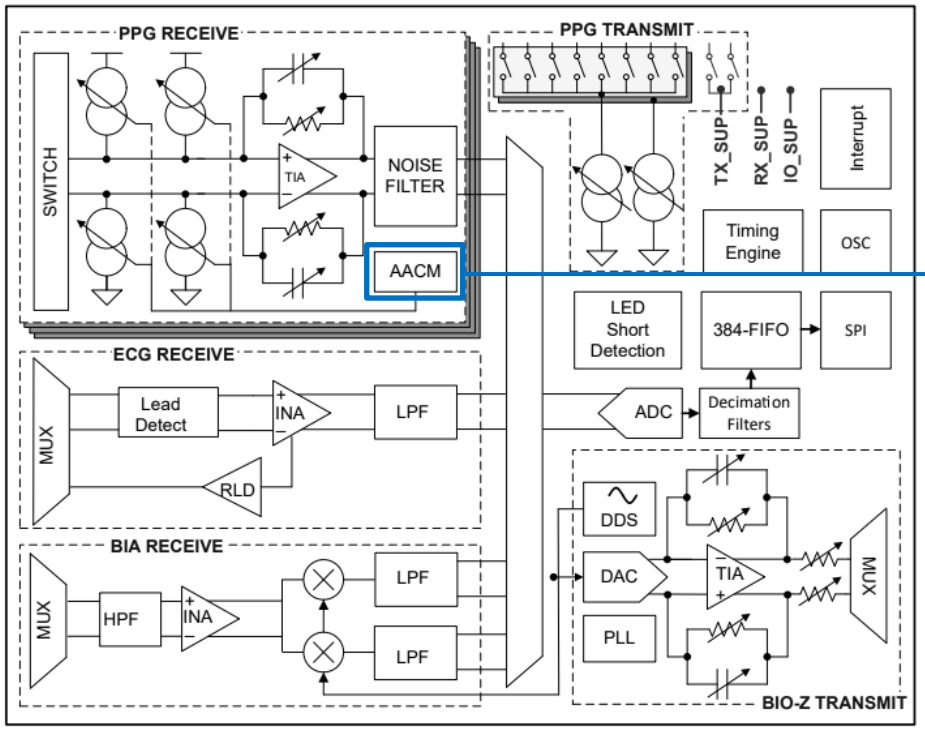
Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

A technical paper authored by Samsung engineers further explains a PPG signal detection system for use in wearable devices configured to operate in an Ambient and LED phase:

'455 Patent Claim	Samsung Accused System[1]
	B. Ambient Light Cancellation (ALC) The ambient light component in the detected PPG signal can be removed in the ALC block, which is shown in Fig. 2. When the LED light turns on, the measured signal corresponding to both the LED light and the ambient light is sampled at the charge reservoir Cr, and when the LED light turns off, the measured signal corresponding to only the ambient light is sampled at an another charge reservoir Ca. Then, the charge redistribution occurs to cancel the ambient  Figure 1. Top block diagram of LED driving and PD detection circuit for PPG application.

’455 Patent Claim	Samsung Accused System[1]
	 Figure 2. Detailed architecture of the ambient light cancellation (ALC) block. Source: J. Kim et al., “Ambient light cancellation in photoplethysmogram application using alternating sampling and charge redistribution technique,” 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), at 6441-42.
8[k] increase the signal-to-noise ratio by comparing the	The detection system in the Accused Smartwatch is configured to **increase the signal-to-noise ratio by comparing the first signal and the second signal**, either literally or under the doctrine of equivalents.

’455 Patent Claim	Samsung Accused System[1]
first signal and the second signal; and	For example, ambient light is considered as noise in PPG sensors. Therefore, the presence of ambient light decreases the SNR of PPG sensors. Ambient light cancellation is performed to cancel out the ambient light noise, thereby increasing the SNR. The BioActive Sensor of the Galaxy Watch Ultra performs ambient light cancellation (also referred to as “Digital Ambient Subtraction”), to increase the SNR, by comparing the measured signal when the LED sources are off (“first signal”) and the measured signal when the LED sources are on (“second signal”).  Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw.

’455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic**

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’455 Patent Claim	Samsung Accused System[1]

Table 1. Specifications for OHRM on Wearables

System Specifications	AFE4432	Comments
Multi-sensor support	4 LEDs, 3 PDs	Combining signals from multiple PDs and LEDs helps mitigate motion artifacts
Sampling rate	1 Hz–1 kHz	A sampling rate of 25 Hz to100 Hz is typically used for continuous HRM
Current consumption	12 µA	For the receiver at 25 Hz PRF
Peak SNR	115 dB over 10-Hz bandwidth	Important consideration to achieve good accuracy in low perfusion cases.
Ambient rejection	> 70 dB up to 160 Hz	Good ambient rejection helps remove the spurious tones caused by ambient light from sources such as indoor lighting

Figure 3 shows the PPG signal chain in AFE4432.

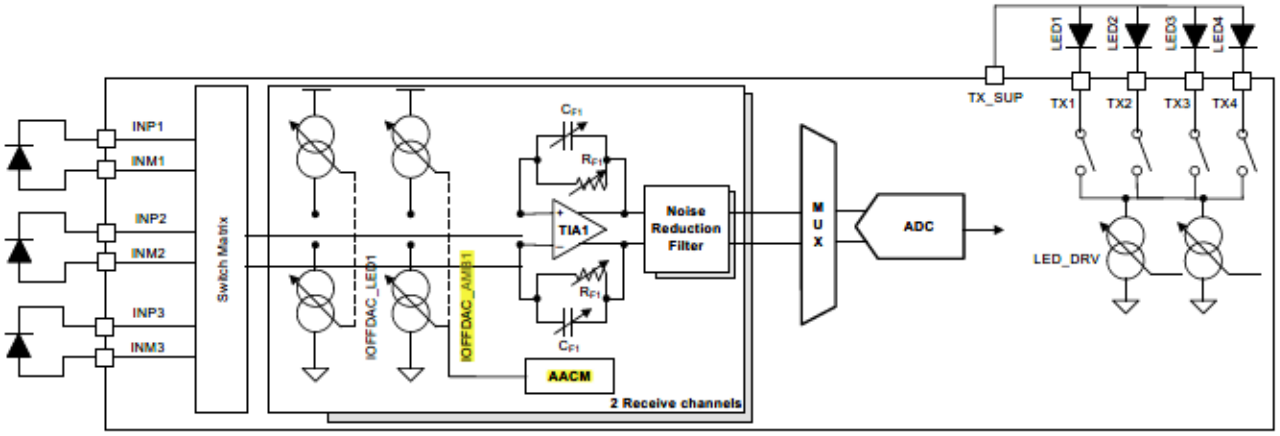


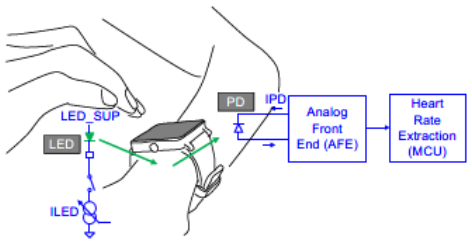
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

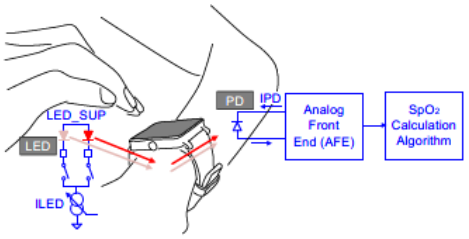
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	Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

TEXAS INSTRUMENTS

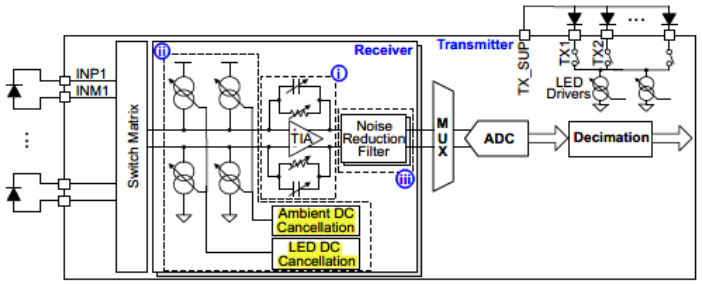
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Heart Rate Monitoring

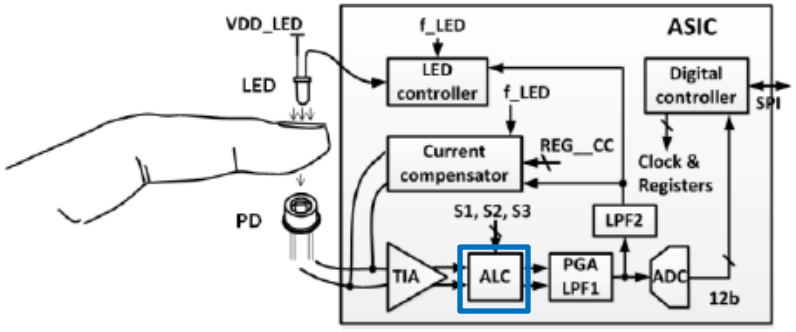


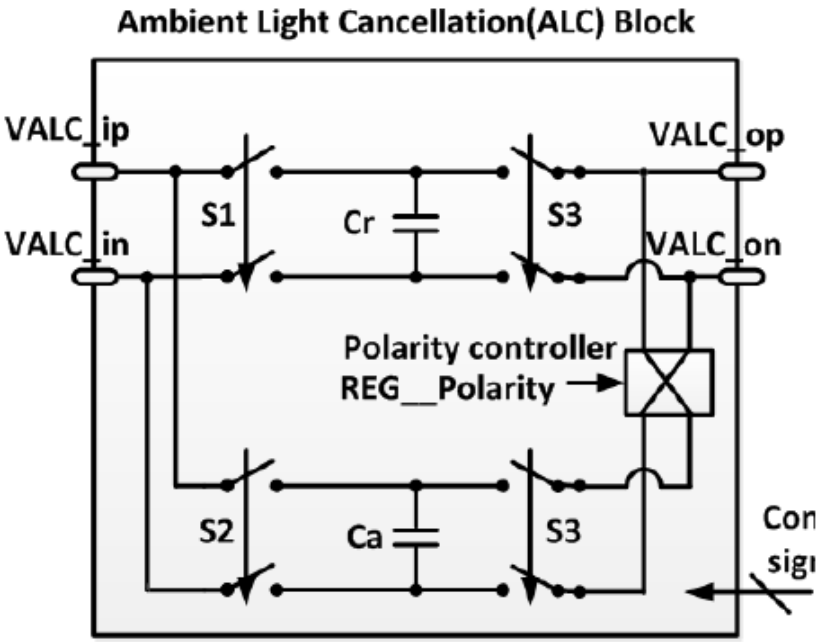
SpO_2 Monitoring

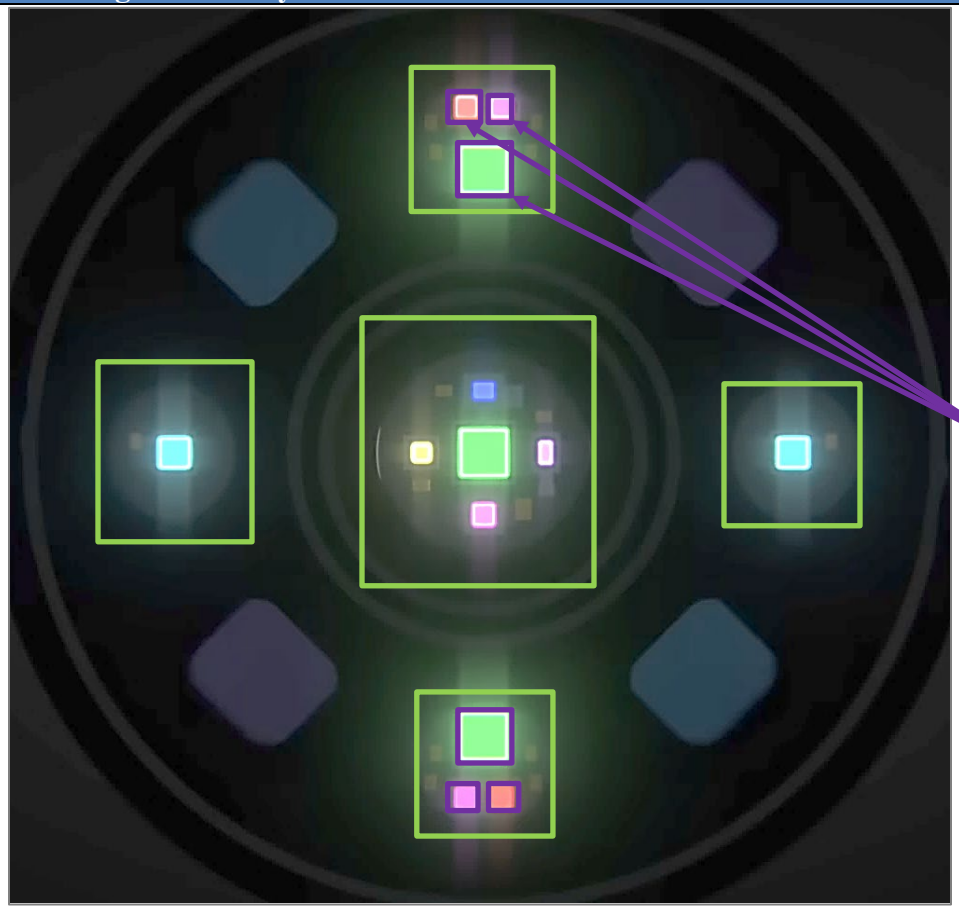


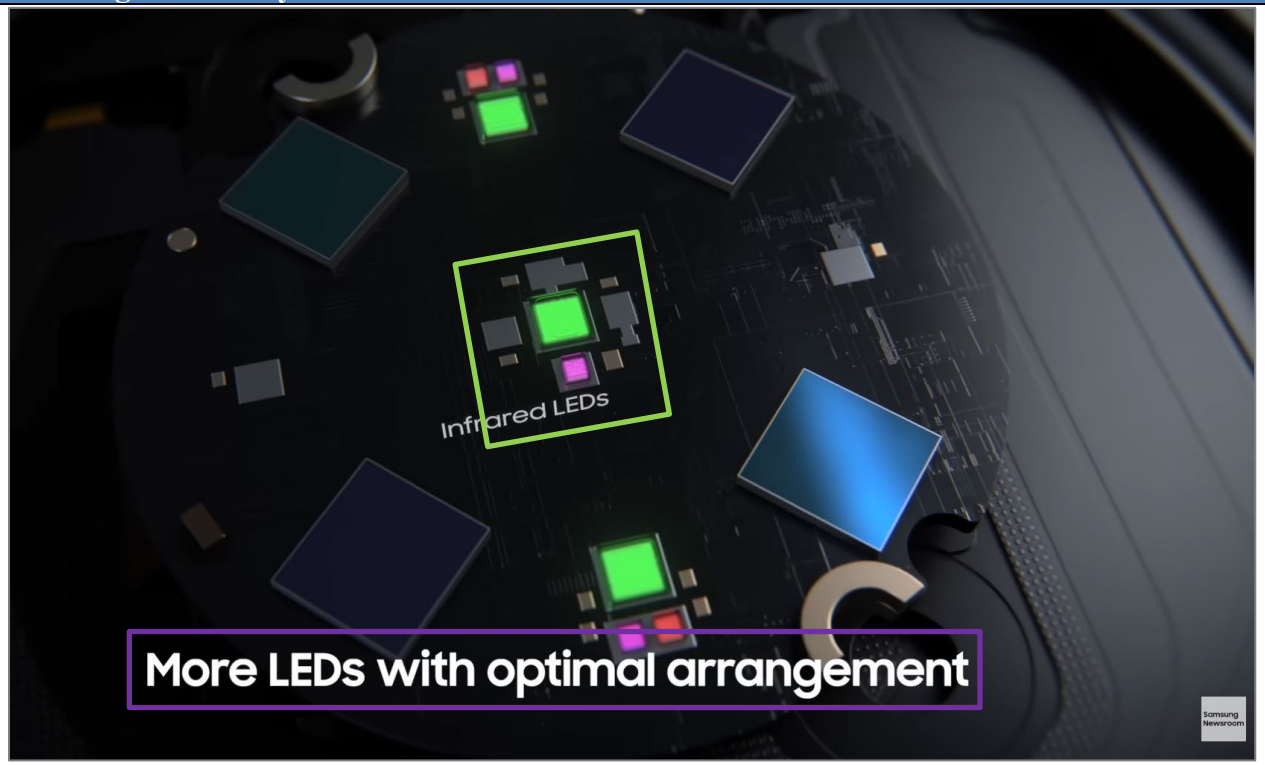
Block Diagram

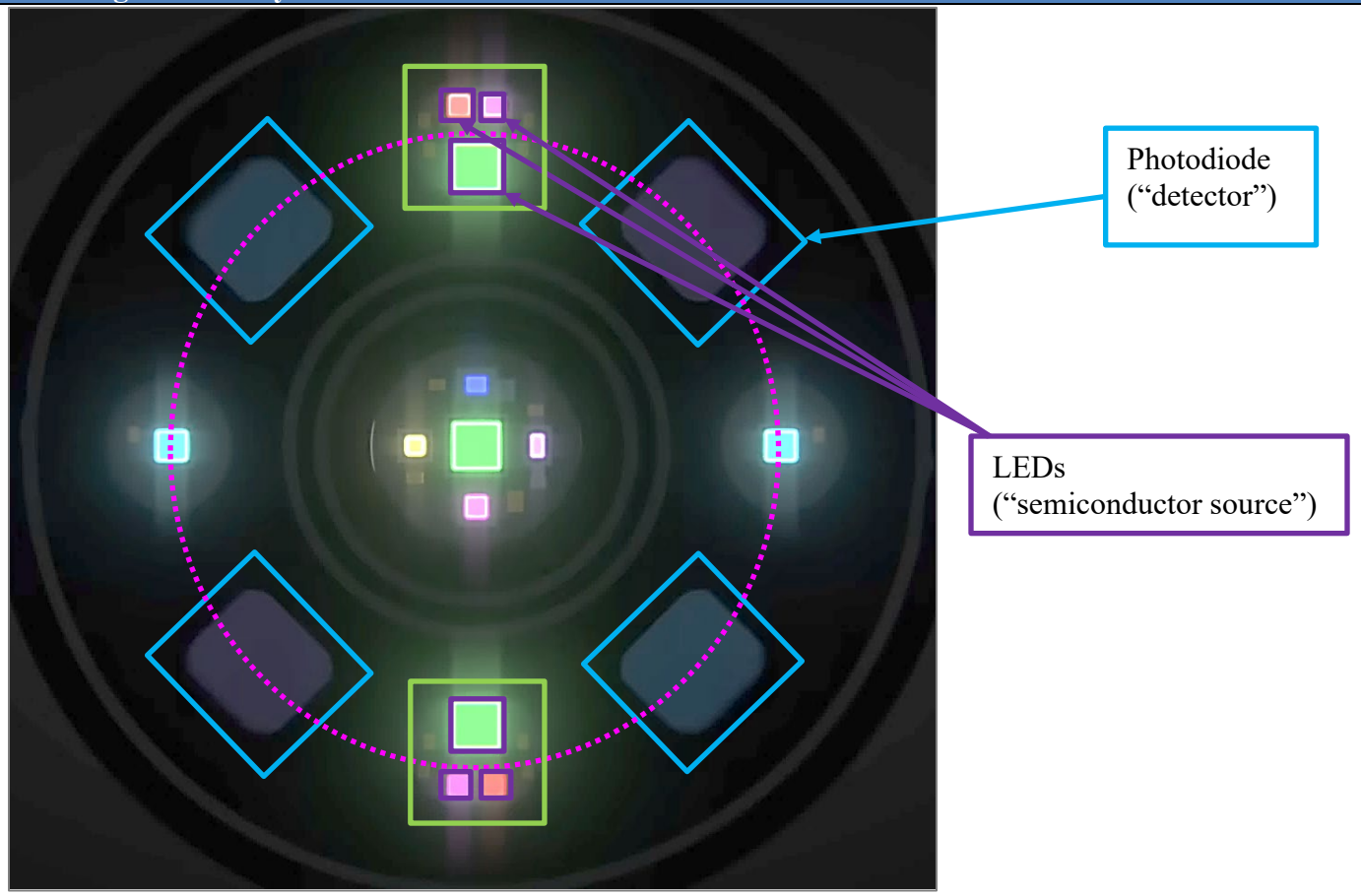
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	Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F. **5 AFE4500 Register Generation Excel** The AFE4500_Register_Generation_v*.xlsm will be given by TI. This configuration file will be in the EVM software installation directory. Default file location: ***C:\Program Files\Texas Instruments\Bio-Sensing\AFE4500EVM\Register config\AFE4500_Register_Generation_v*.xlsm*** By default the EVM ships in LDO enable mode with following configuration • Clocking : Internal oscillator • PPG configuration – PPG output data rate: 50 Hz – 3 Phases (Phase1, Phase2, Phase3) are defined for PPG: AMB1, LED, AMB2 – PPG Phases are sampled from Green PD of sensor board – TX1 (connected to Green LED on sensor board) is used to LED Phase. – TIA Gain (i.e. Rf): 250 kΩ – Sampling width: 117 µS – Noise reduction filter: 2.5 KHz – ANA AACM: Enabled to cancel ambient signal from all Phases – DIG AACM: Enabled to cancel the DC in LED Phase. • ECG Configuration – ECG output data rate: 500 Hz – ECG INA Gain: 21 Source: Texas Instruments, AFE4500 EVM User Guide, SBAU370 – April 2021, at 23, *available at* https://www.manualslib.com/download/2652772/Texas-Instruments-Afe4500evm.html.

'455 Patent Claim	Samsung Accused System[1]
	Samsung engineers authored a technical paper further describing ambient light cancellation in PPG applications for wearable devices: *B. Ambient Light Cancellation (ALC)* The ambient light component in the detected PPG signal can be removed in the ALC block, which is shown in Fig. 2. When the LED light turns on, the measured signal corresponding to both the LED light and the ambient light is sampled at the charge reservoir Cr, and when the LED light turns off, the measured signal corresponding to only the ambient light is sampled at an another charge reservoir Ca. Then, the charge redistribution occurs to cancel the ambient  Figure 1. Top block diagram of LED driving and PD detection circuit for PPG application. light component out by reconnecting the two charge reservoirs in a manner of reversed polarity.

’455 Patent Claim	Samsung Accused System[1]
	 Figure 2. Detailed architecture of the ambient light cancellation (ALC) block. Source: J. Kim et al., “Ambient light cancellation in photoplethysmogram application using alternating sampling and charge redistribution technique,” 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), at 6441-42.
8[l] wherein the plurality of semiconductor sources comprises	The Accused Smartwatch comprises a **plurality of semiconductor sources** which **comprises six light emitting** diodes, either literally or under the doctrine of equivalents.

’455 Patent Claim	Samsung Accused System[1]
six light emitting diodes.	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor
9. The system of claim 8, wherein the plurality of semiconductor sources and the plurality of spatially	In the Accused Smartwatch, **the plurality of semiconductor sources and the plurality of spatially separated detectors are located on one or more arcs**, either literally or under the doctrine of equivalents.

’455 Patent Claim	Samsung Accused System[1]
separated detectors are located on one or more arcs.	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor
10. The system of claim 9, wherein the output optical light comprises three	In the Accused Smartwatch, the plurality of semiconductor sources are configured to generate an output optical light having a plurality of optical wavelengths, **wherein the plurality of optical wavelengths comprises three optical wavelengths for measuring at least a portion of the one or more of the physiological parameters**, either literally or under the doctrine of equivalents.

’455 Patent Claim	Samsung Accused System[1]
optical wavelengths for measuring at least a portion of the one or more of the physiological parameters, and wherein the optical wavelengths comprise near infrared and visible wavelengths.	Samsung states that “[t]he optimal allocation of **Green, Red and Infrared LEDs** sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. **This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels.** Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor.” Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor The SDK supports an **improved health tracking capability to allow your applications to track the user's health data accurately with the accelerometer, raw ECG (Electrocardiogram), PPG (Photoplethysmogram)**, and heart rate including inter-beat interval. In addition, it provides more advanced health features such as the body composition measurement, to enable compelling use cases for health and fitness applications. **The blood oxygen level** and sweat loss after a running workout are also useful data to check a user's health status.” Samsung Developer, “Samsung Privileged Health SDK,” *available at* https://developer.samsung.com/health/privileged/overview.html LEDs outputting light at different colors do so at different optical wavelengths. For example, a green LED, a red LED, and an infrared LED all output light at different optical wavelengths:

'455 Patent Claim	Samsung Accused System[1]

Table 1. LEDs – Wavelengths and Applications	
LED Wavelength (Color)	**LED Applications**
410–420 nm (Violet)	Skin therapy
430–470 nm (Blue)	Dental curing instruments
470 nm (Blue)	White LEDs using phosphor
520–530 nm (Green)	Green traffic signal lights
580–590 nm (Amber)	Amber traffic signal lights
630–640 nm (Red)	Red signal lights
660 nm (Deep Red)	Blood oximetry
680 nm (Deep Red)	Blood analysis
800–850 nm (Near-IR)	Night-vision illuminators and beacons for use with night-vision goggles or CCDs
850–940 nm (Near-IR)	Photoelectric controls
940 nm (Near-IR)	Covert illumination CCD-based systems

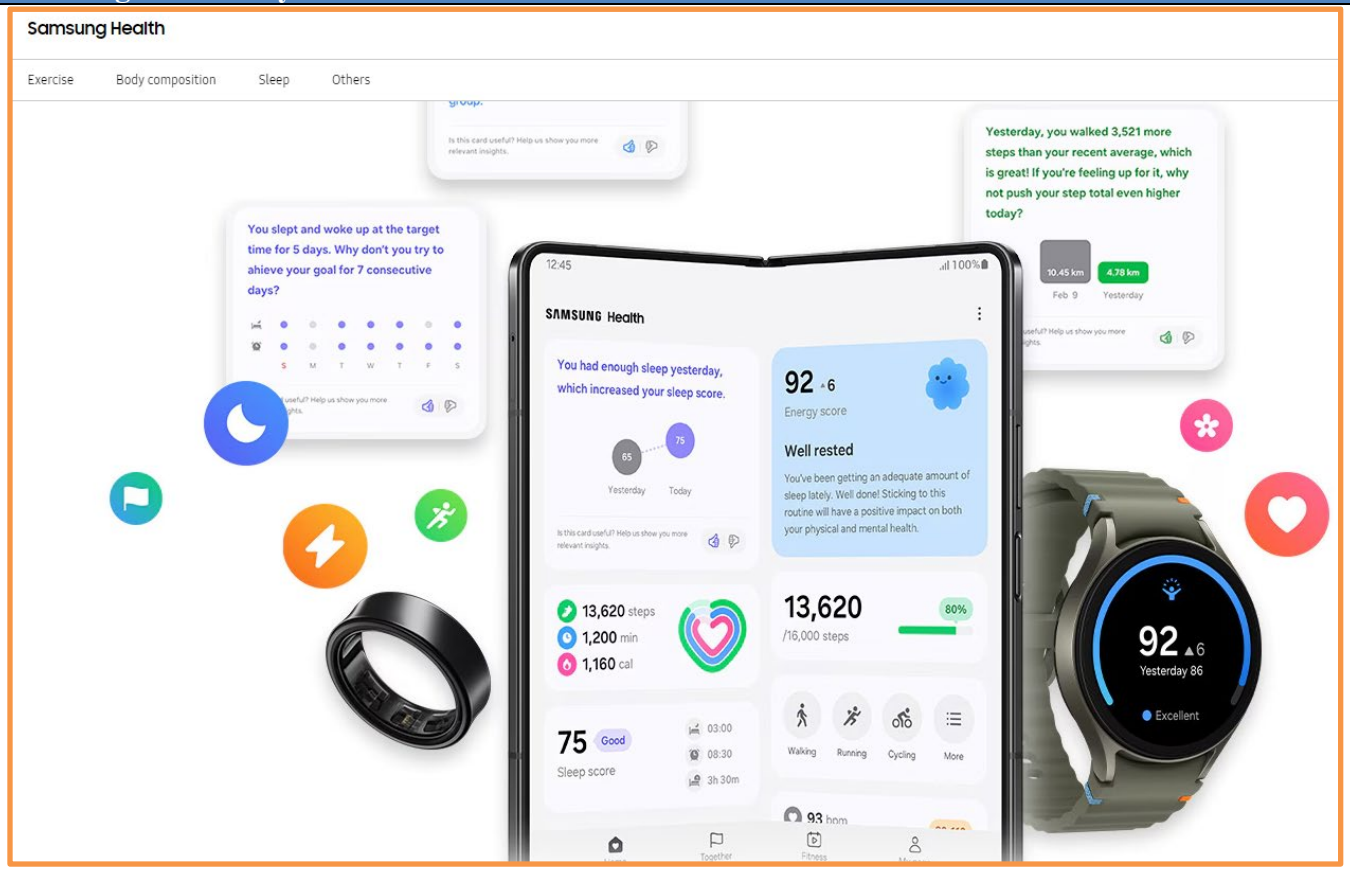
Source: https://www.photonics.com/Articles/Light-Emitting_Diodes_A_Primer/a36706

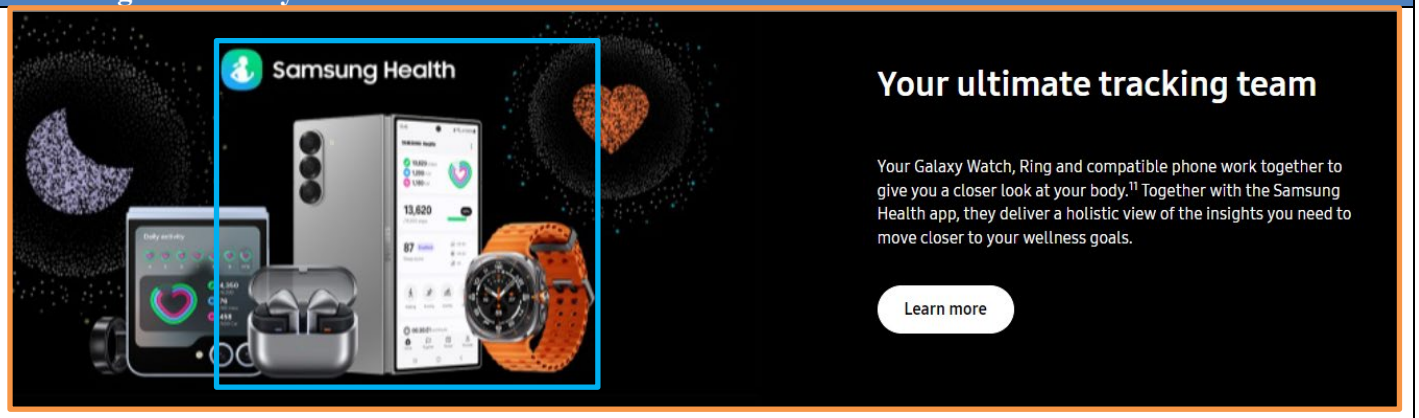
System Specifications	AFE4432	Comments
Multi-sensor support for SpO_2, heart rate monitoring	4 LEDs, 3 photodiodes (PDs)	A typical SpO_2 system can use a green LED in addition to red and infrared (IR) LEDs. The red and IR wavelengths share the same PD, whereas the green wavelength can use a different PD.

Texas Instruments, Application Brief, "Measuring Oxygen Saturation (SpO2) on Wearables," SBAA566, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa566/sbaa566.pdf.

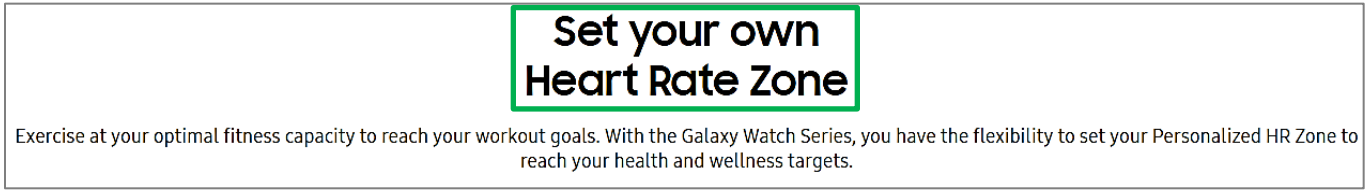
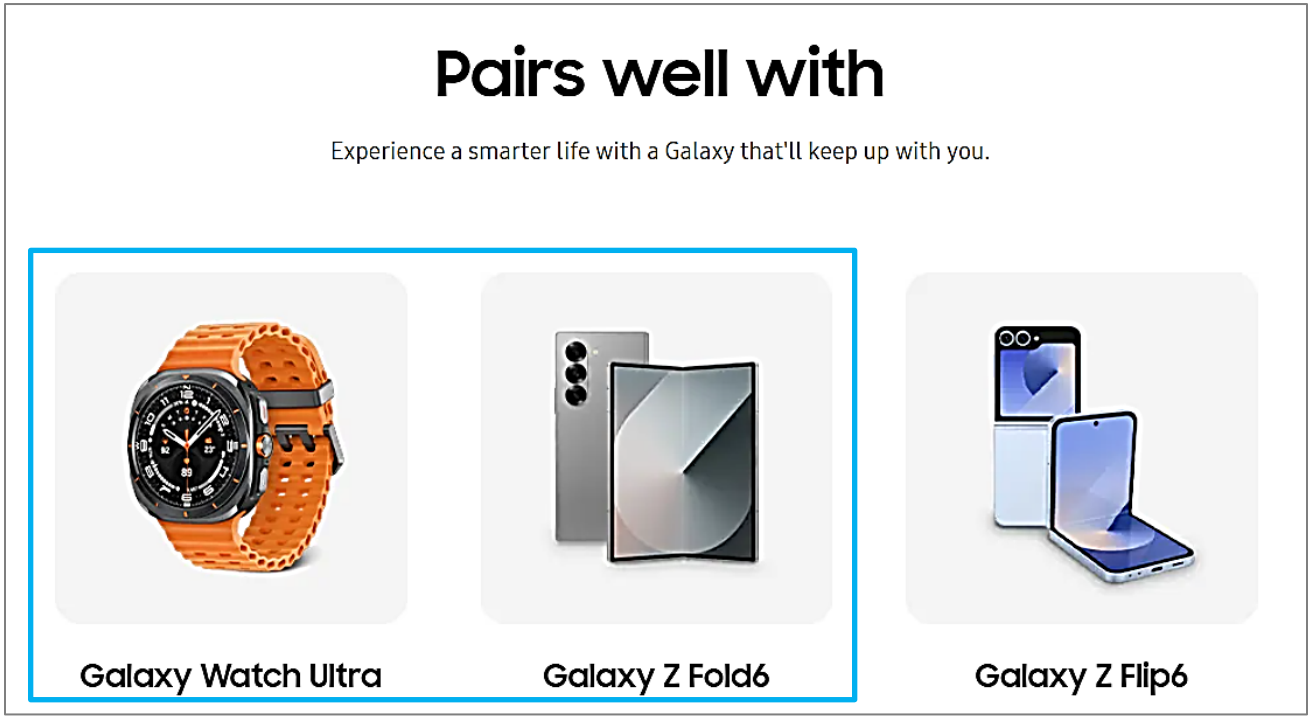
’455 Patent Claim	Samsung Accused System[1]
	Samsung states that “[t]he optimal allocation of **Green, Red,** and Infrared LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor.” Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor **The Visible Light Spectrum** **Color** / **Wavelength (nm)** Red — 625 - 740 Orange — 590 - 625 Yellow — 565 - 590 Green — 520 - 565 Cyan — 500 - 520 Blue — 435 - 500 Violet — 380 - 435

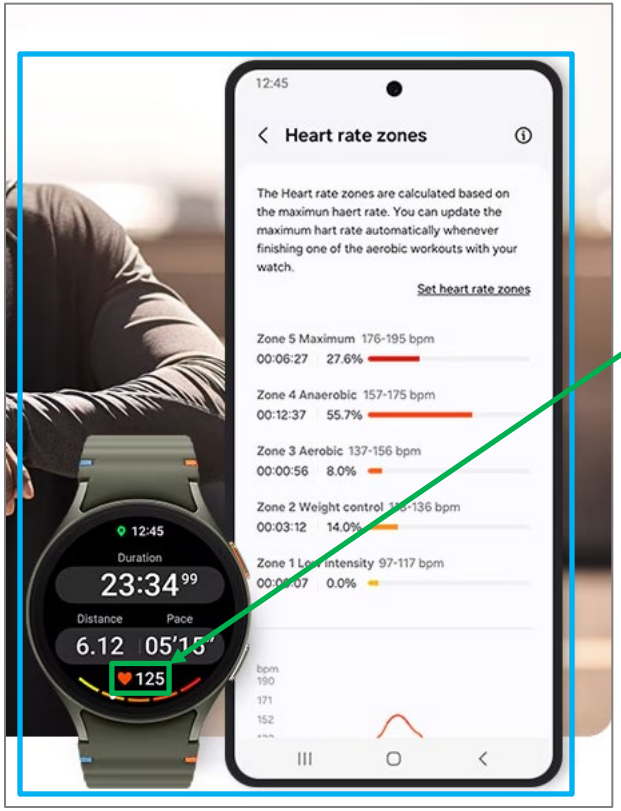
'455 Patent Claim	Samsung Accused System[1]
	Source: https://www.thoughtco.com/the-visible-light-spectrum-2699036
15[Pre] A system for measuring one or more physiological parameters and for use with a smart phone or tablet, the system comprising:	Without conceding that the preamble of Claim 15 is limiting, Samsung has made, used, offered to sell, sold in the United States, and/or has imported into the United States, and/or, continues to make, use, offer to sell, and sell within the United States, and/or imports into the United States, Accused Systems for measuring one or more physiological parameters and for use with a smart phone or tablet, either literally or under the doctrine of equivalents. For example, Samsung provides a system, including a Galaxy Watch Ultra, a Samsung smartphone or tablet, and Samsung Cloud ("system") for measuring "one or more physiological parameters" of a user, such as heart rate, blood oxygen level, and electrocardiogram. When the user wears a Galaxy Watch Ultra on their wrist, the watch measures physiological parameters using various hardware components, such as Samsung's "BioActive sensor," and transfers the information related to these parameters to an Accused Phone/Tablet and to the Accused Cloud.

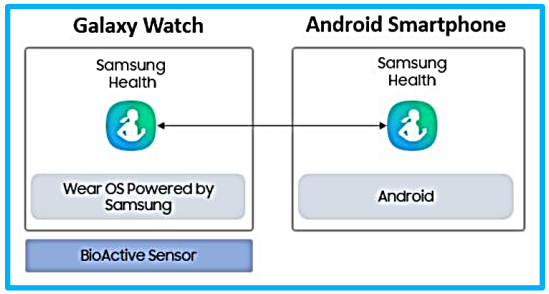
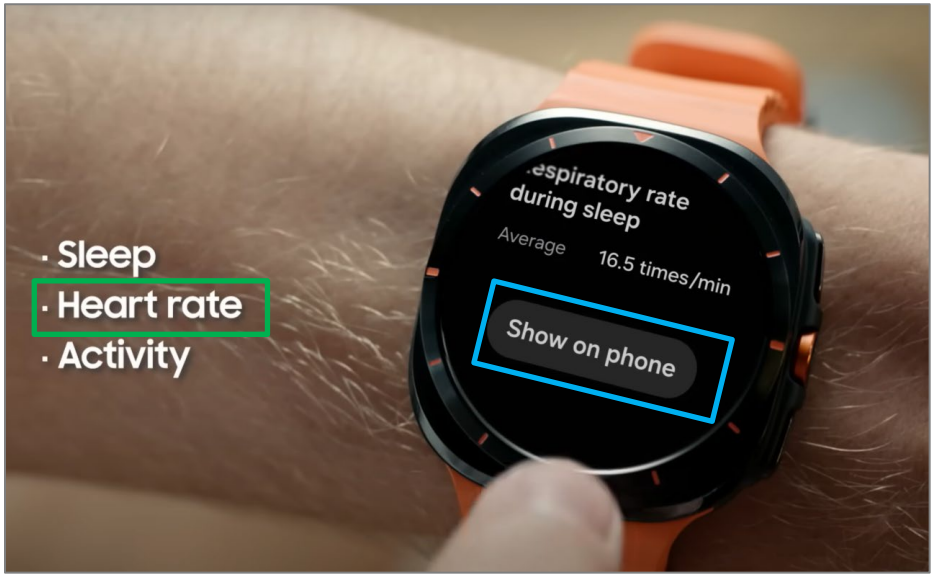
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

'455 Patent Claim	Samsung Accused System[1]
	 **More precise Heart Rate Tracking** Zero in on more precise readings during workouts using Heart Rate Tracking[3, 4, 5] with Galaxy AI[2] that filters out the physical movements of your body. Insights are collected by your Watch and analyzed on your phone. Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/buy/galaxy-watch-ultra-47mm-titanium-gray-sm-l705udaaxaa/

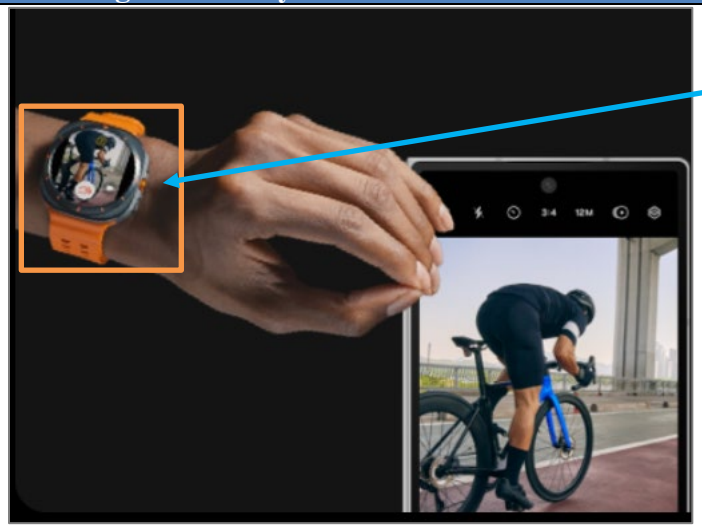
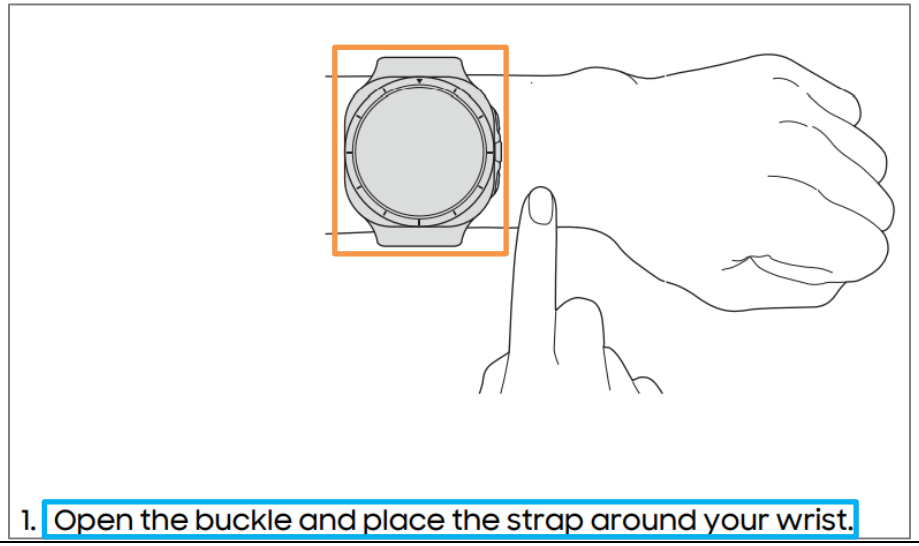
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/#Improve_your_life  Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/#Improve_your_life

'455 Patent Claim	Samsung Accused System[1]
	The Samsung Health application is installed on both the Galaxy Watch and a smartphone. The application synchronizes the measurements between both devices and manages the user's health data securely on them.  Figure 1: Samsung Health on Galaxy Watch and Android smartphone Source: https://developer.samsung.com/health/blog/en/health/blog/accessing-samsung-health-data-through-health-connect 

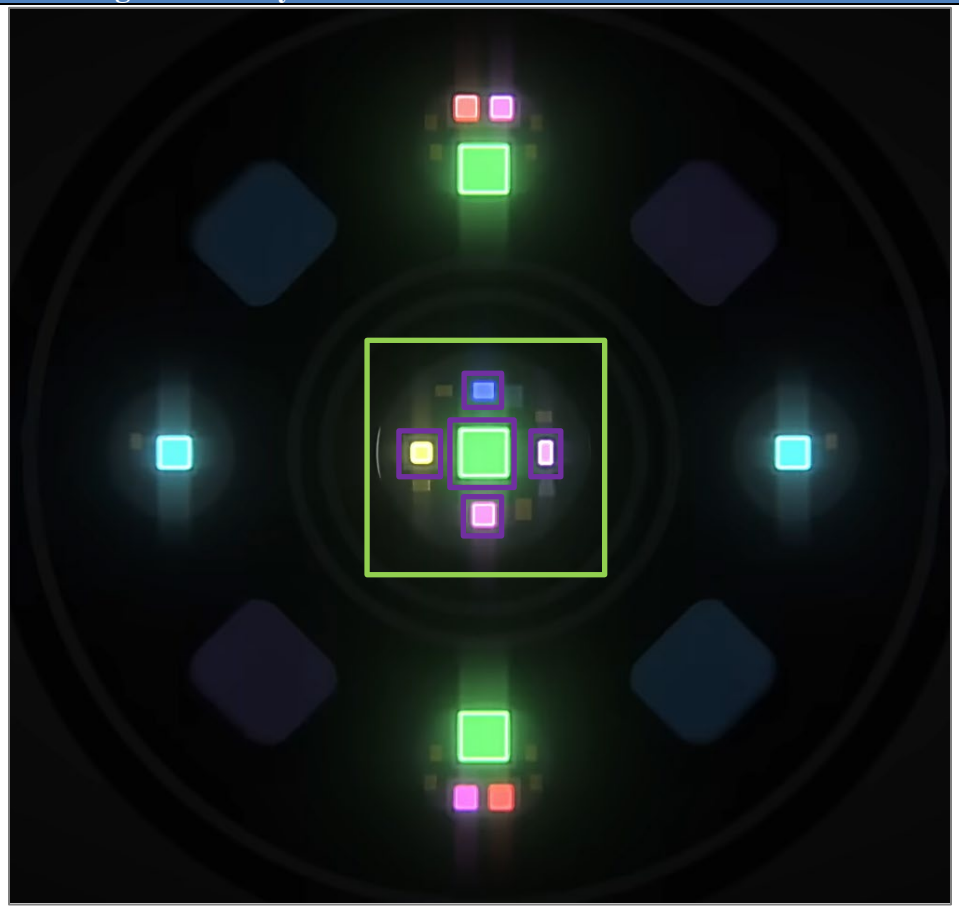
’455 Patent Claim	Samsung Accused System[1]
	Source: https://www.youtube.com/watch?v=VQW-ZpdAm5M  Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/
15[a] a wearable device adapted to be placed on teeth, a wrist, or an ear of a user, including a light source comprising a driver	The Accused System comprises **a wearable device adapted to be placed on** teeth, **a wrist,** or an ear **of a user, and including a light source comprising a driver and a plurality of semiconductor sources** literally or under the doctrine of equivalents. For example, the Accused Smartwatch (“wearable device”) is worn on the wrist of the user.

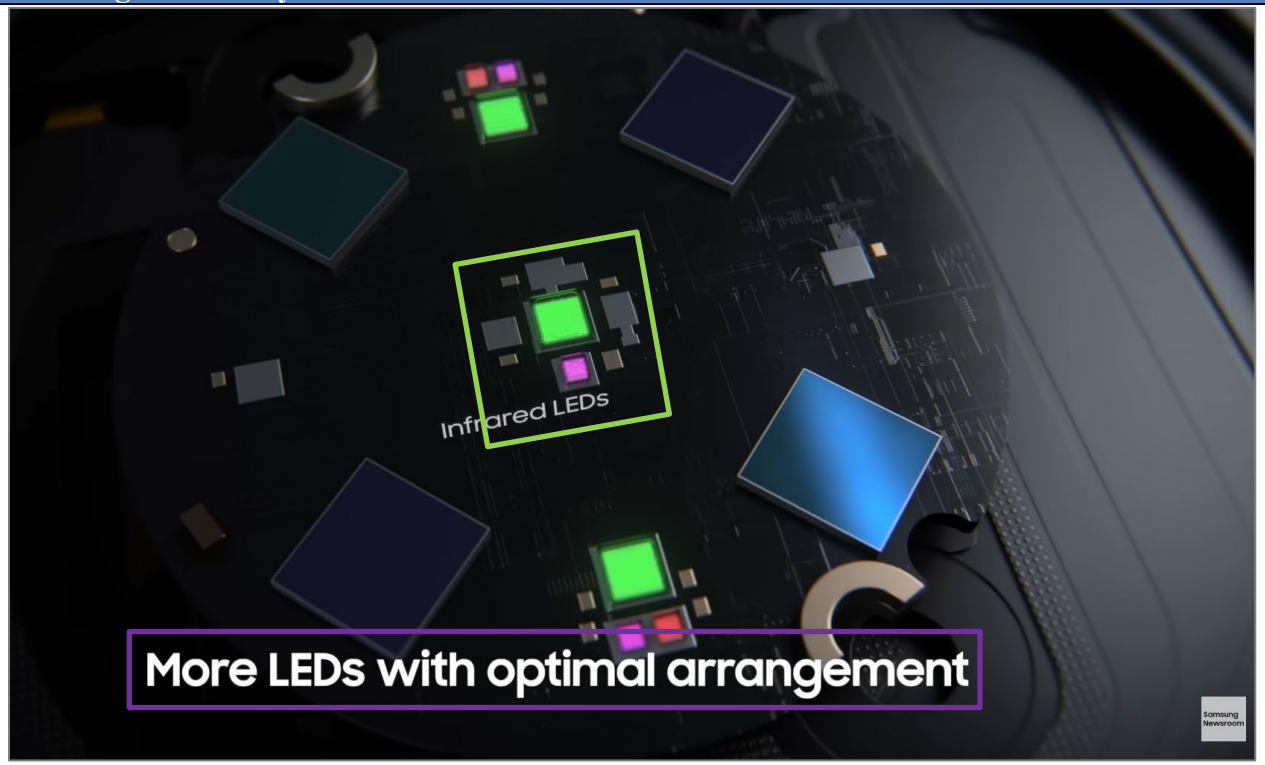
’455 Patent Claim	Samsung Accused System[1]
and a plurality of semiconductor sources that are light emitting diodes,	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/buy/galaxy-watch-ultra-47mm-titanium-gray-sm-l705udaaxaa/

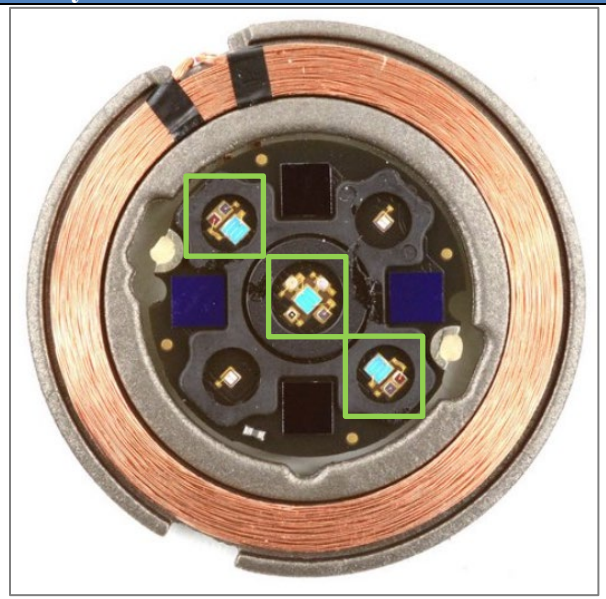
’455 Patent Claim	Samsung Accused System[1]
	 Accused Smartwatch is adapted to be placed on a wrist of a user. Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/  1. Open the buckle and place the strap around your wrist.

'455 Patent Claim	Samsung Accused System[1]
	Source: Samsung Galaxy Watch7 | Watch Ultra User Guide at p. 10, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240717003704208/WEA_L30X_L31X_L70X_EN_UG_XF3_070324_FINAL.pdf. The Accused Smartwatch includes a light source comprising multiple light emitting diodes ("LEDs"), such as a green LED, a red LED, and an infrared LED, each of which includes a "semiconductor source." Samsung states, for example, that its "BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of light-receiving photodiodes, **adding additional colors of light-emitting diodes (LEDs)** and arranging them optimally across the sensor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor Samsung further states that "[**t]he optimal allocation of Green, Red and Infrared LEDs** sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

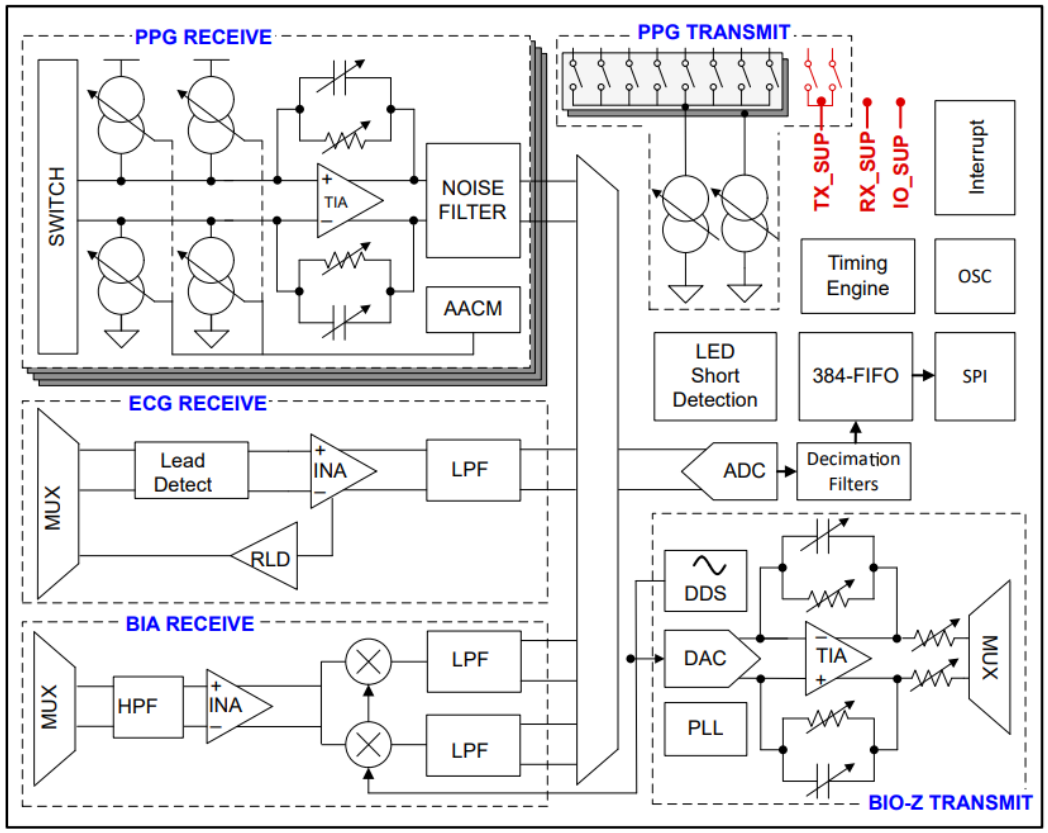
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
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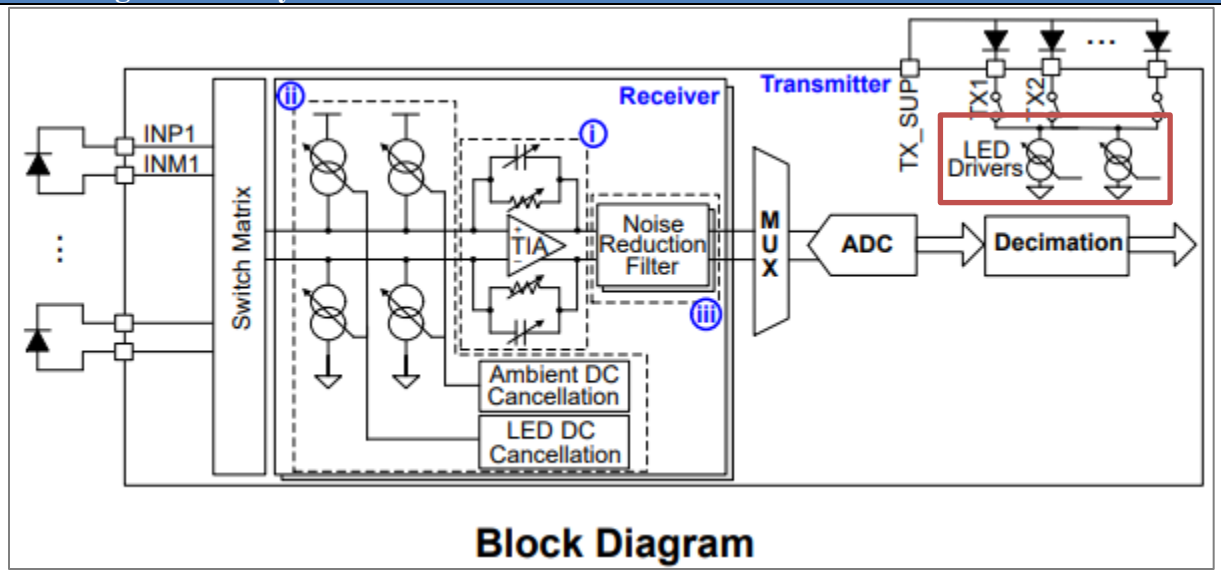
’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 “The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. A PPG signal chain comprises **a current driver for LEDs** and a receiver that senses the signal from PDs. An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.” Texas Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]

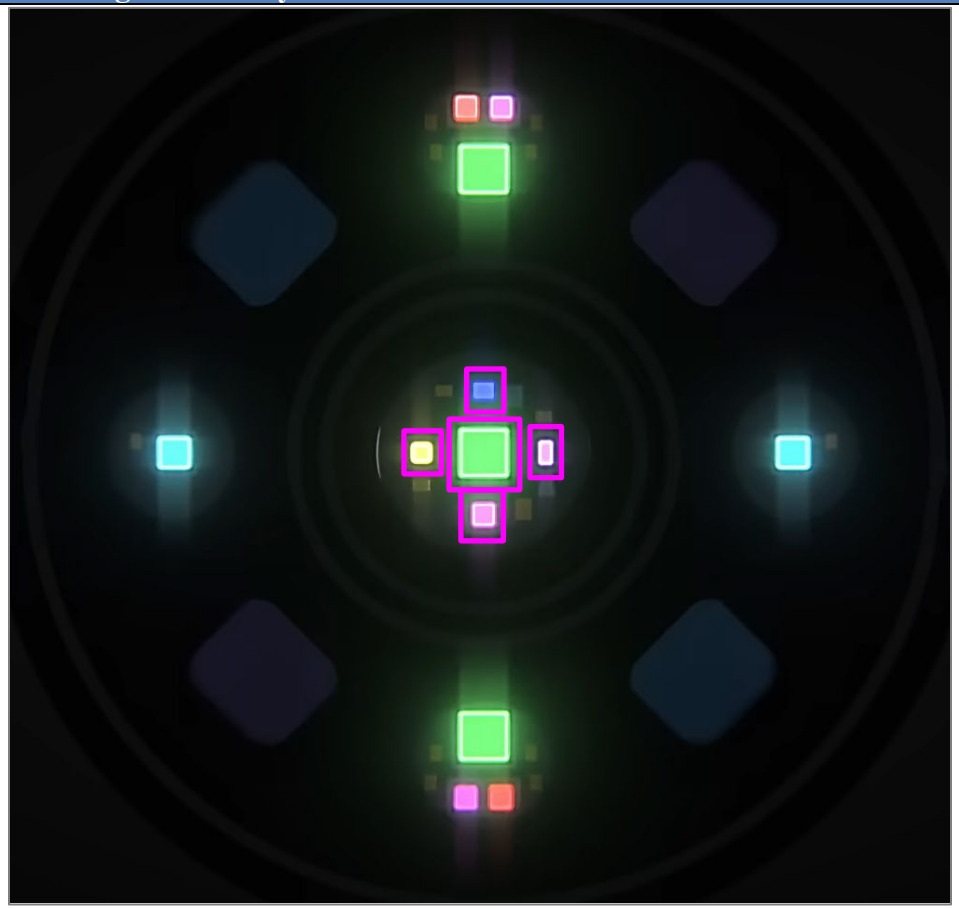


Simplified Schematic

Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

'455 Patent Claim	Samsung Accused System[1]
	 Source: Texas Instruments, Product Overview, "Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing," Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.
15[b] the light emitting diodes configured to generate an output optical light having one or more optical wavelengths;	In the Accused Smartwatch, **the LEDs are configured to generate an output optical light having a plurality of optical wavelengths**, literally or under the doctrine of equivalents. For example, the Accused Smartwatch includes multiple LEDs ("semiconductor sources"), such as a green LED, a red LED, and an infrared LED. Different color LEDs and infrared LEDs each generate output optical light having different optical wavelengths. Samsung states that "[t]he optimal allocation of **Green, Red and Infrared** LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of

’455 Patent Claim	Samsung Accused System[1]
	health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor.” Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor The following data types are supported by the Samsung Privileged Health SDK: **PPG green** — Raw data from PPG green LED. Provided as a batching event. **PPG IR** — Raw data from PPG infrared LED. Provided as an on-demand event. **PPG red** — Raw data from PPG red LED. Provided as an on-demand event. Source: Samsung Developer, Samsung Privileged Health SDK, *available at* https://developer.samsung.com/health/privileged/overview.html

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327

<table>
<tr><th>’455 Patent Claim</th><th>Samsung Accused System[1]</th></tr>
<tr><td></td><td>LEDs outputting light at different colors do so at different optical wavelengths. For example, a green LED, a red LED, and an infrared LED all output light at different optical wavelengths:

<table>
<tr><th colspan="2">Table 1. LEDs – Wavelengths and Applications</th></tr>
<tr><th>LED Wavelength (Color)</th><th>LED Applications</th></tr>
<tr><td>410–420 nm (Violet)</td><td>Skin therapy</td></tr>
<tr><td>430–470 nm (Blue)</td><td>Dental curing instruments</td></tr>
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<tr><td>520–530 nm (Green)</td><td>Green traffic signal lights</td></tr>
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<tr><td>630–640 nm (Red)</td><td>Red signal lights</td></tr>
<tr><td>660 nm (Deep Red)</td><td>Blood oximetry</td></tr>
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<tr><td>800–850 nm (Near-IR)</td><td>Night-vision illuminators and beacons for use with night-vision goggles or CCDs</td></tr>
<tr><td>850–940 nm (Near-IR)</td><td>Photoelectric controls</td></tr>
<tr><td>940 nm (Near-IR)</td><td>Covert illumination CCD-based systems</td></tr>
</table>
Source: https://www.photonics.com/Articles/Light-Emitting_Diodes_A_Primer/a36706</td></tr>
<tr><td><u>15[c]</u> the wearable device comprising one or more lenses</td><td>The Accused System comprises a wearable device comprising one or more lenses configured to receive at least a portion of the output optical light and to deliver a lens output light to tissue, literally or under the doctrine of equivalents.</td></tr>
</table>

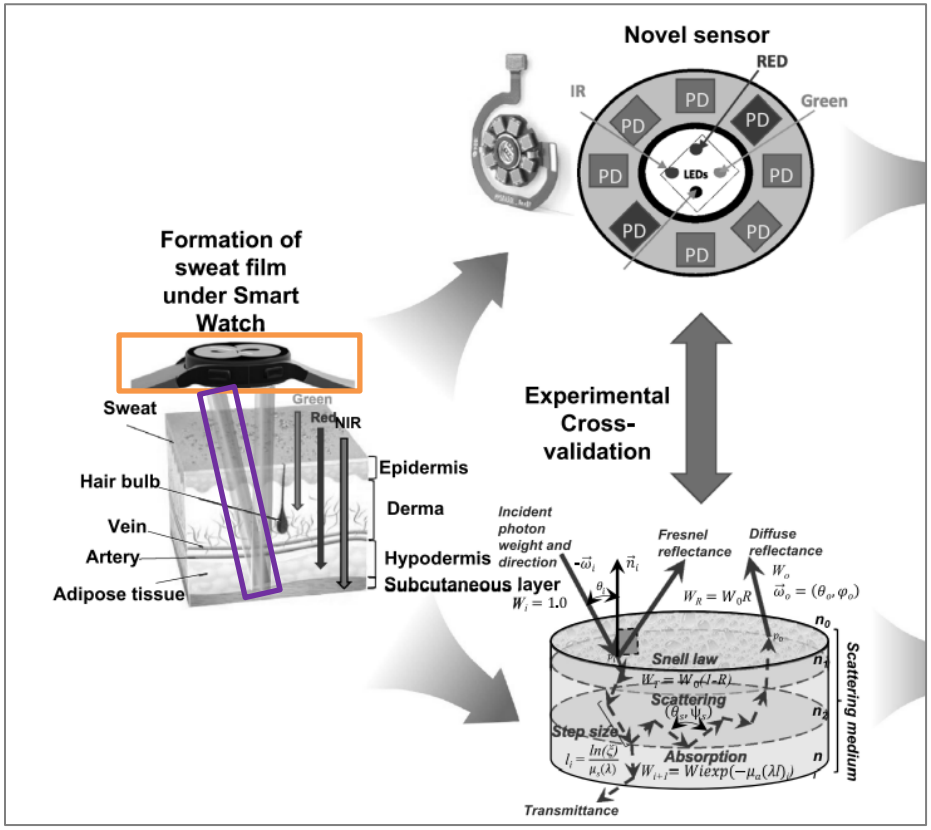
'455 Patent Claim	Samsung Accused System[1]
configured to receive at least a portion of the output optical light and to deliver a lens output light to tissue;	For example, the Accused Smartwatch ("wearable device") comprises one or more lenses positioned between LEDs and the wrist of a user when worn by the user. The lenses receive output optical light from the LEDs and deliver the light to tissue of the user (*e.g.*, skin, blood vessels, veins).  Source: https://www.youtube.com/watch?v=lZ6Q7JqtiA0 Samsung states that "[t]he **Galaxy Watch** uses light sensors that operate within the limits set by the IEC62471 safety regulations. However, **people with photosensitive skin may have adverse reactions to light,** such as skin discoloration or a rash." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor. Thus, the one or more lenses in the Accused Smartwatch delivers light that is output from the LEDs to skin of the user ("lens output light to tissue").

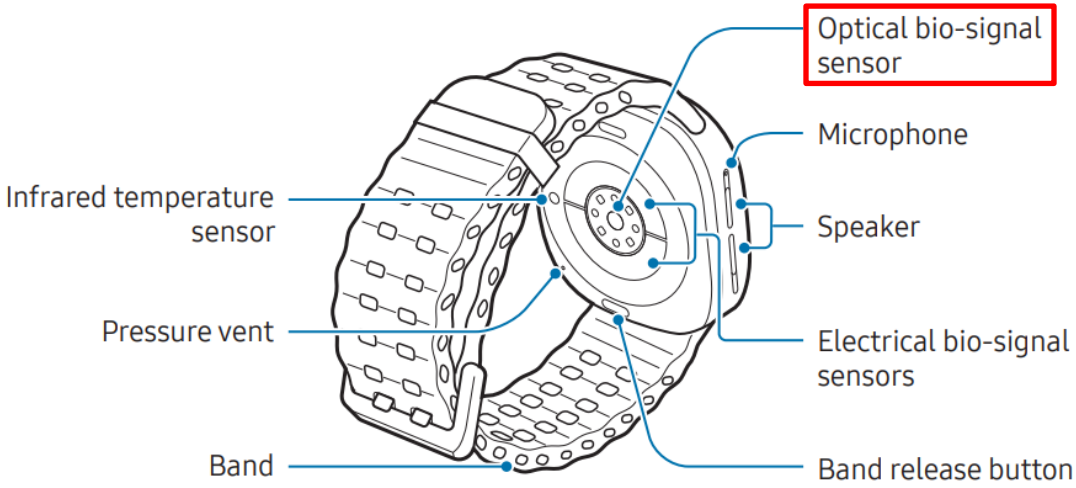
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=lZ6Q7JqtiA0 

'455 Patent Claim	Samsung Accused System[1]
	Source: https://www.youtube.com/watch?v=jlW0i7u4FVk Additionally, in a technical paper, Samsung engineers and pixel designers for photoplethysmography ("PPG") sensors explained "**applying micro lenses**" and using "**micro lens** focusing" techniques to enhance the delivery of infrared ("IR") light sources. J. Lim et al., "A single chip PPG sensor with enhanced IR sensitivity for low power and small size," 2021 IS&T Int'l Symp. Elec. Imaging, at 2-3, *available at* https://library.imaging.org/admin/apis/public/api/ist/website/downloadArticle/ei/33/7/art00002. Samsung's Galaxy Watch7 and Watch Ultra user guide also states the following: "The accuracy of the information and data provided by this device and its related software, including heart rate readings, may be affected by factors such as environmental conditions, **skin condition**, specific activity performed while using/wearing the device, settings of the device, user configuration/user-provided information, **placement of the sensor on the body**, and other end-user interactions." Samsung Galaxy Watch7 | Watch Ultra User Guide, at p. 42, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240717003704208/WEA_L30X_L31X_L70X_EN_UG_XF3_070324_FINAL.pdf. The Accused Smartwatch ("wearable device") utilizes a biosensor manufactured by Texas Instruments ("TI")—*e.g.*, an analog front end ("AFE") integrated circuit component for PPG, electrocardiography ("ECG") and other biosensing applications.

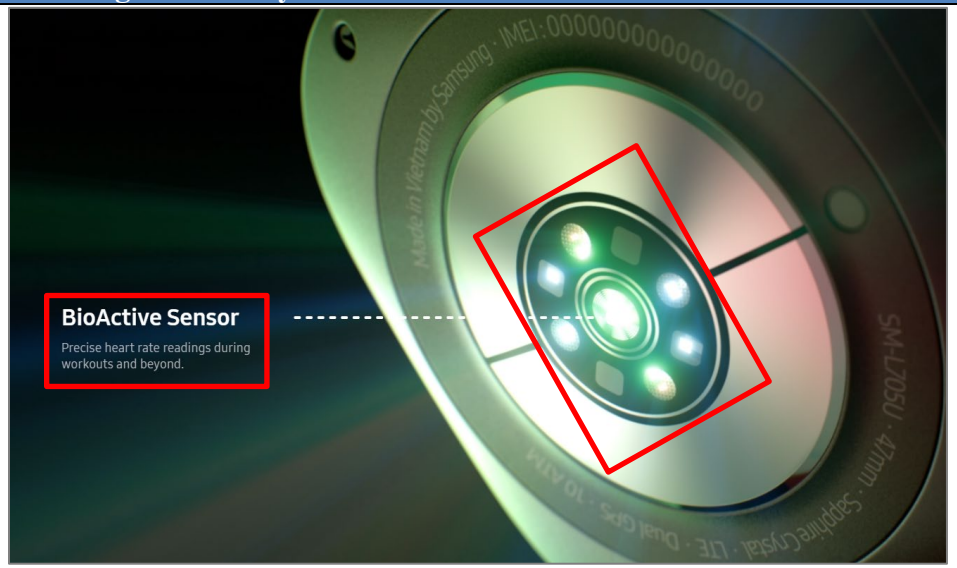
’455 Patent Claim	Samsung Accused System[1]
	Step 6 Bio Sensor Assembly   • Texas Instruments AFE4510 biosensing analog front-end Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw. Such AFEs from TI include AFE44S30, AFE4432, AFE44I30, AFE4460, AFE49I30, AFE4950, AFE4500. *See* Texas Instruments, Biosensing AFEs, https://www.ti.com/data-converters/integrated-special-function/medical-afes/biosensing-afes/overview.html. TI’s AFEs enable wearable devices to perform multiple optical biosensing applications. For example, TI explains in a technical paper:

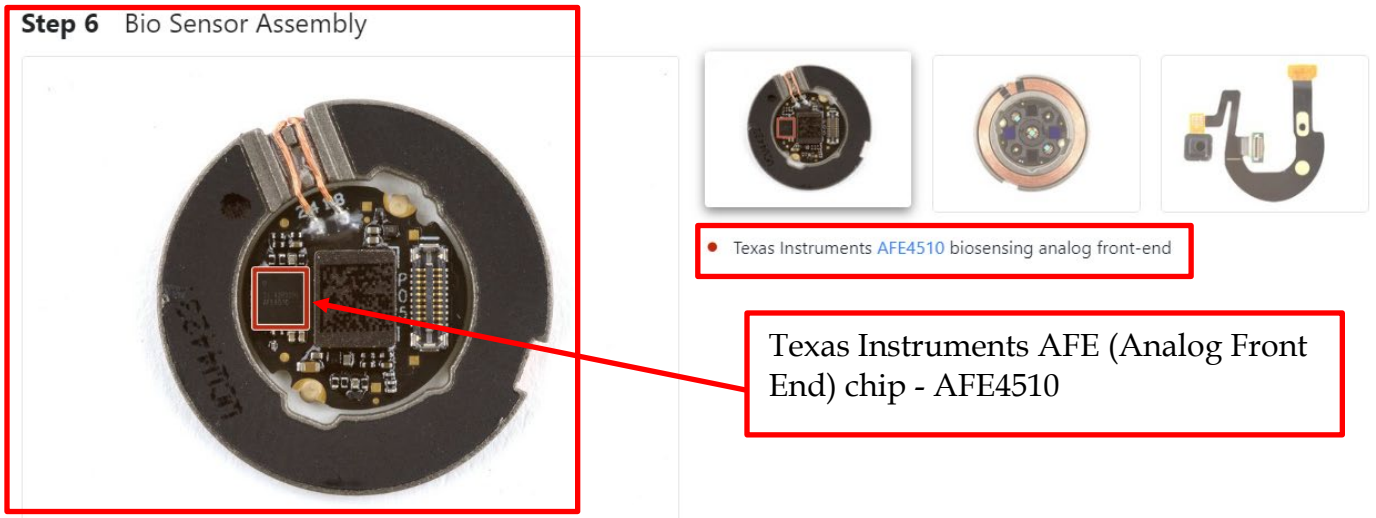
'455 Patent Claim	Samsung Accused System[1]
	Application *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR). In a device like a smartwatch, the LED and PD both face the wrist. The light from the LED is incident on the skin, and the reflection of the light from the artery results in a pulsating component. Typically, green LEDs are used, and the signal from multiple spatially-separated PDs are combined to mitigate effects such as motion. Texas Instruments, Application Brief, "Optical Heart Rate Monitoring (OHRM) on Wearables," SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

’455 Patent Claim	Samsung Accused System[1]
	Additionally, the following scientific report authored by multiple Samsung engineers further shows lens output light being delivered to tissue of the user:  Source: E. Volkova et al., “Multispectral sensor fusion in SmartWatch for in situ continuous monitoring of human skin hydration and body sweat loss,” Scientific Reports (2023), at 3, *available at* https://www.nature.com/articles/s41598-023-40339-7.pdf.

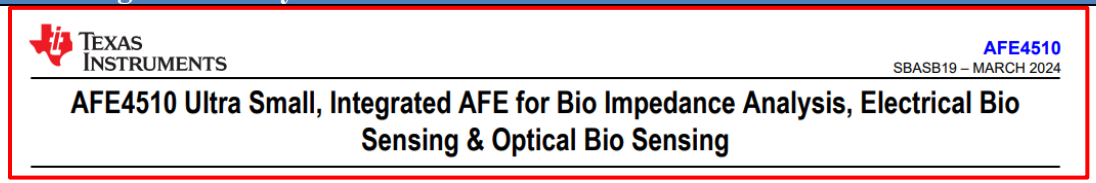
'455 Patent Claim	Samsung Accused System[1]
15[d] the wearable device further comprising a detection system configured to receive at least a portion of the lens output light reflected from the tissue and to generate an output signal having a signal-to-noise ratio,	The **wearable device** of the Accused System further comprises **a detection system configured to receive at least a portion of the lens output light reflected from the tissue and to generate an output signal having a signal-to-noise ratio**, literally or under the doctrine of equivalents. For example, the BioActive Sensor in the Accused Smartwatch ("wearable device") comprises a detection system that: (a) receives light initially output from LEDs and then reflected from tissue of a user, and (b) generates an output PPG signal having a signal-to-noise ratio.  Source: Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 8, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf; *see also* Samsung Developer, Samsung Privileged Health SDK, *available at* https://developer.samsung.com/health/privileged/overview.html.

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 The AFE4510 specification (excerpts shown below) describes a PPG signal receiver, a PPG signal transmitter, and PPG signal acquisition functionality for receiving light output by LEDs that is reflected from skin and body tissue of the user (*e.g.*, by photodiodes (“PDs”)), and for converting the received light into—*i.e.*, generating—a PPG output signal having some signal-to-noise ratio (“SNR”).

’455 Patent Claim	Samsung Accused System[1]



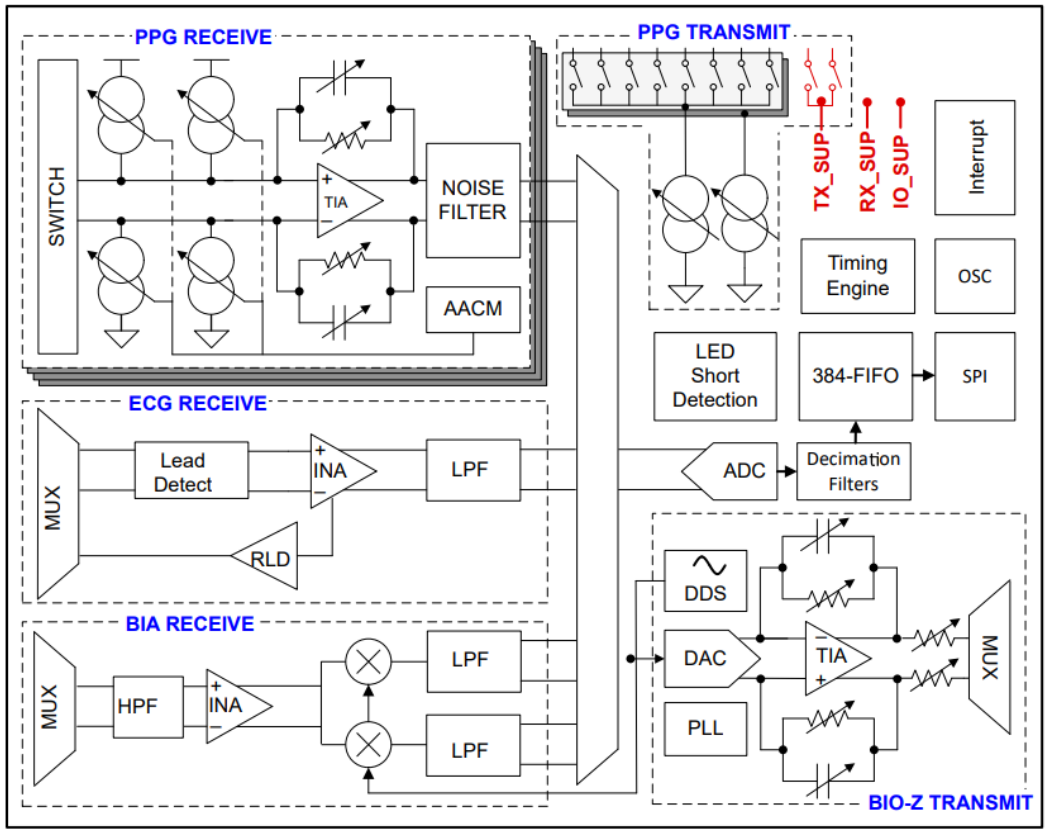
TEXAS INSTRUMENTS

AFE4510
SBASB19 – MARCH 2024

AFE4510 Ultra Small, Integrated AFE for Bio Impedance Analysis, Electrical Bio Sensing & Optical Bio Sensing

- **PPG signal acquisition:**
  - Acquisition of 24 PPG signal sets (LED, AMB)
  - Supports PPG sensors at different data rates
  - Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement
  - Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver
- **PPG Transmitter:**
  - 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA
  - LED Short Detection
  - Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy
- **PPG Receiver:**
  - Supports 5 PDs, 4 parallel receive paths
  - Noise filtering with programmable bandwidth
  - Trans-impedance Gain: 3.7kΩ to 1MΩ
  - 8-bit Ambient Offset Subtraction DAC up to 256µA
  - 9-bit LED Offset Subtraction DAC up to 64µA
  - Digital Ambient Subtraction at ADC Output

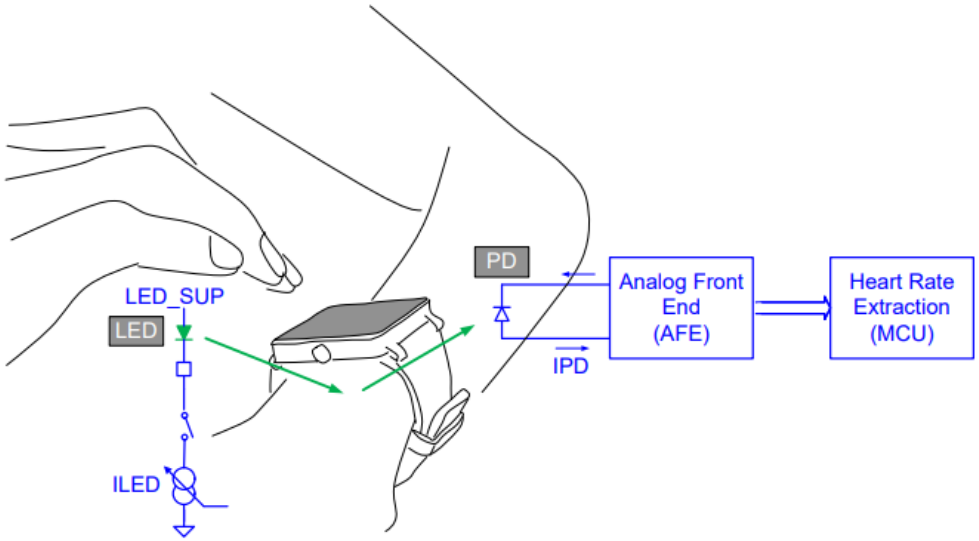
’455 Patent Claim	Samsung Accused System[1]



Simplified Schematic

Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

'455 Patent Claim	Samsung Accused System[1]
	The BioActive Sensor ("detection system") in the Accused Smartwatch is configured to receive lens output light that is reflected from body tissue of the user and to generate and output PPG signal to enable multiple biosensing applications, including optical heart rate monitoring ("OHRM"). For example, TI explains OHRM using its AFE biosensors as follows: *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR). In a device like a smartwatch, the LED and PD both face the wrist. The light from the LED is incident on the skin, and the reflection of the light from the artery results in a pulsating component. Typically, green LEDs are used, and the signal from multiple spatially-separated PDs are combined to mitigate effects such as motion.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 1. Heart Rate Monitoring on a Wearable Device** Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf. An exemplary “PPG signal chain” for a TI AFE biosensor (shown below) further illustrates how the BioActive Sensor (“detection system”) of the Accused Smartwatch is configured to receive a lens output light reflected from tissue of a user and generate a PPG output signal.

’455 Patent Claim	Samsung Accused System[1]

Figure 3 shows the PPG signal chain in AFE4432.

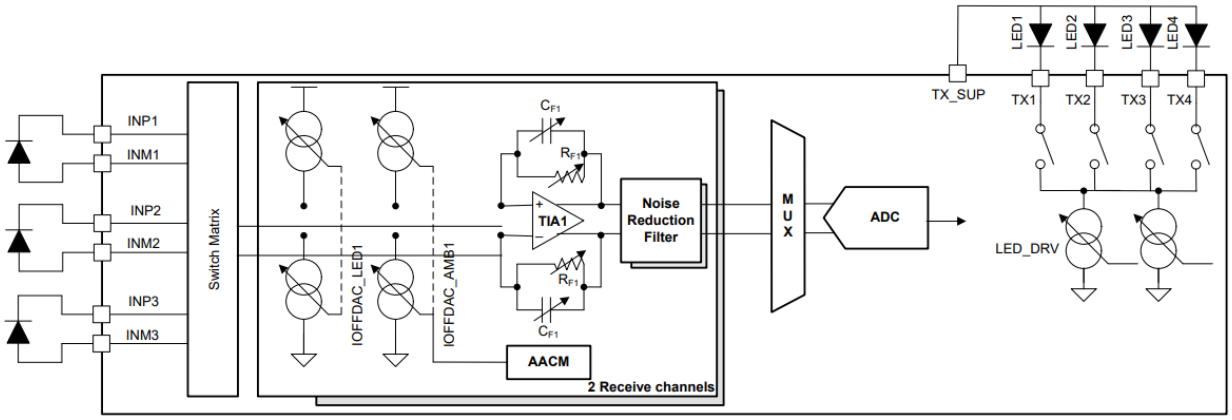


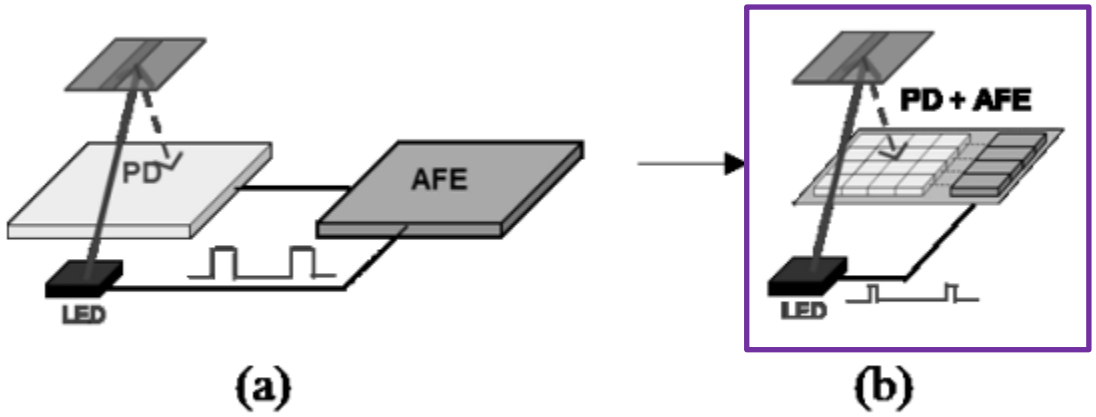
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

Samsung engineers further explain in technical papers a detection system configured to receive light reflected from tissue of a user and to generate an output PPG signal.

For example: “Recently, the technology is migrated to wearable devices such as wrist-worn smart watch or a wireless ear set. Among them, PPG sensor is a health sensor that measures the change in blood flow to be modulated by the heart rate. When a separate light source (LED) is irradiated to the skin, the light absorption by the blood vessel is changed in synchronization with the heart rate. **A sensor measures,**

’455 Patent Claim	Samsung Accused System[1]
	transmitted or **reflected signal** represented in Amplitude Modulation It has been used for a long time as a medical tool to measure oxygen saturation (SpO2) in a patient's finger in an emergency status [1]. For the use of PPG sensors as various health care products, features of low power and smaller size are essentially required.”  *Figure 1. (a) Separated chip PPG sensor and (b) Single chip PPG sensor* Source: J. Lim et al., “A single chip PPG sensor with enhanced IR sensitivity for low power and small size,” 2021 IS&T Int’l Symp. Elec. Imaging, at 2-3, *available at* https://library.imaging.org/admin/apis/public/api/ist/website/downloadArticle/ei/33/7/art00002. For example: “Nowadays, our Smart watches are equipped with Samsung’s BioActive Sensor which has evolved to become far more advanced and miniature technology and not only able to ‘just’ count HR, steps and calories, but also can monitor sleep, measure blood pressure and more. . . . At present, wearable devices, including smart watches and fitness trackers, routinely monitor/analyze the PPG signal and provide non-invasive information of the aforementioned human health indicators with recent additions of temperature, blood oxygen level (SpO2), etc. monitoring capabilities.”

’455 Patent Claim	Samsung Accused System[1]

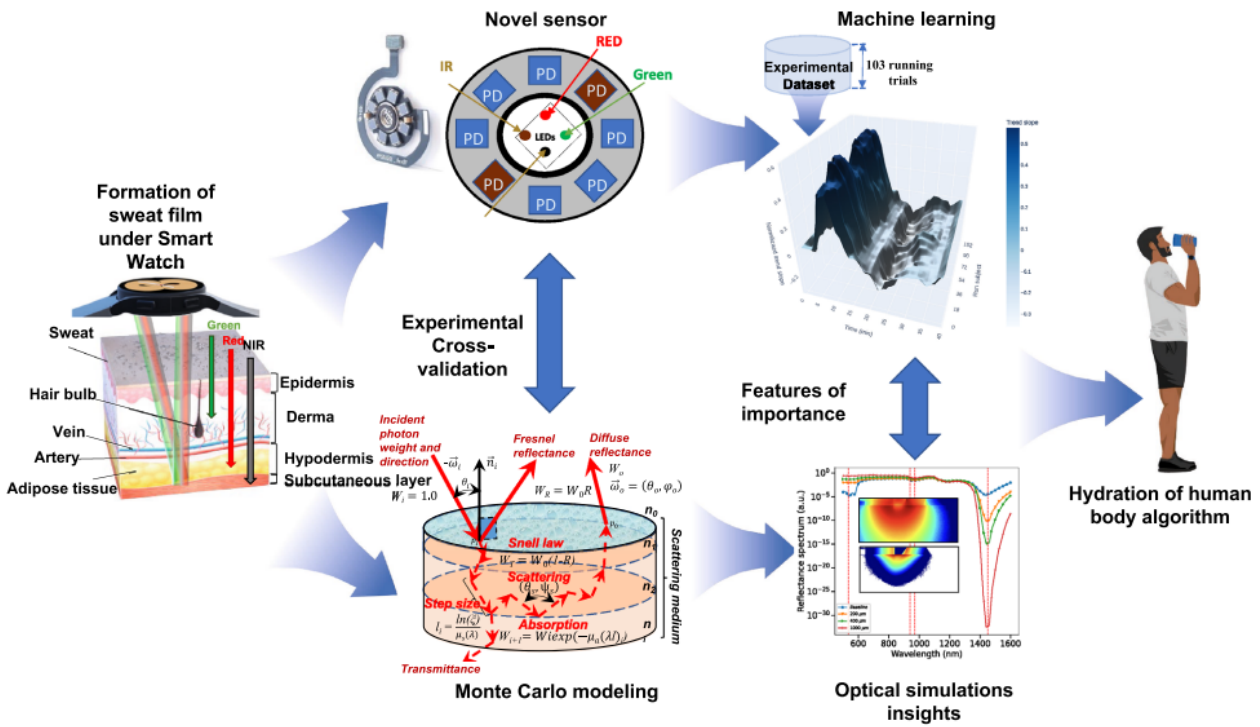
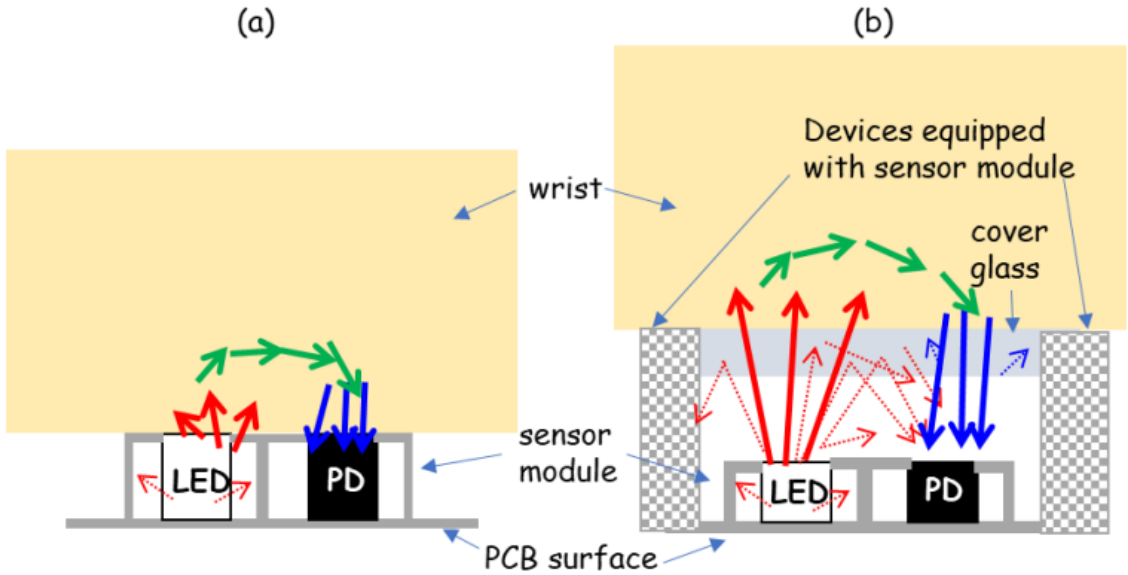
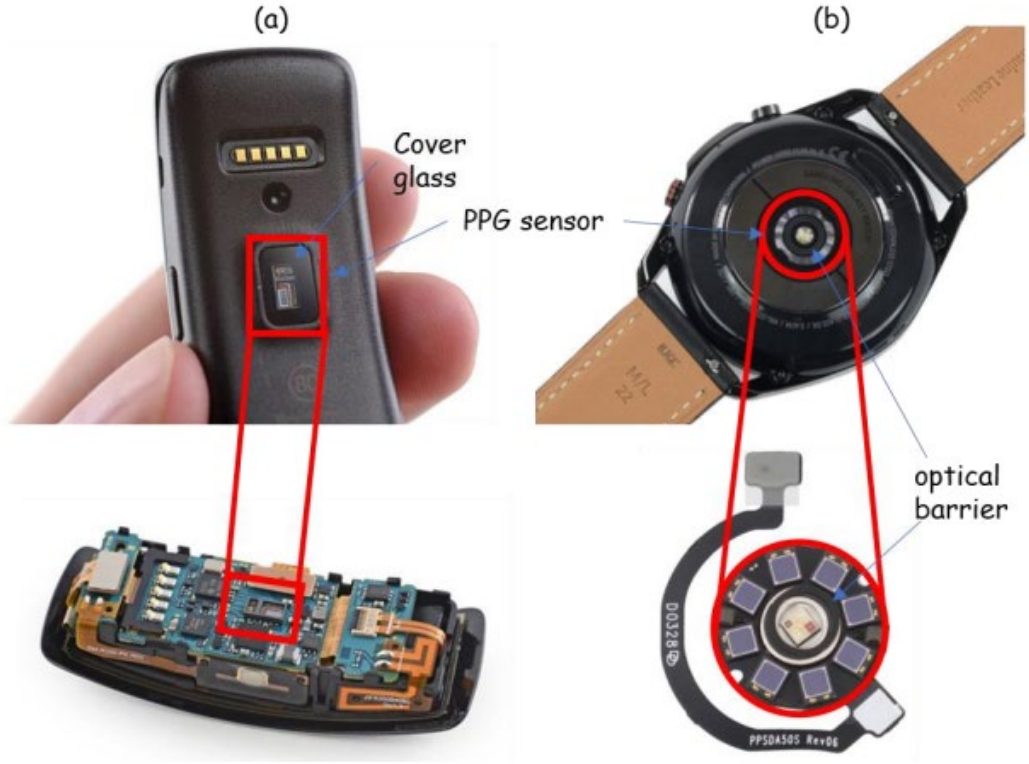


Figure 2. Our capture-to-sensing pipeline. Here: a sweat film is formed under the SmartWatch prototype; Custom-made sensor evaluates change in PPG signal at a range of wavelengths and distances; The trends in the signal are investigated using experimentally validated numerical algorithms of light transport in skin; Particular features of importance due to fluctuations of wet/dry skin optical properties are extracted based on their significance and a ML method is trained to readily detect them; Finally, sweat loss is quantitatively accessed and recommendations to consumer are made.

Source: E. Volkova et al., “Multispectral sensor fusion in SmartWatch for in situ continuous monitoring of human skin hydration and body sweat loss,” Scientific Reports (2023), at 1-3, *available at* https://www.nature.com/articles/s41598-023-40339-7.pdf.

’455 Patent Claim	Samsung Accused System[1]
	The detection system of the Accused Smartwatch has been detailed in other technical documents as well. For example:

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 3.** Conceptual diagram of a PPG sensor module with an embedded LED–PD pair. The diagram illustrates two scenarios: (**a**) when the integrated sensor module is in direct contact with the wrist and (**b**) when the sensor module is embedded in a device and covered with a glass surface. In the diagram, the red solid line represents incident light from the LED entering skin tissue, while the green solid line indicates light causing various reactions inside the tissue. The blue solid line represents light entering the PD from skin tissue and being detected. Additionally, the red dotted line in the diagram illustrates light reflected inside the sensor module that does not enter the skin, some of which directly enters the light-receiving unit. The blue dotted line represents the light that is reflected back by the cover glass among the light entering towards the PD.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 4.** Representative examples of PPG sensor systems applied to commercial wrist-worn wearable devices: (**a**) the Samsung Galaxy Gear Fit, released in 2014, utilizes a sensor module with an embedded LED–PD optopair, and (**b**) the Samsung Galaxy Watch 3, released in 2020, uses separate LEDs and PDs as a sensor. An analog front end (AFE) is employed in both devices to measure the PD output as a PPG signal.

’455 Patent Claim	Samsung Accused System[1]

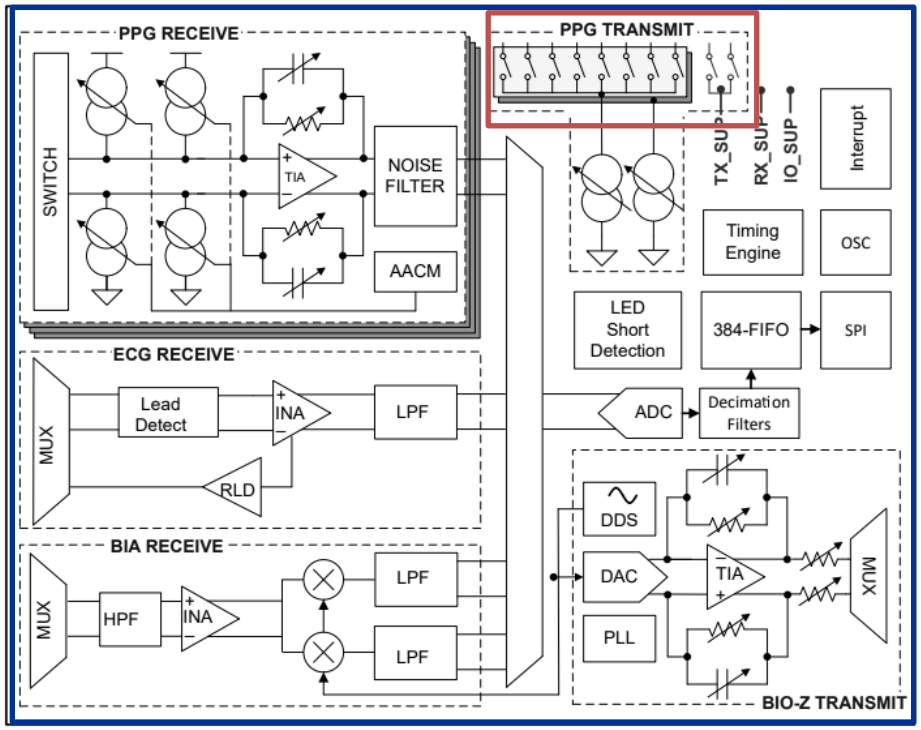


Figure 5. Examples of PPG sensor configurations that use multiple LEDs and PDs, and their application to commercial smartwatches. (**a**–**d**) illustrate different PPG sensor structures, while (**e**) through (**h**) present examples of these structures in use: (**e**) structure (**a**) applied to the Samsung Galaxy Gear s3; (**f**) structure (**d**) applied to the Samsung Galaxy Watch; (**g**) shows the sensor structure of the Garmin Fenix 5 with three LEDs and one PD in the center, and (**h**) shows the sensor structure of the Apple Watch with two LEDs and two PDs.

Source: Kim, K.B. et al., “Photoplethysmography in Wearable Devices: A Comprehensive Review of Technological Advances, Current Challenges, and Future Directions,” Electronics 2023, 12, 2923, at 7-9, *available at* https://www.mdpi.com/2079-9292/12/13/2923.

’455 Patent Claim	Samsung Accused System[1]
15[e] wherein the detection system is configured to be synchronized to the light source;	The **detection system** in the Accused Smartwatch **is configured to be synchronized to the light source**, literally or under the doctrine of equivalents. For example, the BioActive Sensor (“detection system”) is connected to the light source containing multiple LEDs. It is configured to synchronize with the light source by controlling the LED current (light intensity) and the pulse rate of the LEDs using LED drivers. To measure heart rate, for example, green LEDs are used with a pre-determined intensity and pulse rate. Different LEDs are used to measure other parameters, such as blood oxygen levels. Green LEDs (“light source”) blink when measuring heart rate, and both green and red LEDs (“light source”) blink alternately when measuring blood oxygen levels. This, among other evidence below, shows that the BioActive Sensor (“detection system”) is synchronized with the light source. The BioActive Sensor in the Accused Smartwatch features a biosensing AFE manufactured by TI (*e.g.*, AFE 4510). The AFE component used in the BioActive Sensor has a detection system that is synchronized to programmable LEDs (light source). **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy

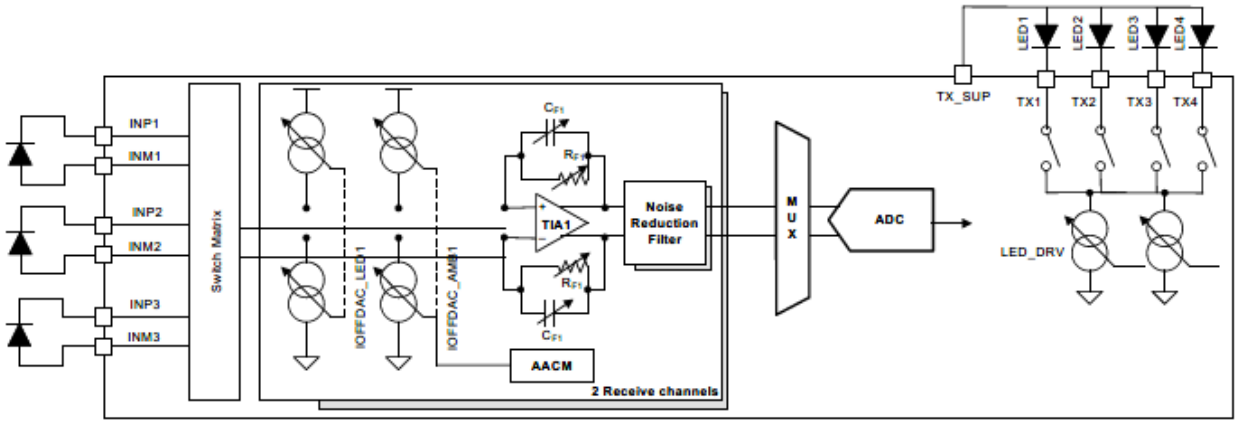
’455 Patent Claim	Samsung Accused System[1]



Simplified Schematic

“**The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. A PPG signal chain comprises a current driver for LEDs** and a receiver that senses the signal from PDs. An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.”

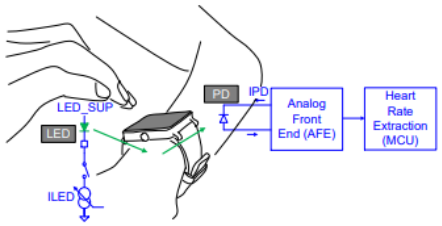
Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 3. PPG Signal Chain in AFE4432** The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices. Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

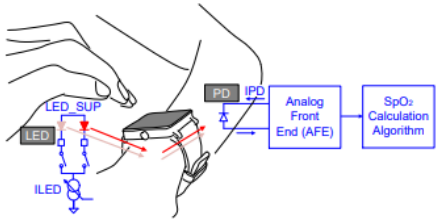
’455 Patent Claim	Samsung Accused System[1]

TEXAS INSTRUMENTS

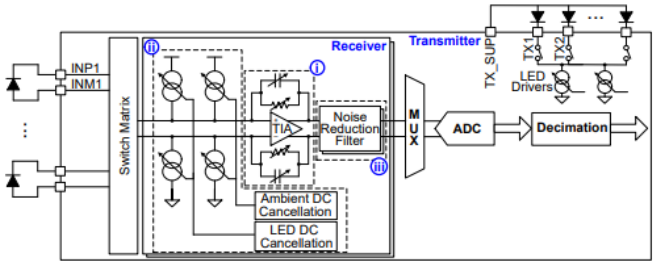
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI's signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.



Heart Rate Monitoring



SpO_2 Monitoring

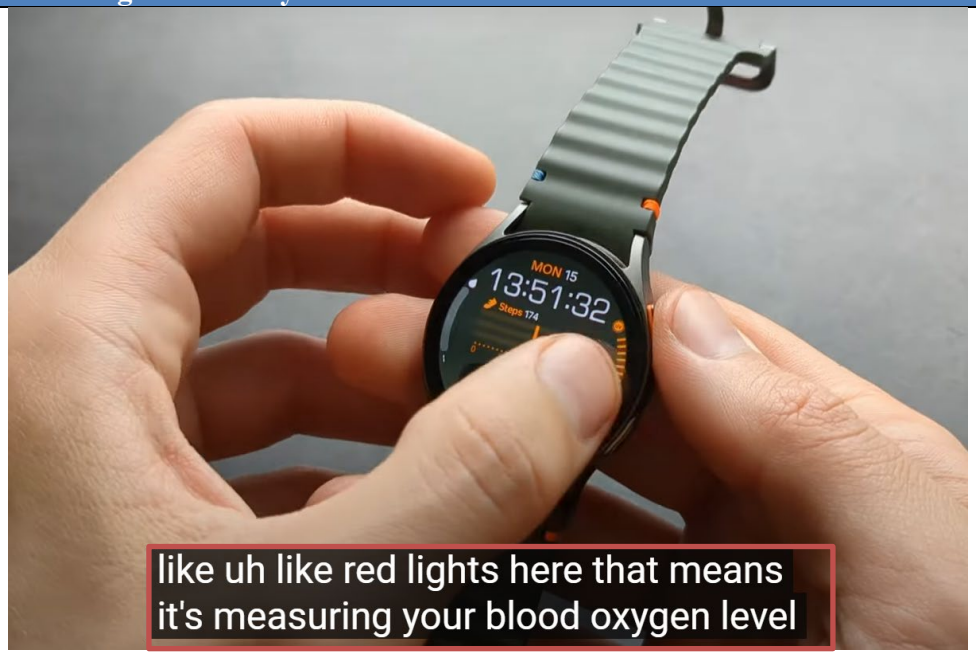


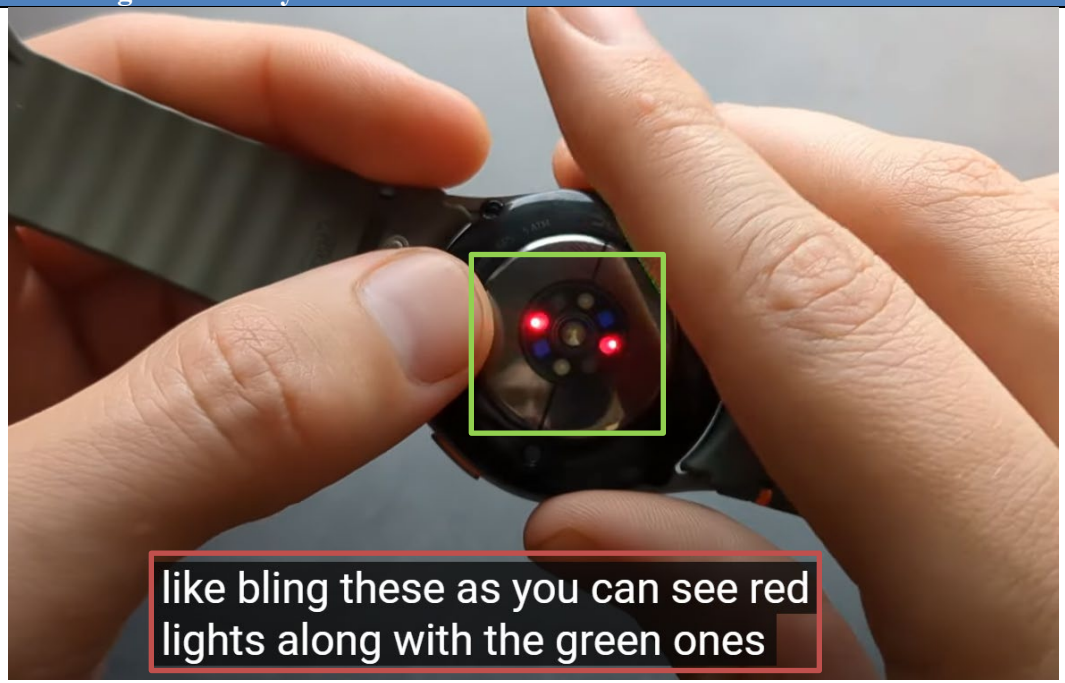
Block Diagram

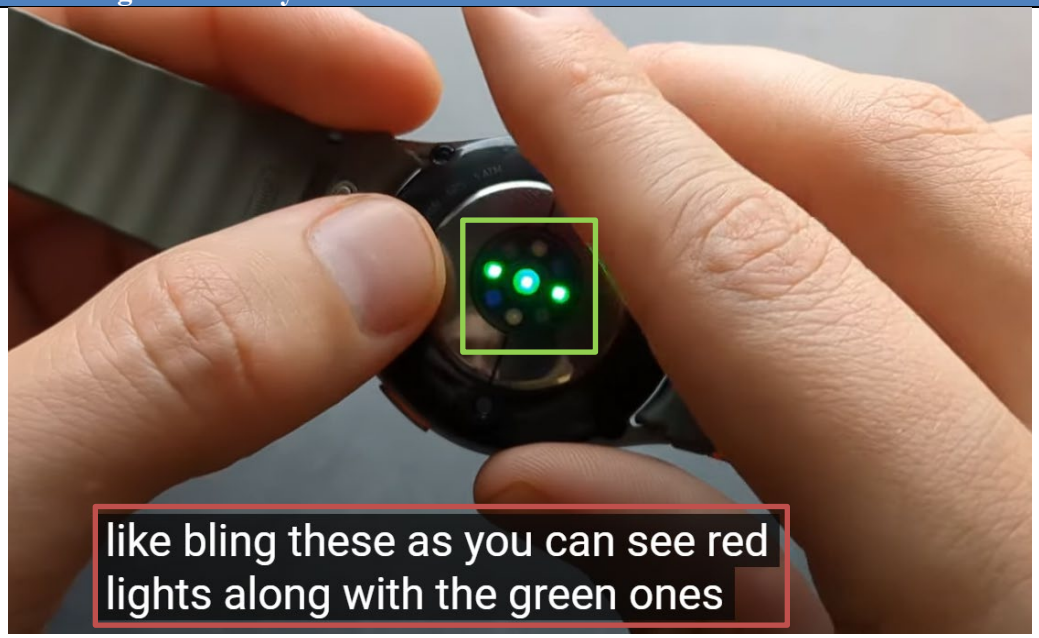
Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

’455 Patent Claim	Samsung Accused System[1]
	“The BioActive sensor has three sensors integrated inside. Apart from body composition, it can measure heart rate, ECG, and blood pressure. . . . It is one of the common uses of the BioActive sensor on your Galaxy Watch. **The sensor relies on built-in green LEDs and infrared lights to calculate heart rate.** These green LEDs are slotted between the BioActive sensor chips.” P. Shah, “What is Samsung BioActive sensor?” Android Police, July 17, 2024, https://www.androidpolice.com/samsung-bioactive-sensor-guide/. “The **diverse colors of LEDs and new photodiodes enable the sensor** to unlock new possibilities in **health monitoring**. One of the new features is the advanced glycation end products (AGEs) index, which is an indicator of metabolic health and biological aging.” “Samsung details BioActive Sensor ahead of Galaxy Unpacked,” fonearena, July 9, 2024, https://www.fonearena.com/blog/428320/samsung-bioactive-sensor-galaxy-unpacked-2024.html. A product video further explains functionalities of the light source (LEDs) and detection system, including how the detection system is configured to synchronize to differing flashing LED colors on the Accused Smartwatch to facilitate calculating different physiological parameters.

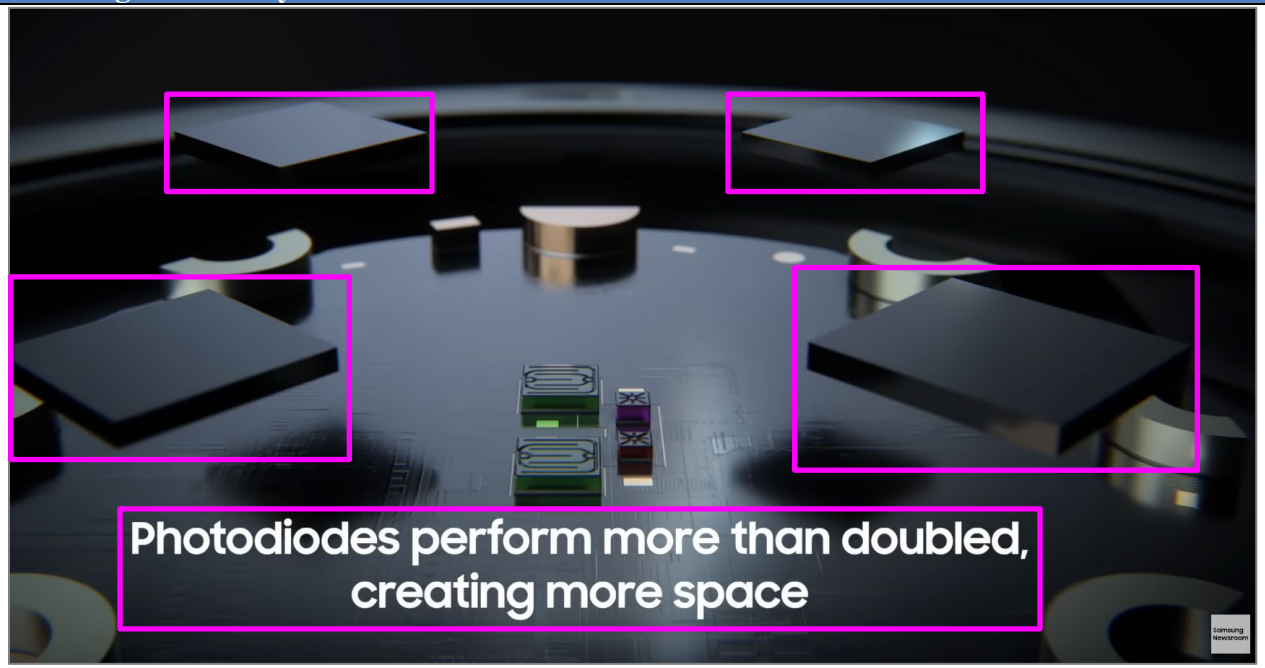
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:24, https://www.youtube.com/watch?v=JG9pGlqmges&t=23s.

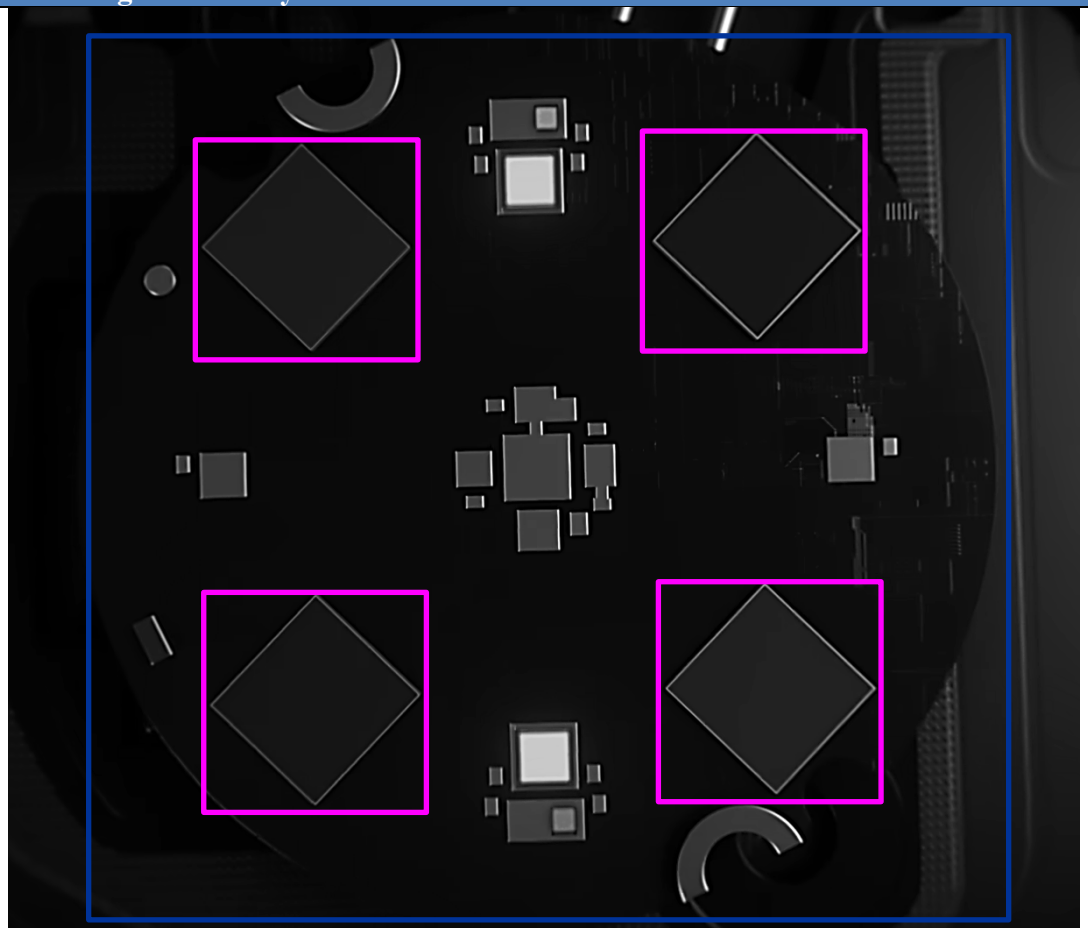
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:37, https://youtu.be/JG9pGlqmges?si=IrcplcEOdHE3cB3l&t=37

’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:53, https://youtu.be/JG9pGlqmges?si=xMBhD11dBJQoADTO&t=53

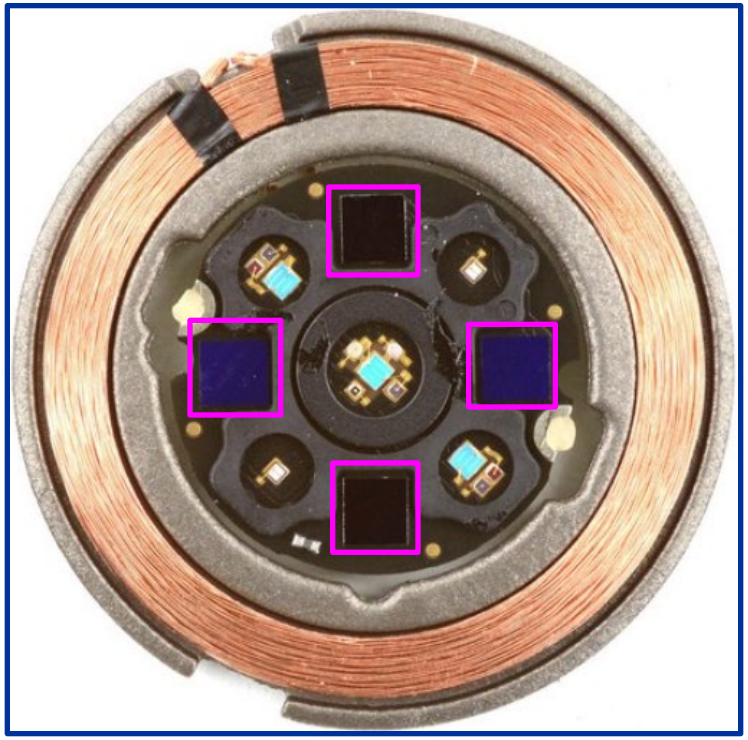
’455 Patent Claim	Samsung Accused System[1]
	 Source: Ultra Value Tech, “Green Flashing Lights on Back of Samsung Galaxy Watch 7 – What Are They & How to Turn Them Off,” July 21, 2024, at 0:53, https://youtu.be/JG9pGlqmges?si=YV8CQ6yVqkvL7ITZ&t=53
15[f] wherein the detection system comprises a plurality of detectors that are spatially separated from each other, and wherein at least one analog to digital converter is coupled	The **detection system** in the Accused Smartwatch comprises **a plurality of detectors that are spatially separated from each other**, literally or under the doctrine of equivalents. For example, the BioActive Sensor (“detection system”) includes multiple photodiodes/PDs (“detectors”) that are spatially separated from each other. “**The all-new BioActive Sensor** is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of **light-receiving**

'455 Patent Claim	Samsung Accused System[1]
to at least one of the spatially separated detectors;	**photodiodes,** adding additional colors of light-emitting diodes (LEDs) and arranging them optimally across the sensor." **Samsung more than doubled the performance of each photodiode, successfully decreasing the number needed to maintain capacity from eight to four.** This redesign freed up additional space for the integration of a larger number and variety of LEDs and ensured their optimal placement across the sensor. The new sensor now includes Blue, Yellow, Violet and Ultraviolet LEDs in addition to an increased number of Green, Red and Infrared LEDs. With the integration and arrangement of these LEDs, photodiodes and specially designed photodiode, Samsung is taking innovation one step further and is now able to pursue unexplored aspects of health monitoring on wearables. . . . The more diverse colors of LEDs and **newly designed photodiodes** unlock new possibilities and empower you to better predict trends and take proactive steps for preventative care. The first of these features will be an advanced glycation end products (AGEs) index — an indicator of metabolic health and biological aging strongly influenced by overall lifestyle and dietary habits. Used as an insightful biomarker, this index provides a snapshot of your biological age to help you make more informed decisions about your wellness journey and work towards a healthier future. The addition of an AGEs index is just one of the many new advanced features planned for the next Galaxy Watch." Samsung Newsroom, "Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor," Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor.

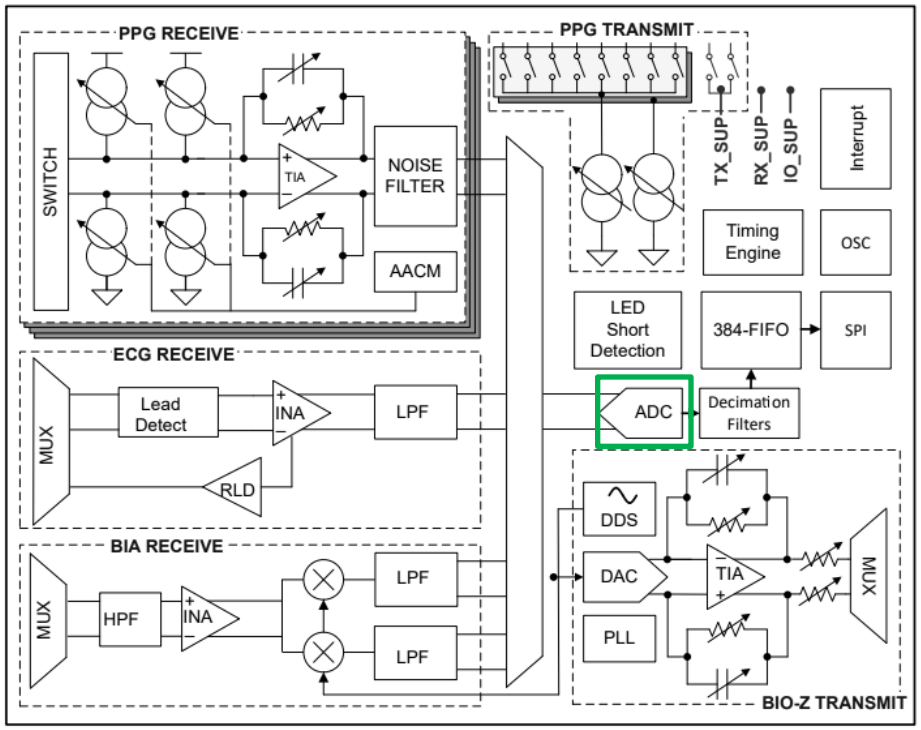
’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung Newsroom, “Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor,” Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor; Samsung Newsroom, “Introducing Samsung’s New BioActive Sensor,” July 8, 2024, https://www.youtube.com/watch?v=snMLajaf0tc&t=7s.

’455 Patent Claim	Samsung Accused System[1]
	

Source: Source: Samsung Newsroom, “Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor,” Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor; Samsung Newsroom, “Introducing Samsung’s New BioActive Sensor,” July 8, 2024, https://www.youtube.com/watch?v=snMLajaf0tc&t=7s.

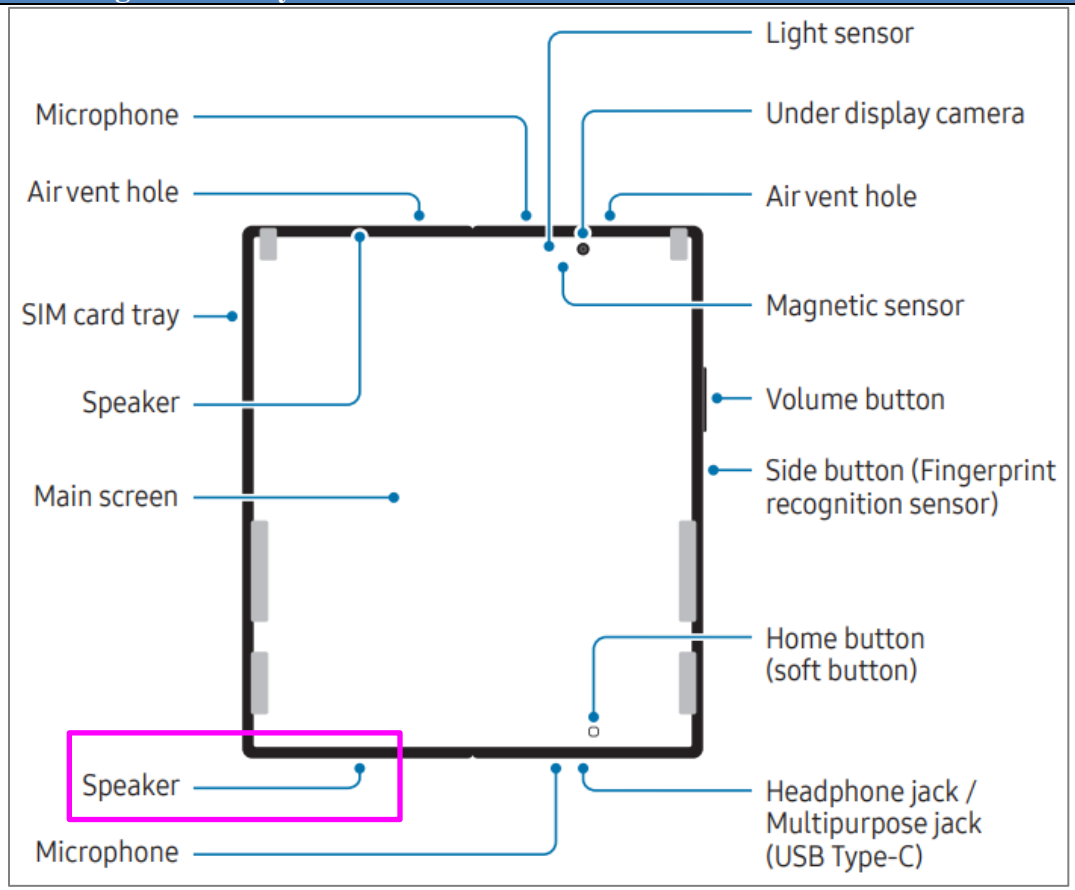
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327 “**The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals.** A PPG signal chain comprises a current driver for LEDs and **a receiver that senses the signal from PDs.** An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface.” Texas

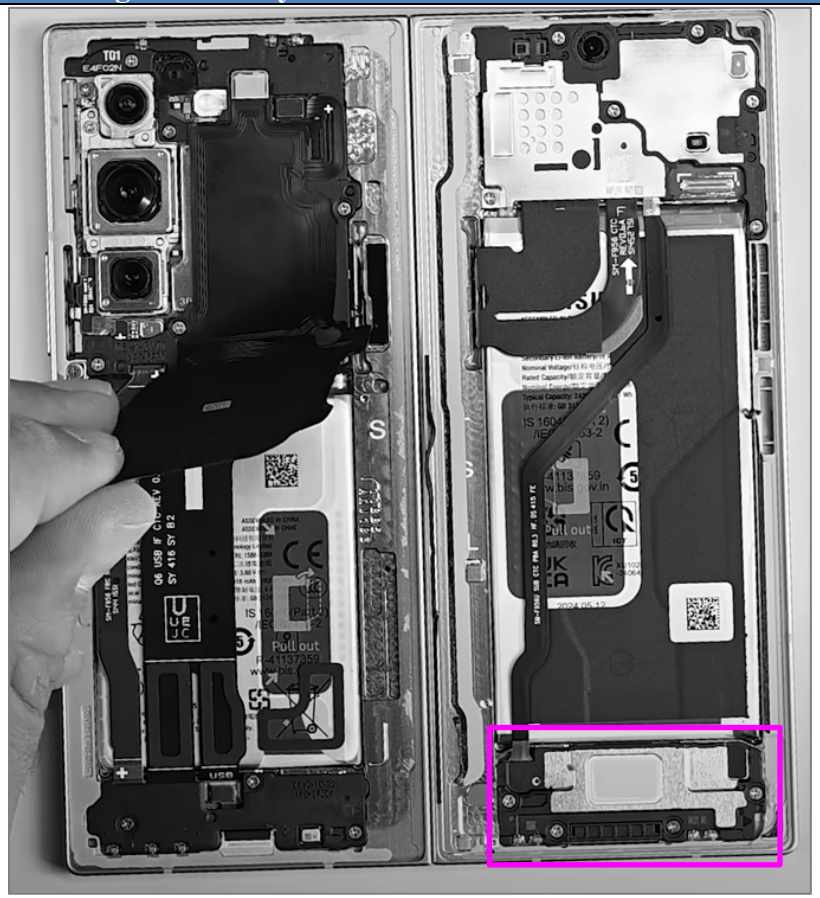
’455 Patent Claim	Samsung Accused System[1]
	Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf. In the Accused Smartwatch, there is **at least one analog to digital converter** that is coupled to **at least one of the spatially separated detectors**, literally or under the doctrine of equivalents. For example, there is at least one analog to digital converter (“ADC”) coupled to at least one of the photodiodes/PDs (“detectors”) in the BioActive Sensor in the Accused Smartwatch. “The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bioimpedance signals. **A PPG signal chain comprises** a current driver for LEDs and **a receiver that senses the signal from PDs.** An ECG receiver with a Rightleg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. **The outputs of the various signal chains are digitized by a common ADC** and stored in a FIFO which can be read out using an SPI interface.” Texas Instruments, AFE4510, SBASB19 – March 2024, at 1, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

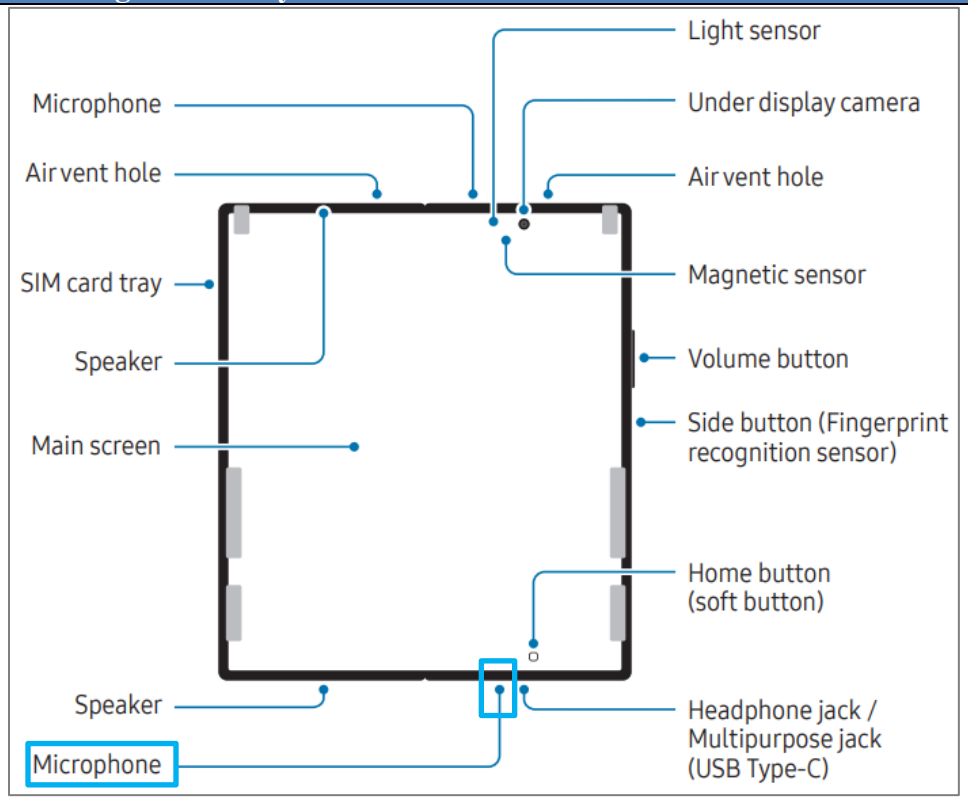
’455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic** Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 2, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.
15[g] the smart phone or tablet comprising a wireless receiver, a wireless transmitter,	The Accused System comprises an **Accused Phone/Tablet** comprising **a wireless receiver, a wireless transmitter, a display, a speaker, a voice input module, a microprocessor** and **a touch screen**, literally of under the doctrine of equivalents.

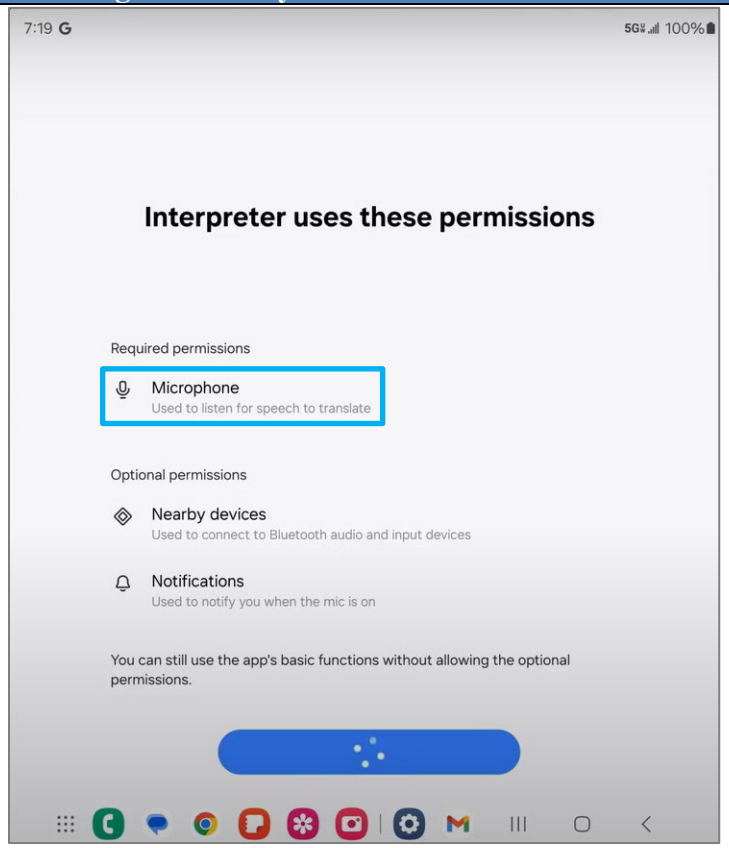
’455 Patent Claim	Samsung Accused System[1]
a display, a microphone, a speaker, a microprocessor and a touch screen,	For example, the Galaxy Watch Ultra pairs with the Galaxy Z Fold6 (“smart phone”). The Galaxy Z Fold6 includes Wi-Fi connectivity, which requires the smart phone to include both **a wireless receiver** and **a wireless transmitter**.  Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/

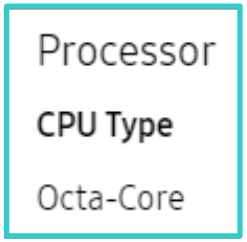
’455 Patent Claim	Samsung Accused System[1]
	Connectivity **Wi-Fi Connectivity** 802.11a/b/g/n/ac/ax 2.4GHz+5GHz+6GHz, HE160, MIMO, 1024-QAM Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/ The Galaxy Z Fold6 (“smart phone”) further includes **a display,** **a speaker,** and a microphone (“**a voice input module**”). Display **Resolution (Main Display)**: 2160 x 1856 (QXGA+) **Main Display Size**: 193.2mm (7.6" full rectangle) / 192.5mm (7.6" rounded corners) **Technology (Main Display)**: Dynamic AMOLED 2X Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/

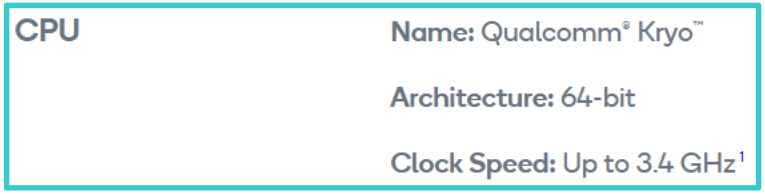
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 5]

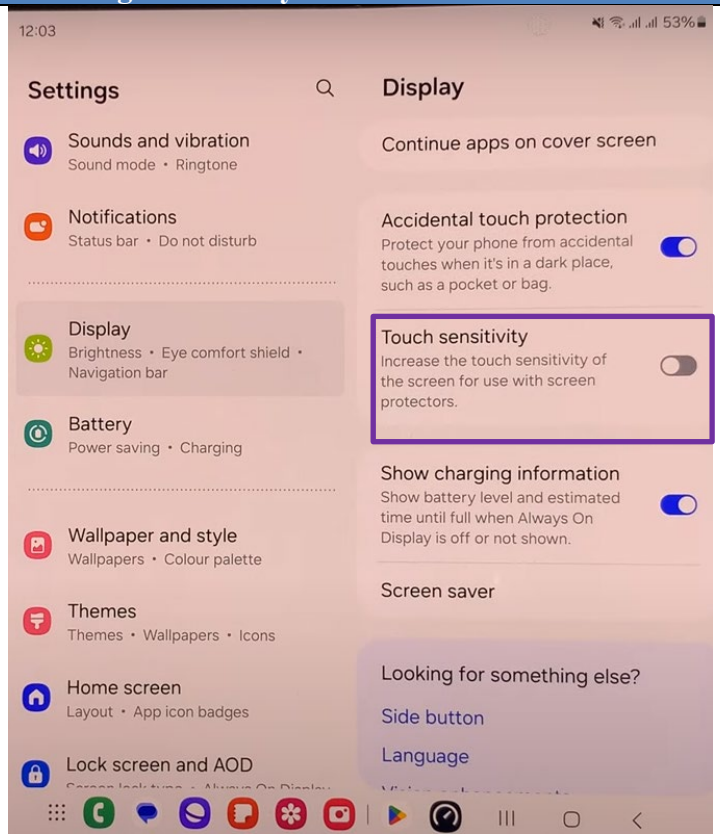
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=xYIe5uDVDWI

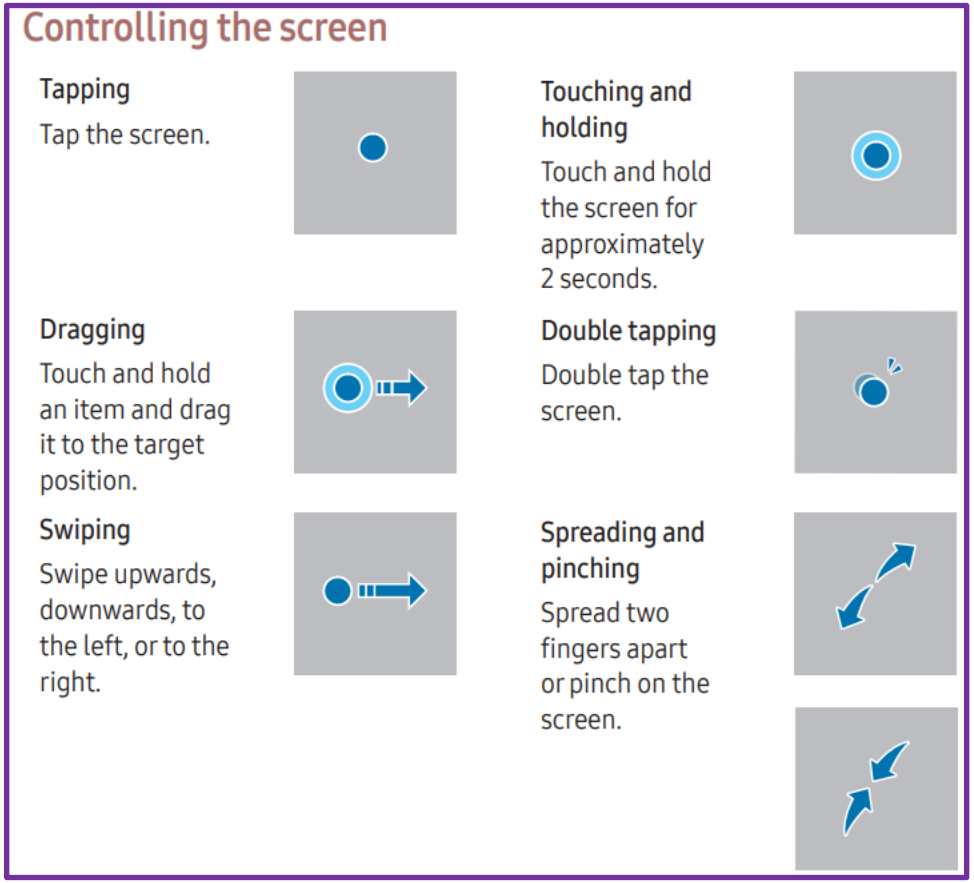
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 5]

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=sPP6NW89Am0 The Galaxy Z Fold6 further includes **a microprocessor** (*e.g.*, Snapdragon 8 Gen 3 SoC (system on chip) having Qualcomm Kryo microprocessor) and **a touch screen**.

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/buy/galaxy-z-fold6-512gb-unlocked-sm-f956uakexaa/  Source: https://www.samsung.com/us/smartphones/galaxy-z-fold6/

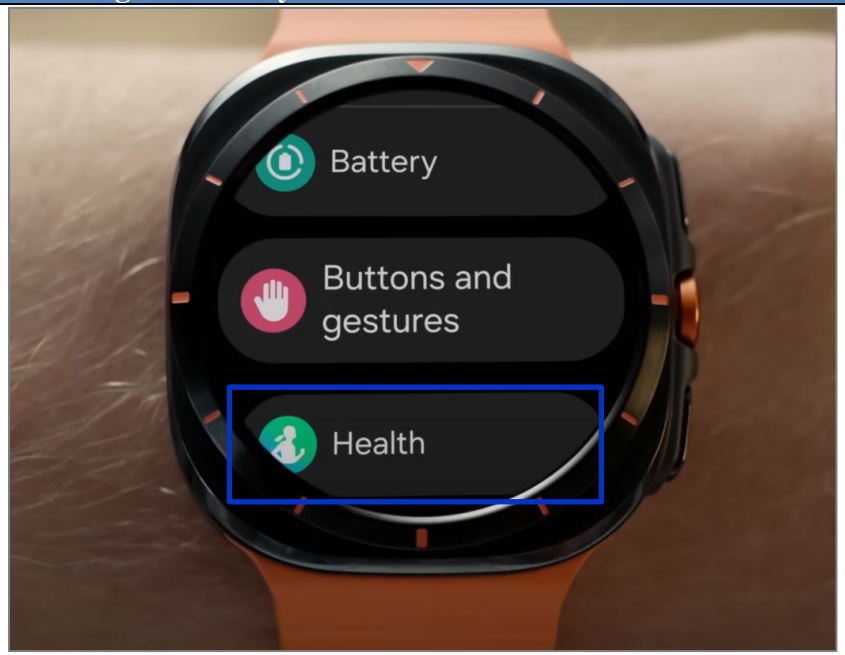
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.qualcomm.com/products/mobile/snapdragon/smartphones/snapdragon-8-series-mobile-platforms/snapdragon-8-gen-3-mobile-platform

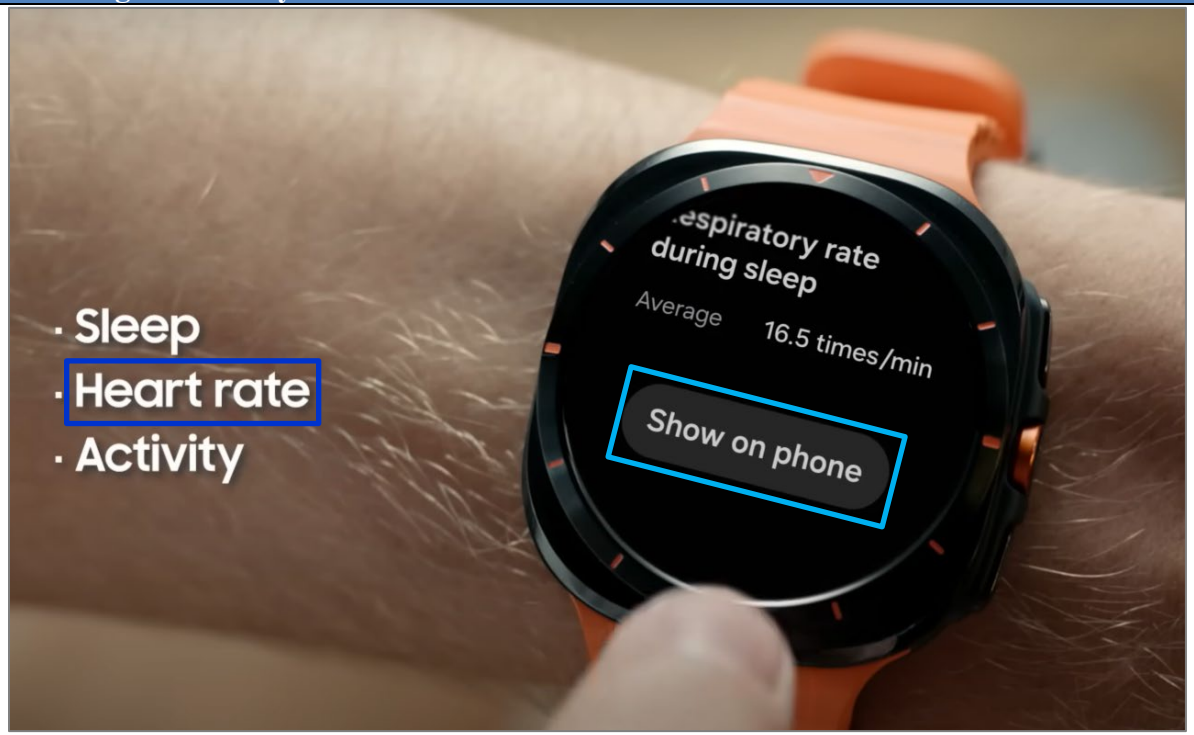
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.youtube.com/watch?v=cn2UQ6Fr4hM

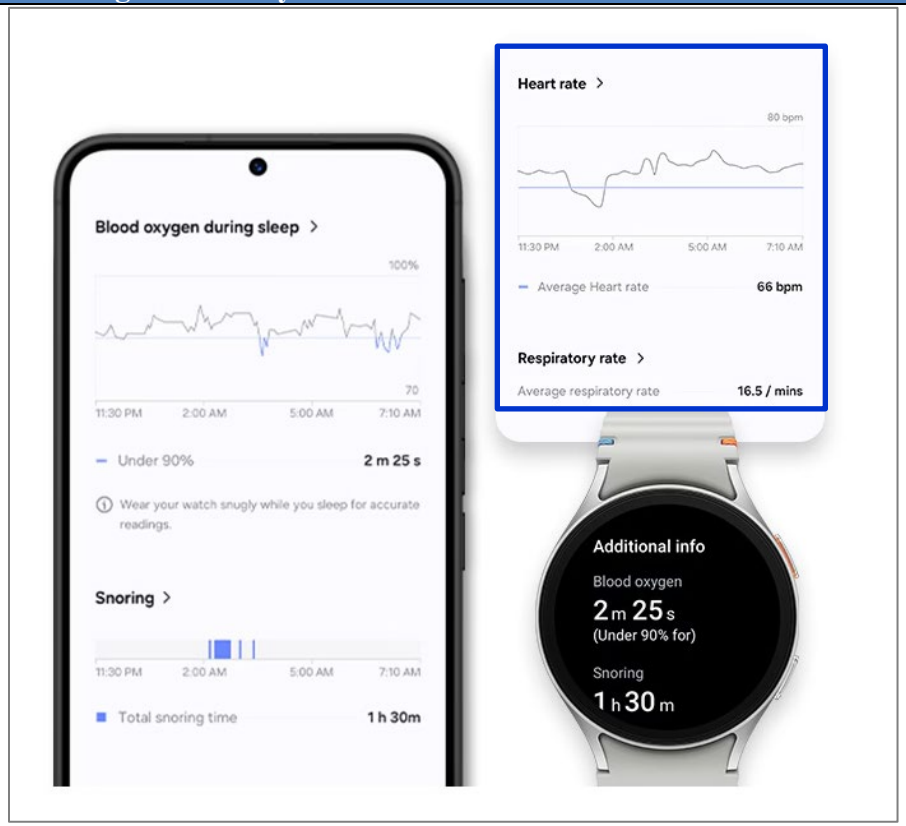
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://downloadcenter.samsung.com/content/UM/202407/20240729134626727/SM-F956B_UG_EU_UU_Eng_Rev.1.0_240717.pdf [Page: 26]

'455 Patent Claim	Samsung Accused System[1]
15[h] the smart phone or tablet configured to receive and process at least a portion of the output signal, wherein the smart phone or tablet is configured to store and display the processed output signal, and wherein at least a portion of the processed output signal is configured to be transmitted over a wireless transmission link;	The Accused Phone/Tablet is configured **to receive and process at least a portion of the output signal**, and the Accused Phone/Tablet is configured **to store and display the processed output signal**, wherein **at least a portion of the processed output signal** is configured **to be transmitted over a wireless transmission link**, literally or under the doctrine of equivalents. For example, the Galaxy Z Fold6 ("the **smart phone**") receives the output signal from the BioActive Sensor via the Samsung Health app, processes the signal (*e.g.*, generates Heart Rate Zones, in addition to other health and wellness metrics and reports), and then stores and displays the Heart Rate Zones ("processed signal"). "The Samsung Privileged Health SDK is specialized for Galaxy Watch4 devices or later. **It provides both raw sensor signal data from the Samsung BioActive Sensor** and processed data with our differentiated features. The SDK supports an improved health tracking capability to allow your applications to track the user's health data accurately with the accelerometer, raw ECG (Electrocardiogram), **PPG (Photoplethysmogram), and heart rate including inter-beat interval.**" Samsung Developer, "Samsung Privileged Health SDK," *available at* https://developer.samsung.com/health/privileged/overview.html.

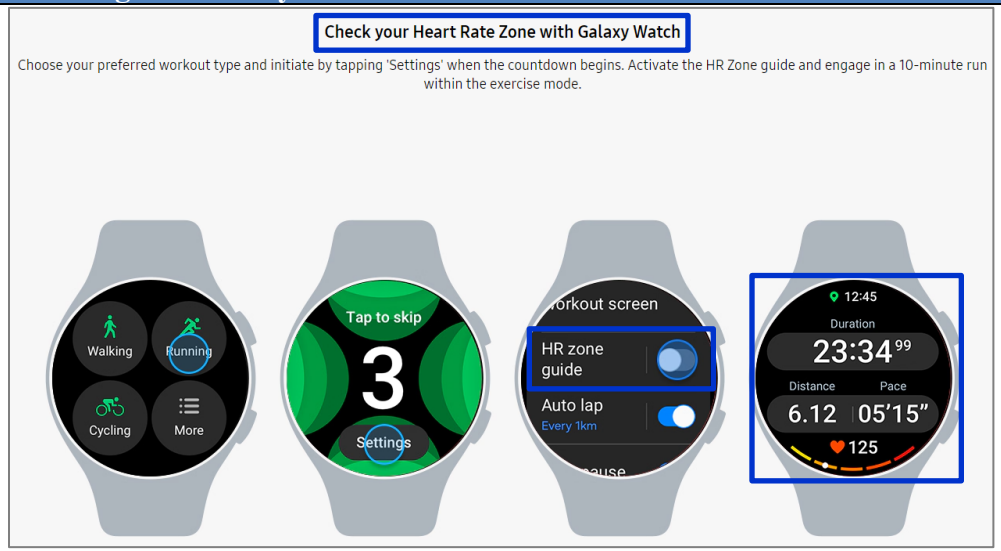
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/.

’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “A friendly guide to Galaxy Watch Ultra, Watch7 and Buds3Pro,” July 24, 2024, https://www.youtube.com/watch?v=VQW-ZpdAm5M.

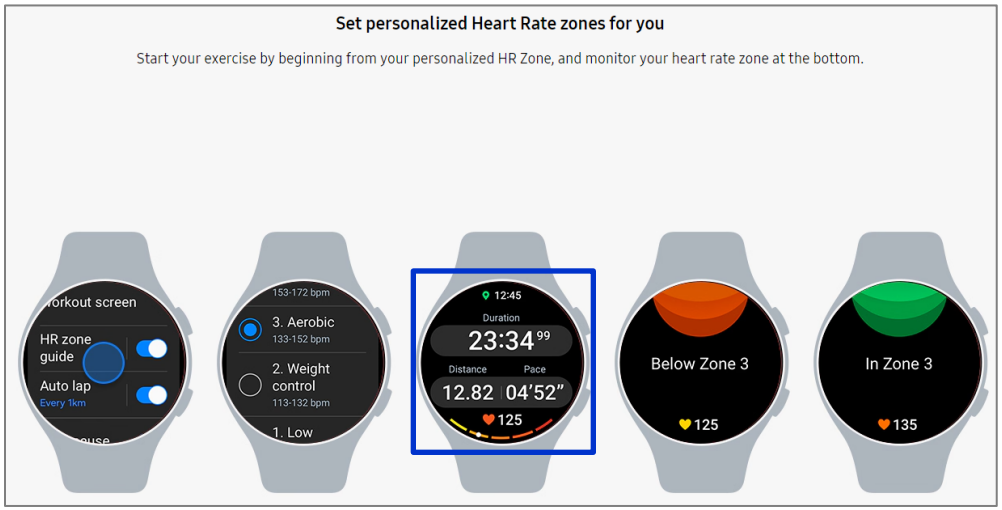
’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “A friendly guide to Galaxy Watch Ultra, Watch7 and Buds3Pro,” July 24, 2024, https://www.youtube.com/watch?v=VQW-ZpdAm5M

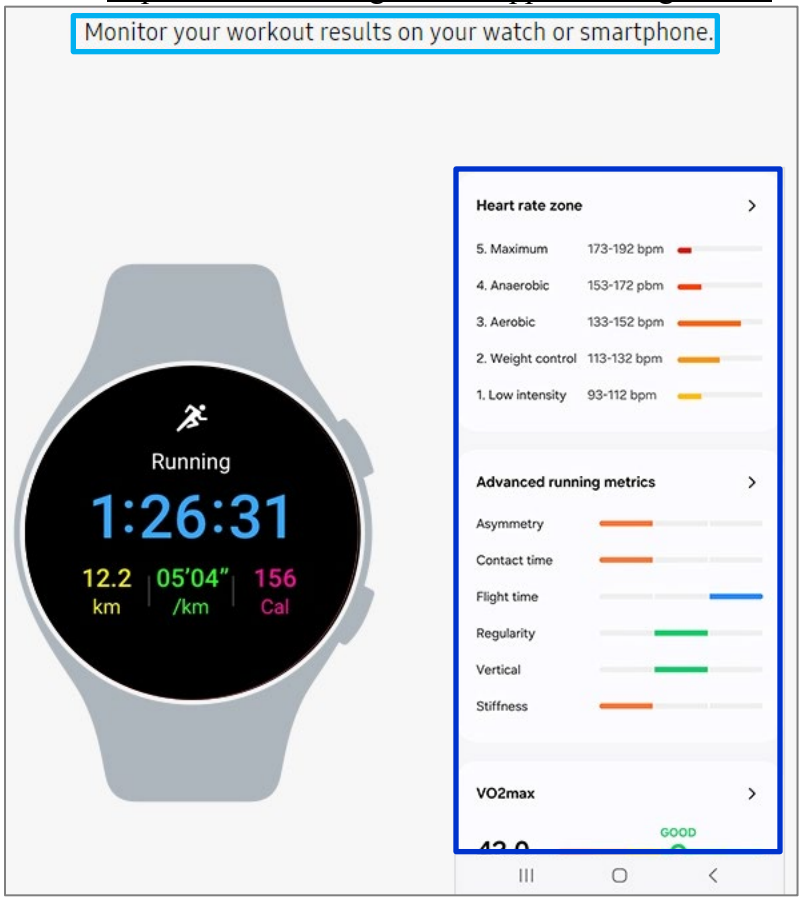
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/apps/samsung-health/

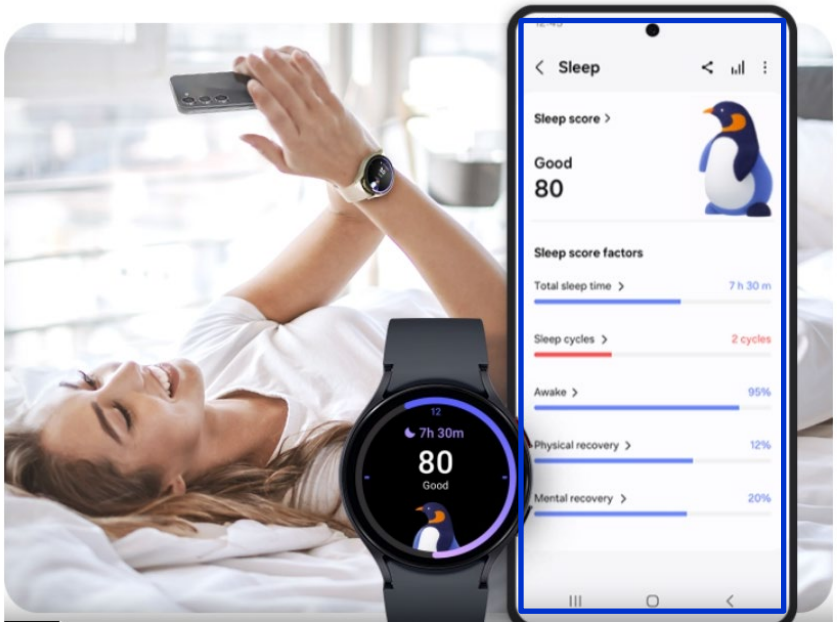
’455 Patent Claim	Samsung Accused System[1]

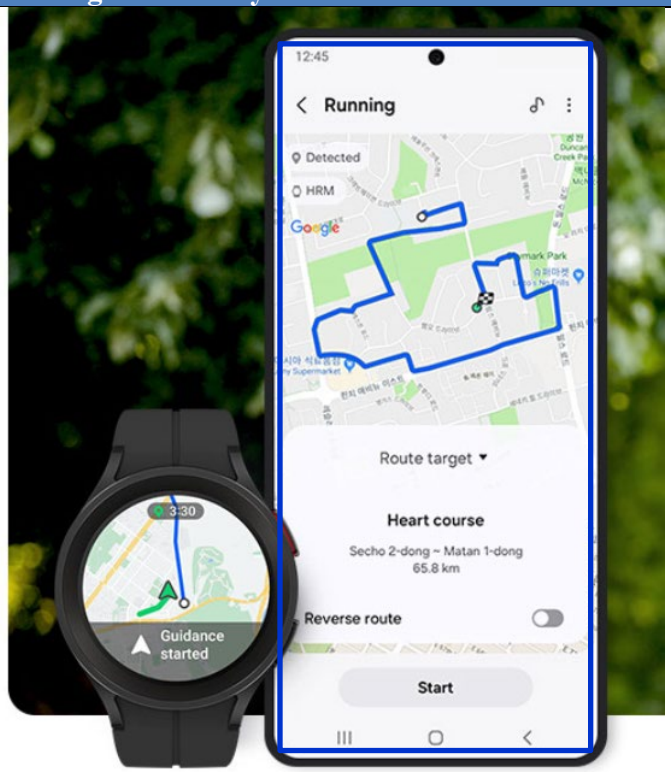


Source: https://www.samsung.com/us/apps/samsung-health/

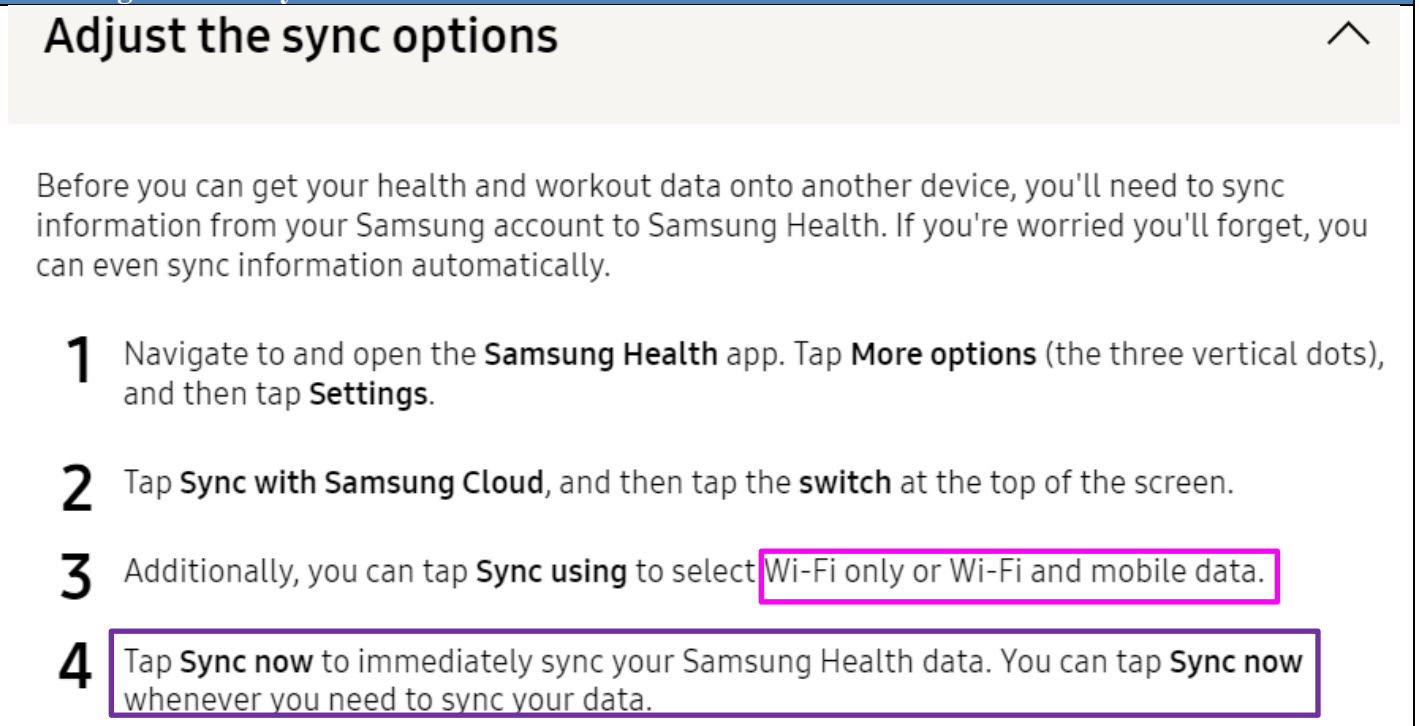


’455 Patent Claim	Samsung Accused System[1]
	Source: https://www.samsung.com/us/apps/samsung-health/  Source: https://www.samsung.com/us/apps/samsung-health/

’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/global/galaxy/apps/samsung-health/

'455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/global/galaxy/apps/samsung-health/ "The **Energy score feature** is available **if the connected phone** has version 6.27 or later of the Samsung Health app installed." Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 53, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf.

’455 Patent Claim	Samsung Accused System[1]
	“The sleep pattern will have its four states (Awake, REM, Light, Deep) analysed by using your movement and changes in your **heart rate** while you are sleeping. **You can check the recommended ranges for each measured sleep state in the graph on your connected phone**.” Samsung Galaxy Watch7 / Galaxy Watch Ultra User Guide (06/2024, Rev.1.0), at 71, *available at* https://downloadcenter.samsung.com/content/UM/202407/20240711132033461/SM-L30X_L31X_L705F_UG_EU_Android_Eng_Rev.1.0_240626.pdf. The Samsung Health app data (“a portion of the processed output signal”) is synchronized with Samsung Cloud to enable transmission of data to Samsung Cloud over Wi-Fi (“wireless transmission link”). “If you just got a new phone or tablet, it doesn’t mean you have to lose your hard work in **Samsung Health. Your workout and health information can be transferred to the new device**; you just need to **sync your Samsung Health profile with your Samsung account!** Once your data is synced, you'll be able to access it on a different device.”

’455 Patent Claim	Samsung Accused System[1]
	 Source: Samsung, “Sync your data in Samsung Health,” https://www.samsung.com/us/support/answer/ANS10001399/.
15[i] wherein the output signal is indicative of one or more of the physiological parameters;	The Accused Smartwatch generates an **output signal** that **is indicative of one or more of the physiological parameters**, either literally or under the doctrine of equivalents. For example, the PPG signal (“output signal”) from the BioActive Sensor indicates, among other things, heart rate and blood oxygen levels (“one or more of the physiological parameters”).

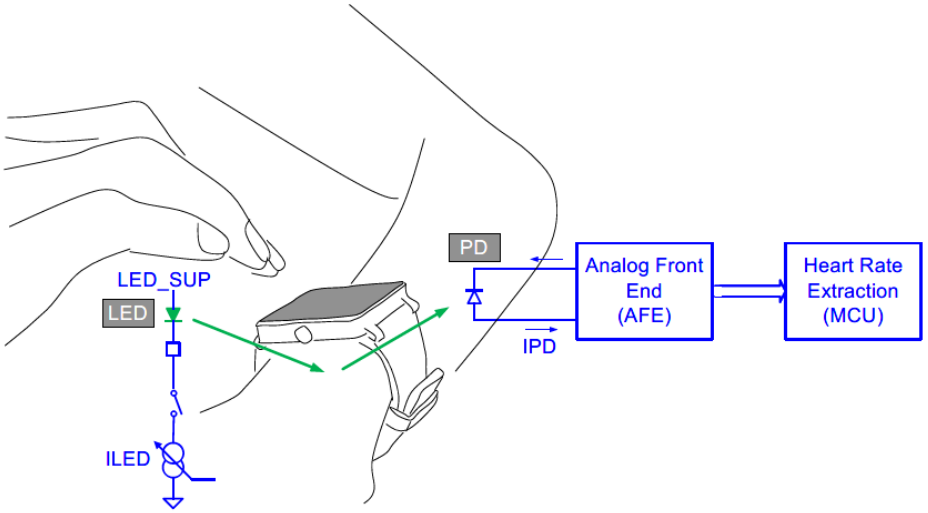
’455 Patent Claim	Samsung Accused System[1]
	 Source: https://www.samsung.com/us/watches/galaxy-watch-ultra/

'455 Patent Claim	Samsung Accused System[1]
	Introducing Samsung's New BioActive Sensor The all-new BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that enable even more precise health insights. Samsung engineers focused on three upgrades to the new sensor: enhancing the performance of light-receiving photodiodes, adding additional colors of light-emitting diodes (LEDs) and arranging them optimally across the sensor. **Bringing Greater Accuracy and New Possibilities for Preventative Wellness** The optimal allocation of Green, Red and Infrared LEDs sets new standards in wearable technology by improving accuracy and enabling exceptional performance across a broad array of health metrics. This allows the new BioActive Sensor to more accurately measure health metrics such as heart rate, sleep quality, blood pressure,[2] blood oxygen levels and stress levels.[3] Even the measurement of heart rate during intensive workouts is 30% more accurate compared to its predecessor. The more diverse colors of LEDs and newly designed photodiodes unlock new possibilities and empower you to better predict trends and take proactive steps for preventative care. The first of these features will be an advanced glycation end products (AGEs) index[4] – an indicator of metabolic health and biological aging strongly influenced by overall lifestyle and dietary habits. Used as an insightful biomarker, this index provides a snapshot of your biological age to help you make more informed decisions about your wellness journey and work towards a healthier future. The addition of an AGEs index is just one of the many new advanced features planned for the next Galaxy Watch. Source: Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor

’455 Patent Claim	Samsung Accused System[1]
	3 Description The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bio-impedance signals. A PPG signal chain comprises a current driver for LEDs and a receiver that senses the signal from PDs. An ECG receiver with a Right-leg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface

'455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy **OHRM**: Optical Heart-rate monitoring Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-4, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

’455 Patent Claim	Samsung Accused System[1]
	Application *Optical Heart Rate Monitoring (OHRM)* uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in Figure 1, an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR).

’455 Patent Claim	Samsung Accused System[1]
	 **Figure 1. Heart Rate Monitoring on a Wearable Device** Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

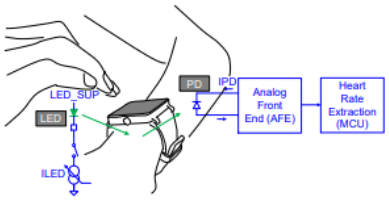
'455 Patent Claim	Samsung Accused System[1]

Product Overview

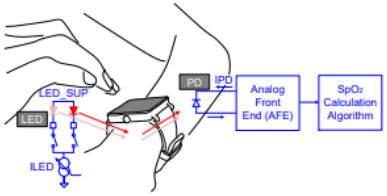
Photoplethysmography (PPG) With Integrated AFE for Optical Biosensing

TEXAS INSTRUMENTS

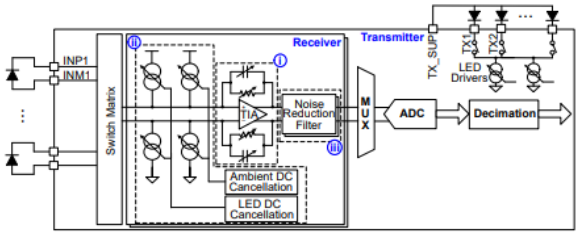
Applications like optical heart rate and SpO_2 monitoring are based on the principle of Photoplethysmography (PPG). The primary challenges in PPG signal acquisition on a wrist-worn variable are: (i) small sensor size, (ii) relatively weak signal on wrist (low perfusion index), and (iii) interferers like ambient light and motion artifacts. TI's signal chain for PPG signal acquisition has 3 unique characteristics that help achieve excellent signal quality even in the most challenging conditions: (i) high gain transimpedance amplifier (TIA) to improve the SNR, (ii) DC offset cancellation DAC at the input, and (iii) noise reduction filter to reduce the optical noise bandwidth. These unique features help achieve excellent dynamic range at extremely low power consumption.



Heart Rate Monitoring

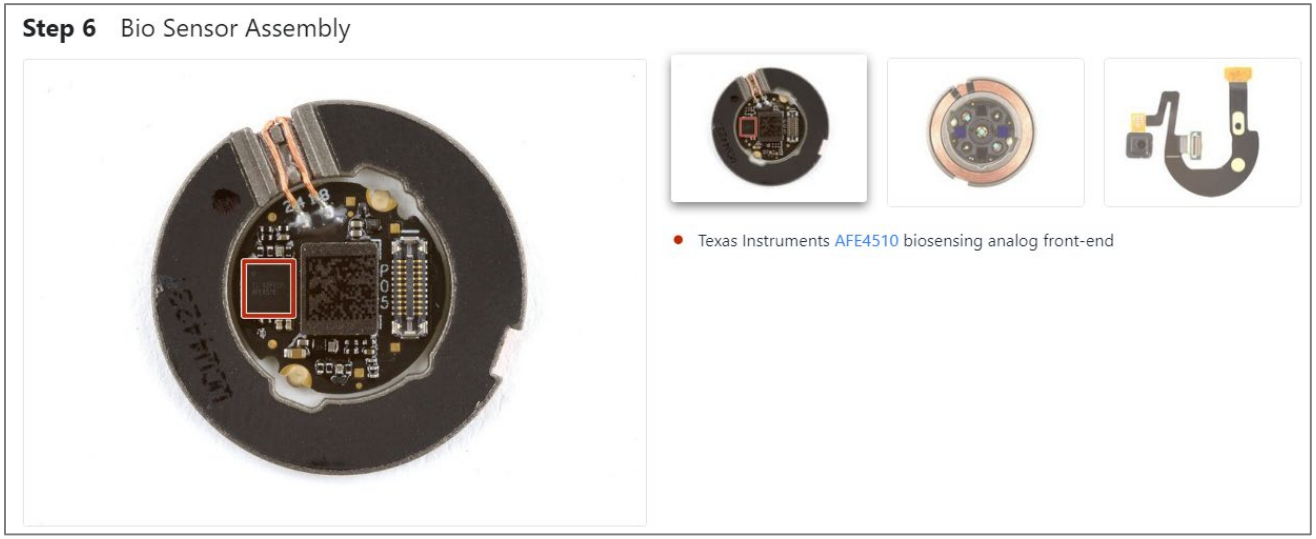


SpO_2 Monitoring



Block Diagram

Source: Texas Instruments, Product Overview, "Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing," Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F.

’455 Patent Claim	Samsung Accused System[1]
	See also https://www.samsung.com/us/apps/samsung-health/; https://www.samsung.com/sg/apps/samsung-health-monitor/; https://www.youtube.com/watch?v=snMLajaf0tc&t=7s; https://news.samsung.com/global/samsung-leads-holistic-health-innovation-with-galaxy-watch5-and-galaxy-watch5-pro.
15[j] the wearable device configured to increase the signal-to-noise ratio by increasing light intensity of at least one of the plurality of semiconductor sources from an initial light intensity; and	The Accused Smartwatch is **configured to increase the signal-to-noise ratio by increasing light intensity of at least one of the semiconductor sources from an initial light intensity**, either literally or under the doctrine of equivalents. For example, the Galaxy Watch Ultra increases the signal-to-noise ratio (“SNR”) of the PPG signal received from the BioActive Sensor. The BioActive Sensor has a peak system SNR of 115 dB, which indicates that the general output SNR is lower than this peak value. To achieve the peak SNR, the sensor is configured to increase the LED current (“light intensity”) of the LEDs (“semiconductor sources”). 

’455 Patent Claim	Samsung Accused System[1]
	Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw. **3 Description** The AFE4510 is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and Bio-impedance signals. A PPG signal chain comprises a current driver for LEDs and a receiver that senses the signal from PDs. An ECG receiver with a Right-leg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation & sense can be used for applications like BIA, EDA, and Impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO which can be read out using an SPI interface

’455 Patent Claim	Samsung Accused System[1]
	PPG signal acquisition: – Acquisition of 24 PPG signal sets (LED, AMB) – Supports PPG sensors at different data rates – Peak system SNR of 115 dB in 0.5-10Hz band enables high-accuracy SpO_2 measurement – Low Current for Continuous Operation with a Typical Value: 19µA for the Receiver **PPG Transmitter:** – 8-Bit Programmable LED Current with a range adjustable from 50mA to 300mA – LED Short Detection – Support of 16 LEDs in Common Anode configuration for SpO2, OHRM, Spectroscopy Source: Texas Instruments, AFE4510, SBASB19 – March 2024, at 1-4, *available at* https://www.ti.com/lit/ds/symlink/afe4510.pdf.

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Figure 3 shows the PPG signal chain in AFE4432.

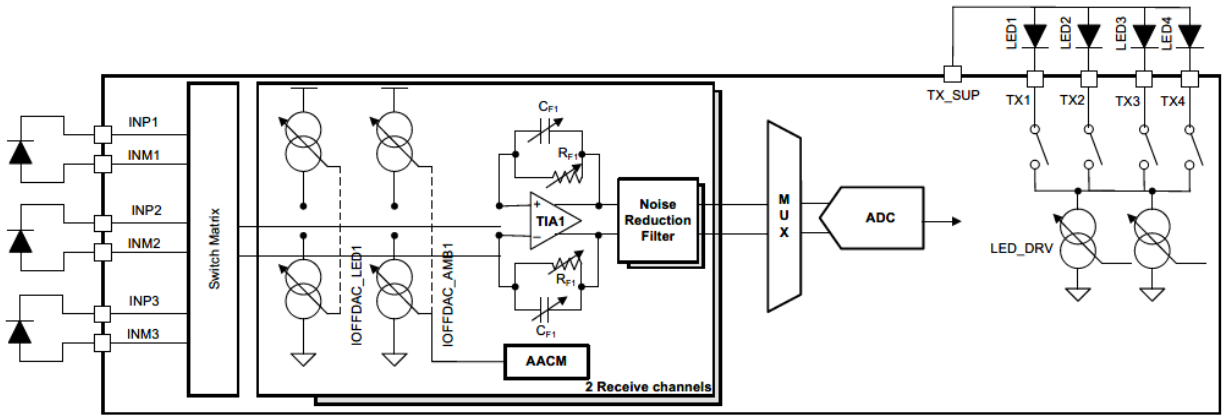
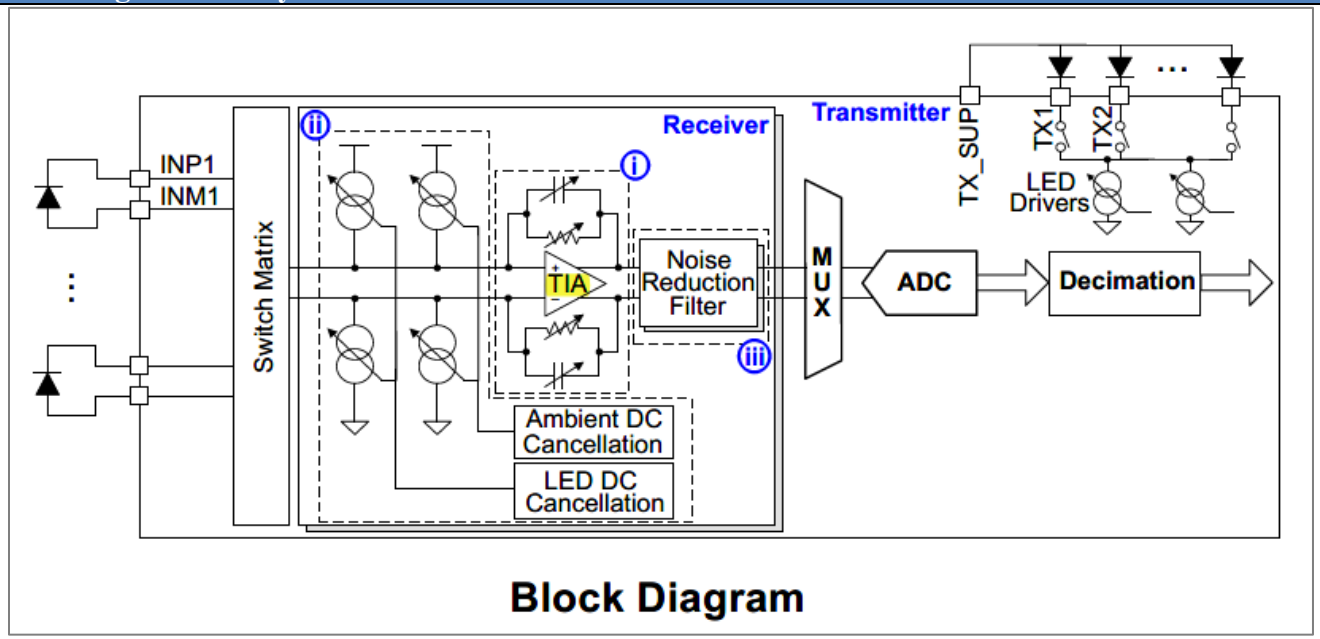


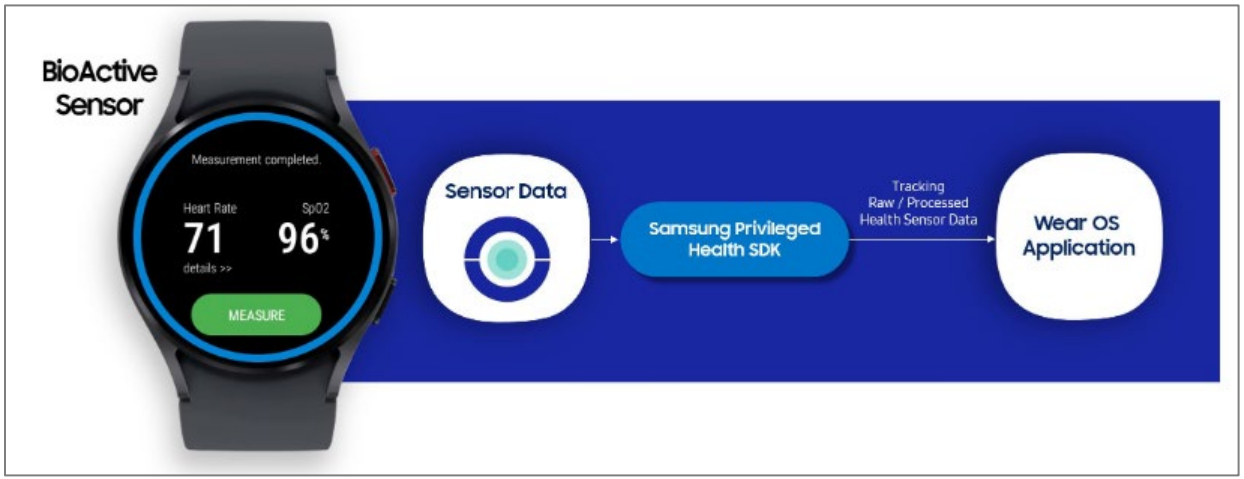
Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

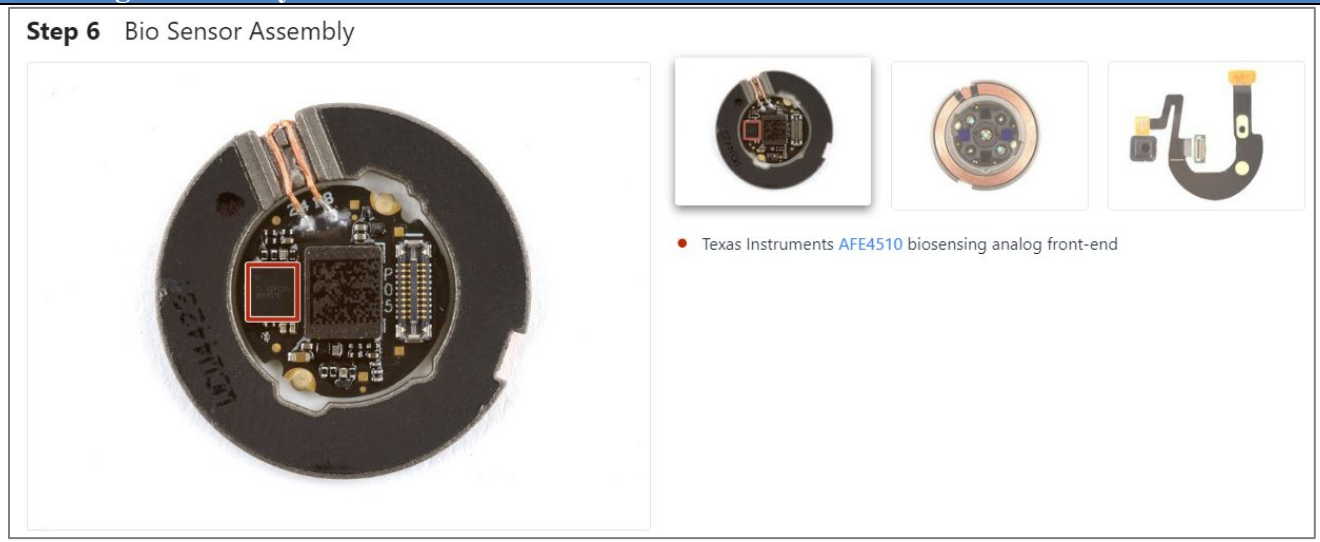
Source: Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 1, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

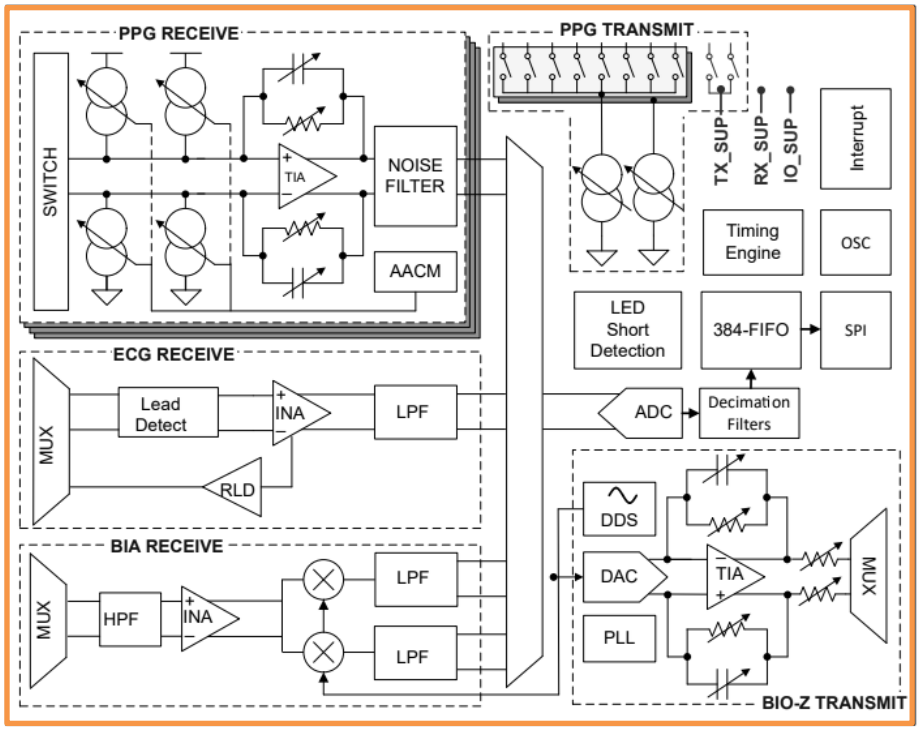
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	 Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F. “However, **increasing the LED current gives better signal quality from the SNR perspective.** The optimal AFE configuration settings are completely dependent on the application. This includes the separation of LED and PD, location of the sensor, and other factors.” Texas Instruments, Application Report, “How to Design Peripheral Oxygen Saturation (SpO_2) and Optical Heart Rate Monitoring (OHRM) Systems Using the AFE4403,” SLAA655 – Mar. 2015, at 3, *available at* https://www.ti.com/lit/an/slaa655/slaa655.pdf.

'455 Patent Claim	Samsung Accused System[1]
	"Coming to the next Galaxy Watch, the new sensor will enable advanced predictive and preventative wellness features never before seen on a wearable device — in addition to **more accurate health measurements**. . . . The all-new BioActive Sensor is essential to bringing you better preventative health experiences on the next Galaxy Watch, with design improvements that **enable even more precise health insights**. . . . This allows the new BioActive Sensor to **more accurately measure** health metrics such as heart rate, sleep quality, blood pressure, blood oxygen levels and stress levels. Even the measurement of heart rate during intensive workouts is **30% more accurate** compared to its predecessor." Samsung Newsroom, Unlocking New Possibilities for Preventative Wellness with New Galaxy Watch and BioActive Sensor, Jul. 8, 2024, *available at* https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor  "The SDK supports an improved health tracking capability to **allow your applications to track the user's health data accurately** with the accelerometer, raw ECG (Electrocardiogram), **PPG (Photoplethysmogram)**, and **heart rate including inter-beat interval**. In addition, it provides more advanced health features such as the body composition measurement, to enable compelling use cases for

'455 Patent Claim	Samsung Accused System[1]
	health and fitness applications. The blood oxygen level and sweat loss after a running workout are also useful data to check a user's health status." Source: Samsung Developer, "Samsung Privileged Health SDK," https://developer.samsung.com/health/privileged/overview.html
15[k] the detection system further configured to: generate a first signal responsive to light received while the light emitting diodes are off, generate a second signal responsive to light received while at least one of the light emitting diodes is on, and	The **detection system** in the Accused Smartwatch is further configured to **generate a first signal responsive to light received while the semiconductor sources are off,** and **generate a second signal responsive to light received while at least one of the semiconductor sources is on**, either literally or under the doctrine of equivalents. For example, the BioActive Sensor includes a PPG sensor that operates in multiple phases, including (1) Ambient (when the LEDs, or "semiconductor sources," are off) and (2) LED (when the LEDs, or "semiconductor sources," are on). During the Ambient phase, the sensor receives light with the LEDs off and generates a first signal. In the LED phase, the sensor receives light from the LEDs and generates a second signal.

’455 Patent Claim	Samsung Accused System[1]
	 Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw.

’455 Patent Claim	Samsung Accused System[1]
	 **Simplified Schematic**

’455 Patent Claim	Samsung Accused System[1]
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'455 Patent Claim	Samsung Accused System[1]

5.1 PPG Configuration

5.1.1 Phase Definition

This sheet is used to specify number of phases, timing, signal chain parameters associated with each phase, and the LED/PD association for each phase. The phase type is selected from the drop down menu (Ambient and LED) and the appropriate parameters for the phase type are automatically shaded in blue. Specify only the parameters that show up in the Blue boxes. Manually fill each cell using the drop down boxes (do not cut and paste values across cells). Also, fill only the boxes that show up in blue. Do not modify the cream- colored boxes.

3		tLED_SAMP	0	us (LED ON start to SAMP start)		1	No data written into FIFO							Single or Dual TIA		Single		
4						2	Phase [N] - Phase [N-1]							PPG Decimation Fa	PPG_DEC_FA	2	ble PPG Decim	EN_PPG_DEC
5	Phase parameter table					3	Phase [N-1] - Average(Phase [N], Phase [N-2])							TIA1				
6	Phase	Phase type	LED drv1 connects to	LED drv2 connects to	NUMAV	Stagger LED?	4 Phase[N] - Phase [N-2]	FIFO data word	SAMP time (us)	Filter BW Selection	Connect PD4?	Connect PD3?	Connect PD2?	Connect PD1?	Rf (kOhm)	Cf (pF)	IOFFDAC_ TIA1 (uA)	AACM TYPE
7	1	Ambient			2	0	Never mask	1	115	Set1			1		100	20	0	ANA AACM
17	2	LED	TX5	TX5	2	0	Never mask	1	115	Set1			1		100	20	0	LED_DC Cancel
27	3	Ambient			2	0	Never mask	3	115	Set1			1		100	20	0	ANA AACM
37																		
47																		
57																		
67																		
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Figure 5-1. PPG per-phase configuration

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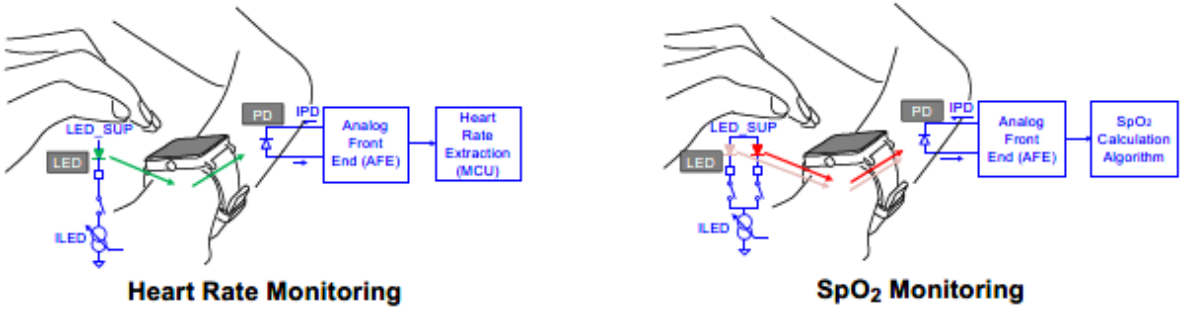
	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
3		tLED_SAMP	0	us (LED ON start to SAMP start)			1	No data written into FIFO						Single or Dual TIA		Single		
4							2	Phase [N] - Phase [N-1]						PPG Decimation Fa	PPG_DEC_FA	2	le PPG Decim	EN_PPG_DEC
5	Phase parameter table						3	Phase [N-1] - Average(Phase [N], Phase [N-2])										
							4	Phase[N] - Phase [N-2]			TIA1							
6	Phase	Phase type	LED drv1 connects to	LED drv2 connects to	NUMAV	Stagger LED?	Fractional masking	FIFO data word	SAMP time (us)	Filter BW Selection	Connect PD4?	Connect PD3?	Connect PD2?	Connect PD1?	Rf (kOhm)	Cf (pF)	IOFFDAC_ TIA1 (uA)	AACM TYPE
7	1	Ambient			2	0	Never mask	1	115	Set1			1		100	20	0	ANA AACM
17	2	LED	TX5	TX5	2	0	Never mask	1	115	Set1			1		100	20	0	LED_DC Cancel
27	3	Ambient			2	0	Never mask	3	115	Set1			1		100	20	0	ANA AACM
37																		
47																		
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67																		
77																		
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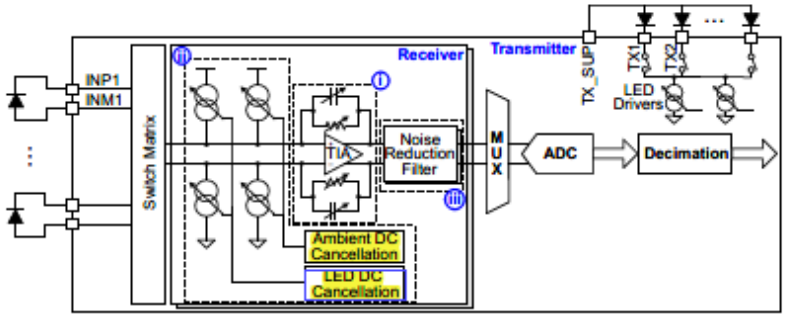
Figure 5-1. PPG per-phase configuration

Source: Texas Instruments, AFE4500 EVM User Guide, SBAU370 – April 2021, at 23, *available at* https://www.manualslib.com/download/2652772/Texas-Instruments-Afe4500evm.html.

“To save power, the LED is pulsed at the PRF rate, turning on for a short window in each PRF cycle. Each turning on of the LED results in one sample in the digital data stream. . . . Input offset cancellation DAC cancels DC from both **ambient** and **LED**, and allows a high TIA gain setting for the best noise performance.” Texas Instruments, Application Brief, “Optical Heart Rate Monitoring (OHRM) on Wearables,” SBAA564, Nov. 2022, at 2, *available at* https://www.ti.com/lit/ab/sbaa564/sbaa564.pdf.

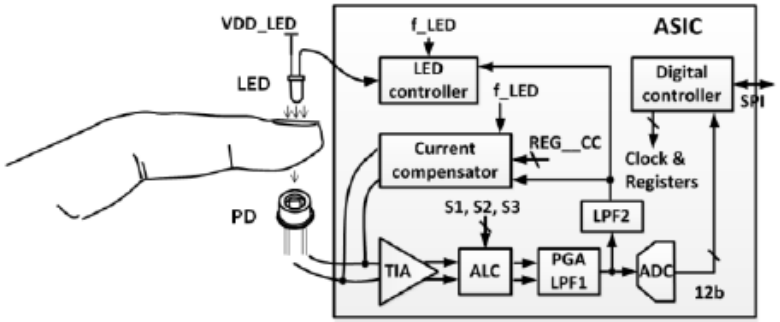
’455 Patent Claim	Samsung Accused System[1]

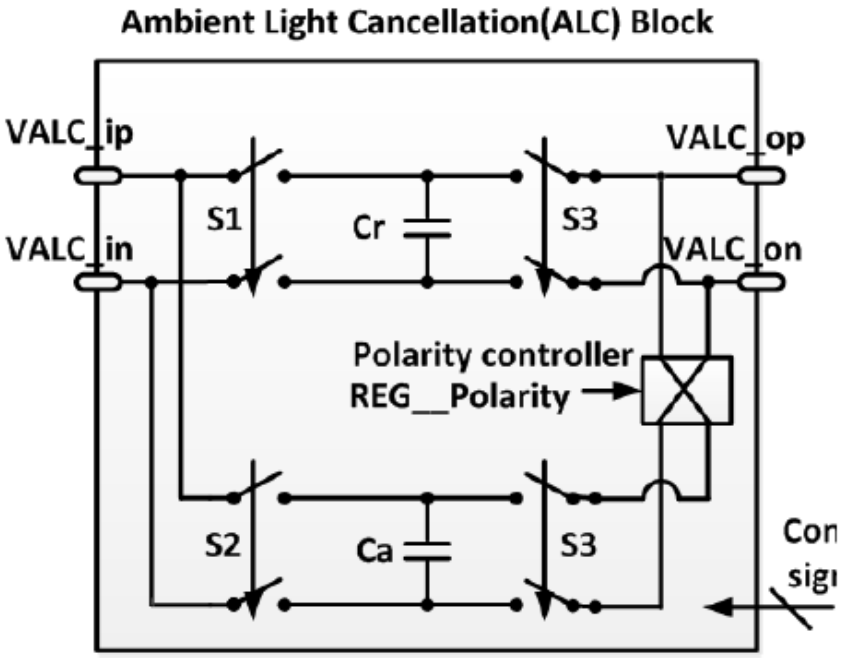


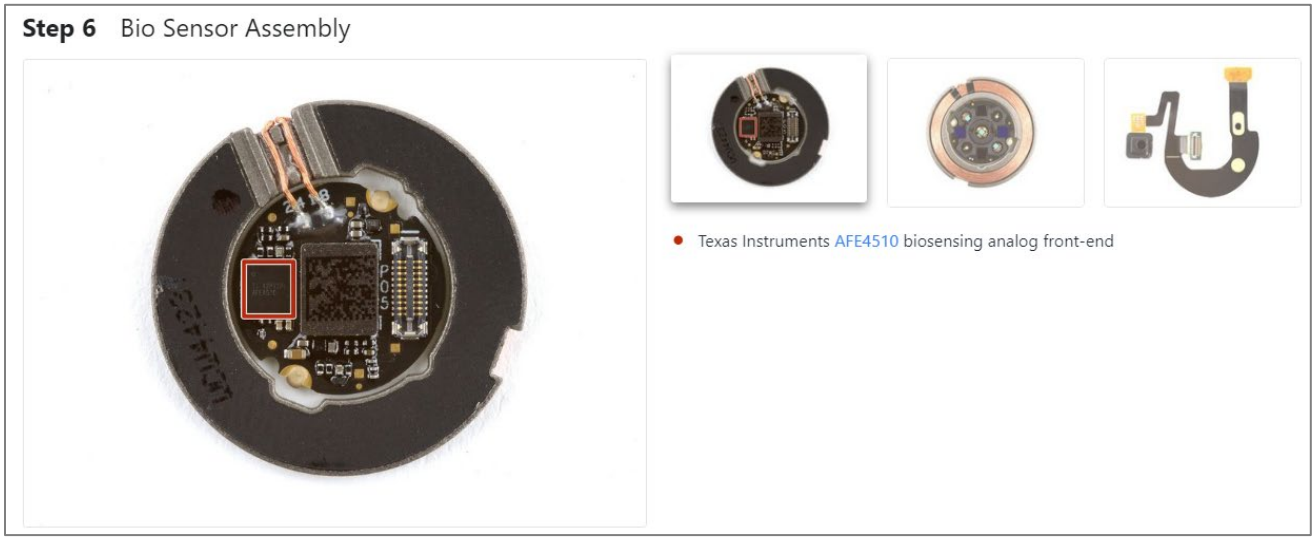


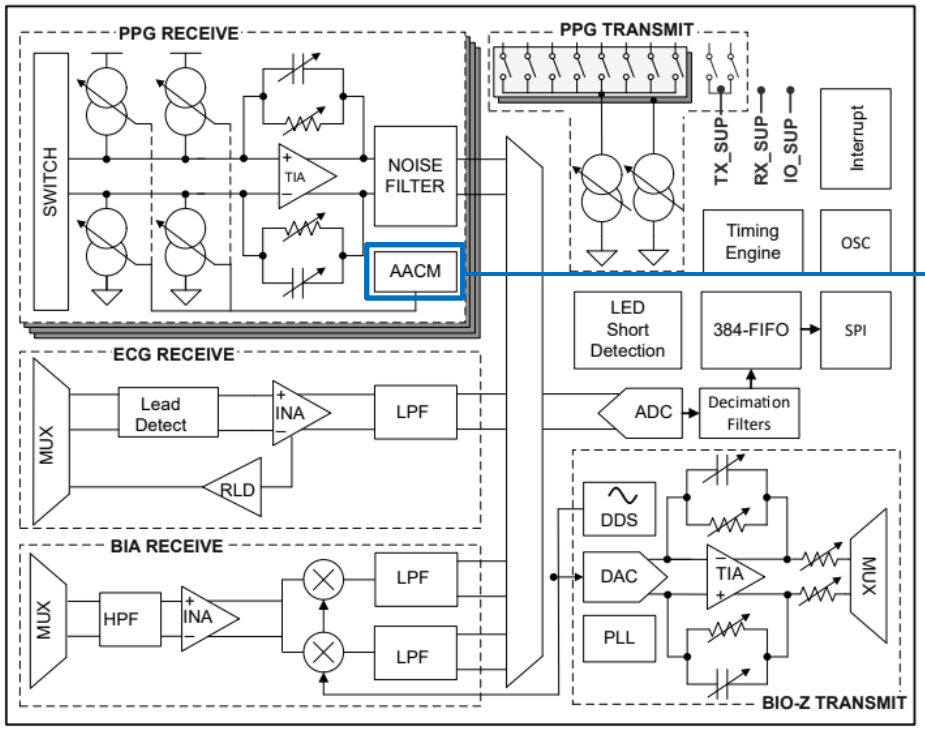
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A technical paper authored by Samsung engineers further explains a PPG signal detection system for use in wearable devices configured to operate in an Ambient and LED phase:

'455 Patent Claim	Samsung Accused System[1]
	B. Ambient Light Cancellation (ALC) The ambient light component in the detected PPG signal can be removed in the ALC block, which is shown in Fig. 2. When the LED light turns on, the measured signal corresponding to both the LED light and the ambient light is sampled at the charge reservoir Cr, and when the LED light turns off, the measured signal corresponding to only the ambient light is sampled at an another charge reservoir Ca. Then, the charge redistribution occurs to cancel the ambient  Figure 1. Top block diagram of LED driving and PD detection circuit for PPG application.

’455 Patent Claim	Samsung Accused System[1]
	 Figure 2. Detailed architecture of the ambient light cancellation (ALC) block. Source: J. Kim et al., “Ambient light cancellation in photoplethysmogram application using alternating sampling and charge redistribution technique,” 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), at 6441-42.

’455 Patent Claim	Samsung Accused System[1]
15[l] increase the signal-to-noise ratio by comparing the first signal and the second signal;	The detection system in the Accused Smartwatch is configured to **increase the signal-to-noise ratio by comparing the first signal and the second signal**, either literally or under the doctrine of equivalents. For example, ambient light is considered as noise in PPG sensors. Therefore, the presence of ambient light decreases the SNR of PPG sensors. Ambient light cancellation is performed to cancel out the ambient light noise, thereby increasing the SNR. The BioActive Sensor of the Galaxy Watch Ultra performs ambient light cancellation (also referred to as “Digital Ambient Subtraction”), to increase the SNR, by comparing the measured signal when the LED sources are off (“first signal”) and the measured signal when the LED sources are on (“second signal”).  Source: IFIXIT, Samsung Galaxy Watch Ultra Chip ID, https://www.ifixit.com/Guide/Samsung+Galaxy+Watch+Ultra+Chip+ID/175327?srsltid=AfmBOoriU1zDb_SwZ7O5CP4JIQFSWUnKHWqSe9g6SXYqF3F-NzUYIGpw.

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Table 1. Specifications for OHRM on Wearables

System Specifications	AFE4432	Comments
Multi-sensor support	4 LEDs, 3 PDs	Combining signals from multiple PDs and LEDs helps mitigate motion artifacts
Sampling rate	1 Hz–1 kHz	A sampling rate of 25 Hz to100 Hz is typically used for continuous HRM
Current consumption	12 µA	For the receiver at 25 Hz PRF
Peak SNR	115 dB over 10-Hz bandwidth	Important consideration to achieve good accuracy in low perfusion cases.
Ambient rejection	> 70 dB up to 160 Hz	Good ambient rejection helps remove the spurious tones caused by ambient light from sources such as indoor lighting

Figure 3 shows the PPG signal chain in AFE4432.

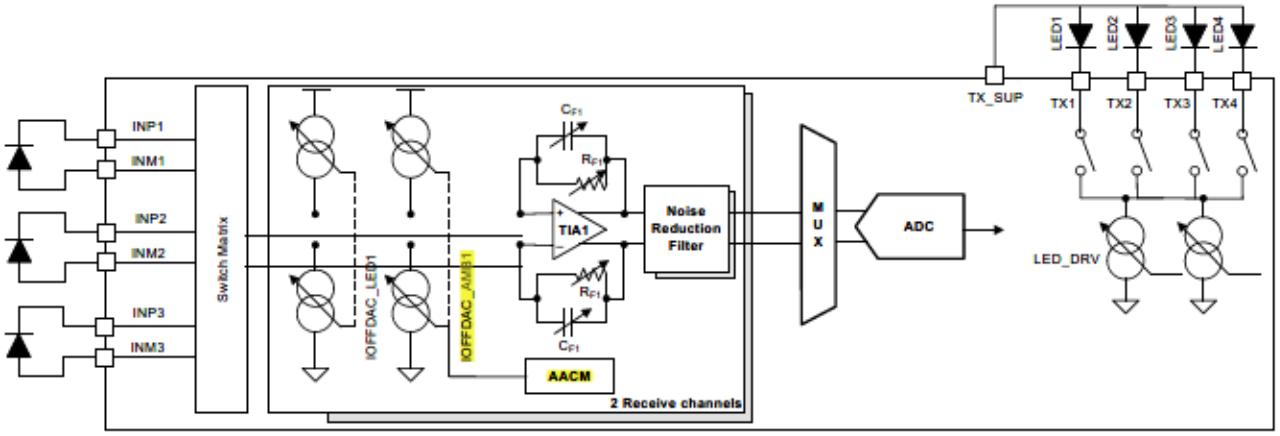


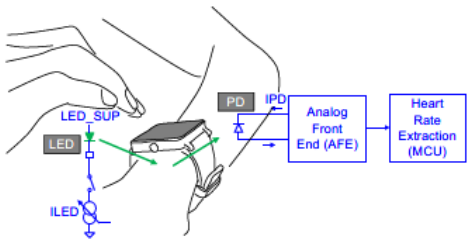
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The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

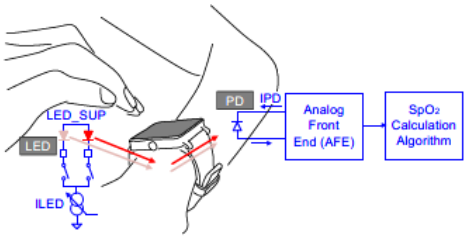
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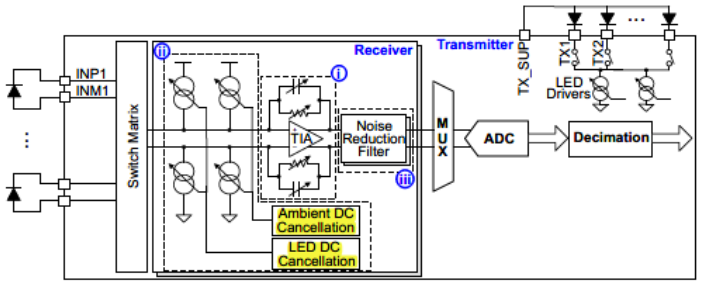
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Heart Rate Monitoring

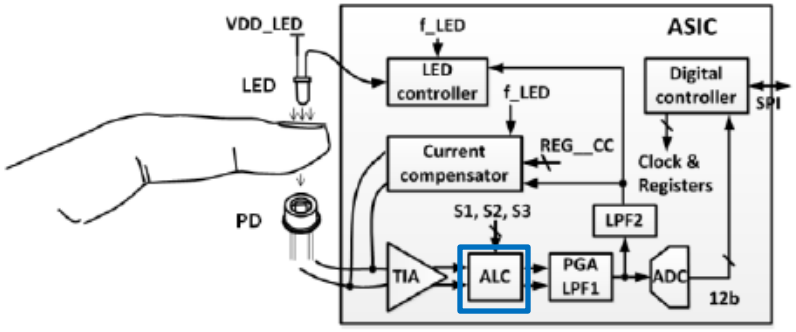


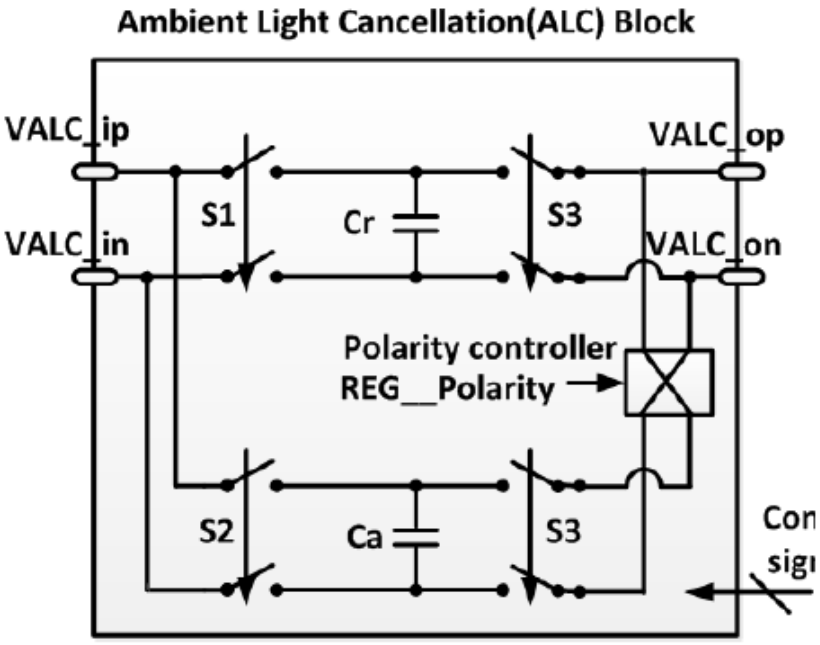
SpO_2 Monitoring

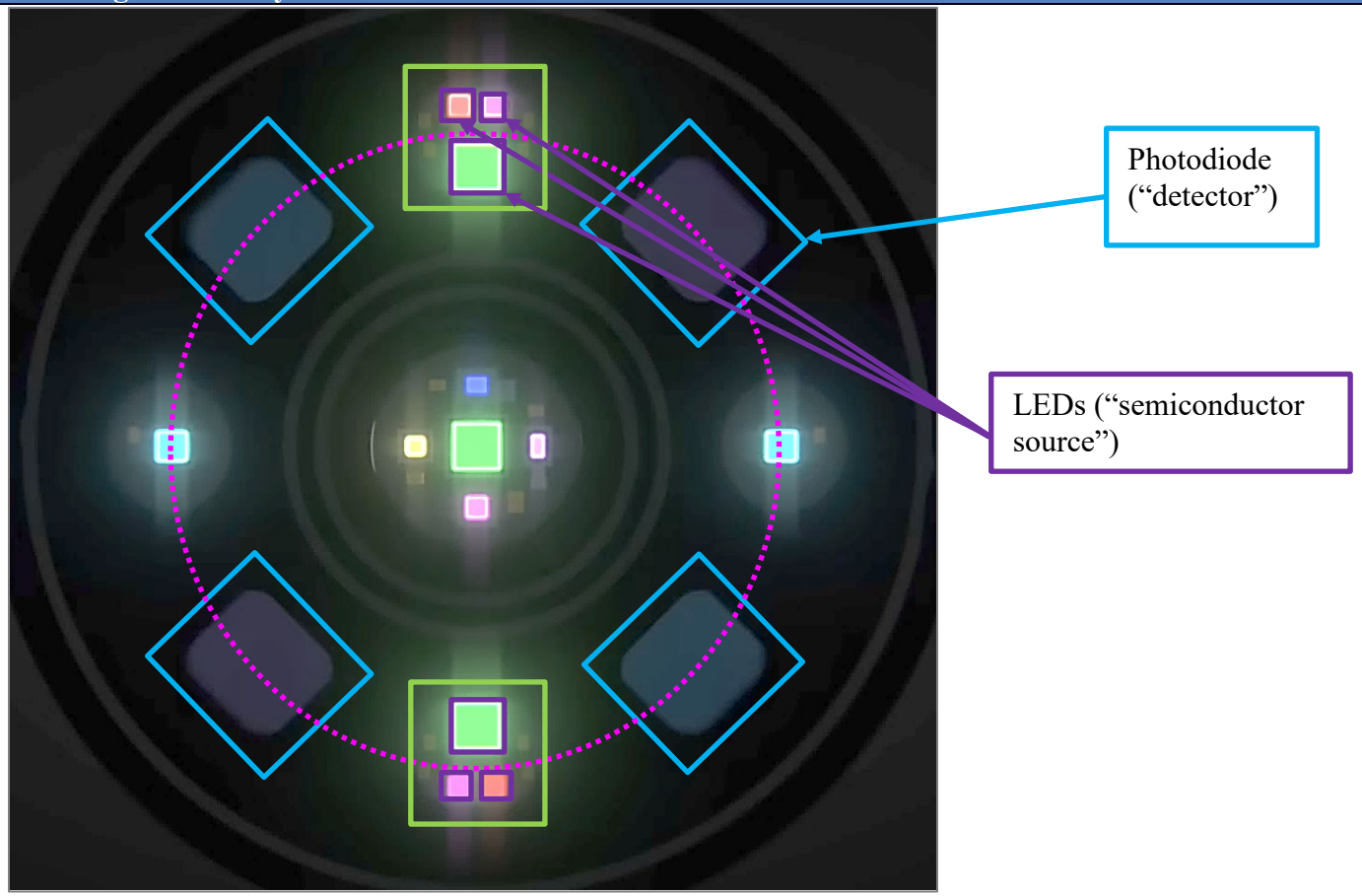


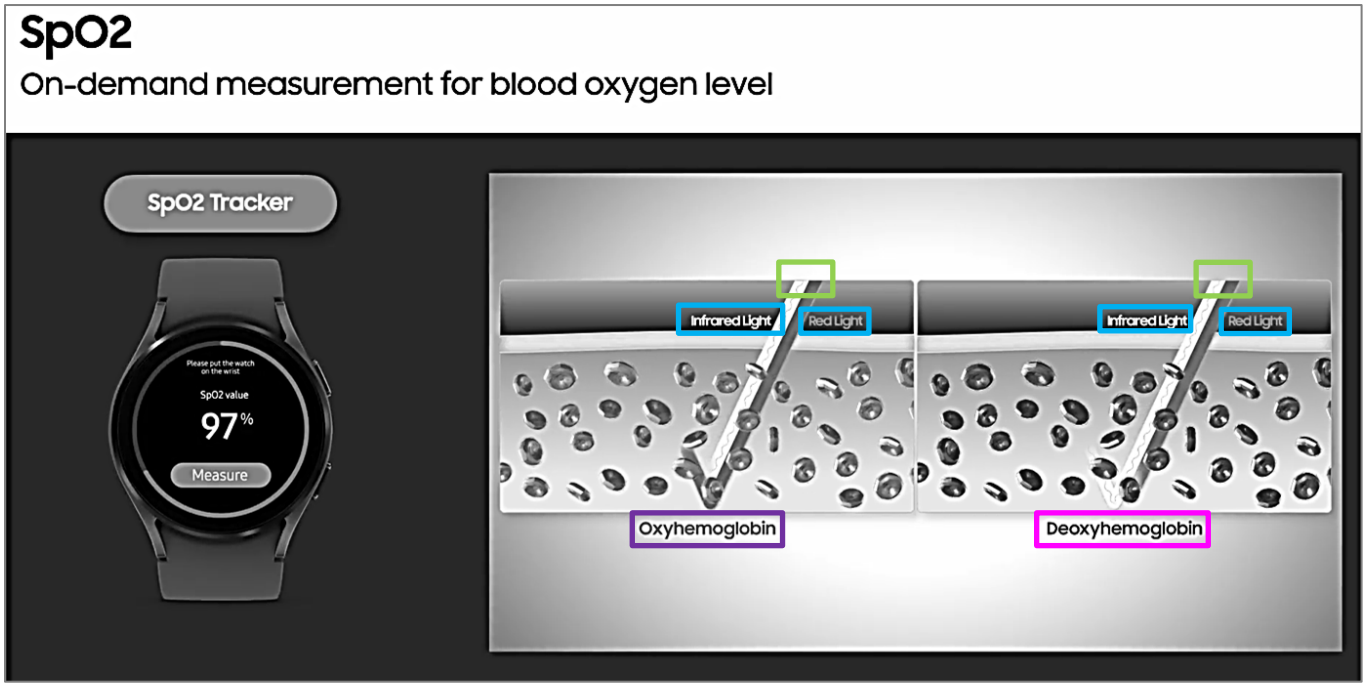
Block Diagram

’455 Patent Claim	Samsung Accused System[1]
	Source: Texas Instruments, Product Overview, “Photoplethysmography (PPG) with Integrated AFE for Optical Biosensing,” Oct. 2023, at 1, *available at* https://www.ti.com/lit/po/sbat014/sbat014.pdf?ts=1724246538793&ref_url=https%253A%252F%252Fwww.google.com%252F. **5 AFE4500 Register Generation Excel** The AFE4500_Register_Generation_v*.xlsm will be given by TI. This configuration file will be in the EVM software installation directory. Default file location: ***C:\Program Files\Texas Instruments\Bio-Sensing\AFE4500EVM\Register config\AFE4500_Register_Generation_v*.xlsm*** By default the EVM ships in LDO enable mode with following configuration • Clocking : Internal oscillator • PPG configuration – PPG output data rate: 50 Hz – 3 Phases (Phase1, Phase2, Phase3) are defined for PPG: AMB1, LED, AMB2 – PPG Phases are sampled from Green PD of sensor board – TX1 (connected to Green LED on sensor board) is used to LED Phase. – TIA Gain (i.e. Rf): 250 kΩ – Sampling width: 117 µS – Noise reduction filter: 2.5 KHz – ANA AACM: Enabled to cancel ambient signal from all Phases – DIG AACM: Enabled to cancel the DC in LED Phase. • ECG Configuration – ECG output data rate: 500 Hz – ECG INA Gain: 21 Source: Texas Instruments, AFE4500 EVM User Guide, SBAU370 – April 2021, at 23, *available at* https://www.manualslib.com/download/2652772/Texas-Instruments-Afe4500evm.html.

'455 Patent Claim	Samsung Accused System[1]
	Samsung engineers authored a technical paper further describing ambient light cancellation in PPG applications for wearable devices: *B. Ambient Light Cancellation (ALC)* The ambient light component in the detected PPG signal can be removed in the ALC block, which is shown in Fig. 2. When the LED light turns on, the measured signal corresponding to both the LED light and the ambient light is sampled at the charge reservoir Cr, and when the LED light turns off, the measured signal corresponding to only the ambient light is sampled at an another charge reservoir Ca. Then, the charge redistribution occurs to cancel the ambient  Figure 1. Top block diagram of LED driving and PD detection circuit for PPG application. light component out by reconnecting the two charge reservoirs in a manner of reversed polarity.

'455 Patent Claim	Samsung Accused System[1]
	 Figure 2. Detailed architecture of the ambient light cancellation (ALC) block. Source: J. Kim et al., "Ambient light cancellation in photoplethysmogram application using alternating sampling and charge redistribution technique," 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), at 6441-42.
15[m] wherein the plurality of semiconductor sources comprises six light emitting	The Accused Smartwatch comprises a **plurality of semiconductor sources** which **comprises six light emitting diodes, and wherein the plurality of semiconductor sources and the plurality of spatially separated detectors are located on one or more arcs**, either literally or under the doctrine of equivalents.

’455 Patent Claim	Samsung Accused System[1]
diodes, and wherein the plurality of semiconductor sources and the plurality of spatially separated detectors are located on one or more arcs; and	 Source: https://news.samsung.com/global/unlocking-new-possibilities-for-preventative-wellness-with-new-galaxy-watch-and-bioactive-sensor
15[n] wherein the output optical light comprises wavelengths	In the Accused System, **the output optical light comprises wavelengths between 600 nm and 1000 nm to measure a level of oxy-hemoglobin and deoxy-hemoglobin**, either literally or under the doctrine of equivalents.

’455 Patent Claim	Samsung Accused System[1]
between 600 nm and 1000 nm to measure a level of oxy-hemoglobin and deoxy-hemoglobin.	For example, the output optical light (from the LEDs), for measuring oxy-hemoglobin and deoxy-hemoglobin levels (during SpO_2 measurement/measuring blood oxygen level) includes red and infrared light, which have wavelengths between 600 nm and 1000 nm.  Source: https://developer.samsung.com/conference/sdc22/sessions/expand-health-experiences-with-galaxy-watch

'455 Patent Claim	Samsung Accused System[1]

Table 1. LEDs – Wavelengths and Applications	
LED Wavelength (Color)	**LED Applications**
410–420 nm (Violet)	Skin therapy
430–470 nm (Blue)	Dental curing instruments
470 nm (Blue)	White LEDs using phosphor
520–530 nm (Green)	Green traffic signal lights
580–590 nm (Amber)	Amber traffic signal lights
630–640 nm (Red)	Red signal lights
660 nm (Deep Red)	Blood oximetry
680 nm (Deep Red)	Blood analysis
800–850 nm (Near-IR)	Night-vision illuminators and beacons for use with night-vision goggles or CCDs
850–940 nm (Near-IR)	Photoelectric controls
940 nm (Near-IR)	Covert illumination CCD-based systems

Source: https://www.photonics.com/Articles/Light-Emitting_Diodes_A_Primer/a36706

"Infrared radiation (IR), also known as thermal radiation, is that band in the electromagnetic radiation spectrum with **wavelengths above red visible light between 780 nm and 1 mm."**
Source: https://www.icnirp.org/en/frequencies/infrared/index.html