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Switchable Speaker Driver for Power-efficient Proximity Sensing and Device Wake-up

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ABSTRACT

This disclosure describes power-efficient ultrasonic techniques for proximity detection and device wake-up from sleep mode. In sleep mode, the host application processor, e.g., the main device processor, is inactive. A low-power embedded controller remains on during sleep mode and generates an ultrasonic waveform that is amplified by a low-power speaker driver that also remains on during sleep mode. In some of the described architectures, a switch is provided that switches between the low-power speaker driver in sleep mode and a high-power speaker amplifier in active mode. A microphone captures echoes of reflected ultrasonic waves. Echoes arising from within a certain distance of the screen of the device are indicative of human presence and trigger the waking up of the device.

KEYWORDS

- Ultrasonic sensing
- Proximity sensing
- Device wake-up
- Speaker driver
- Sleep mode
- Active mode

BACKGROUND

A device such as a laptop or tablet that is in sleep mode can be woken up if a user is detected in its proximity, e.g., within 10-45 cm of its screen. Optical proximity sensors, e.g., passive infrared (IR) sensing, active sensing using IR emitters and photo-detectors, etc., add to the bill of materials for the device and are relatively expensive. Further, optical sensors that operate while the device is in sleep mode consume substantial amounts of power, since these are connected via I2C interface to a sensor hub (typically a microcontroller), and since the device is awoken via an interrupt to the main processor.

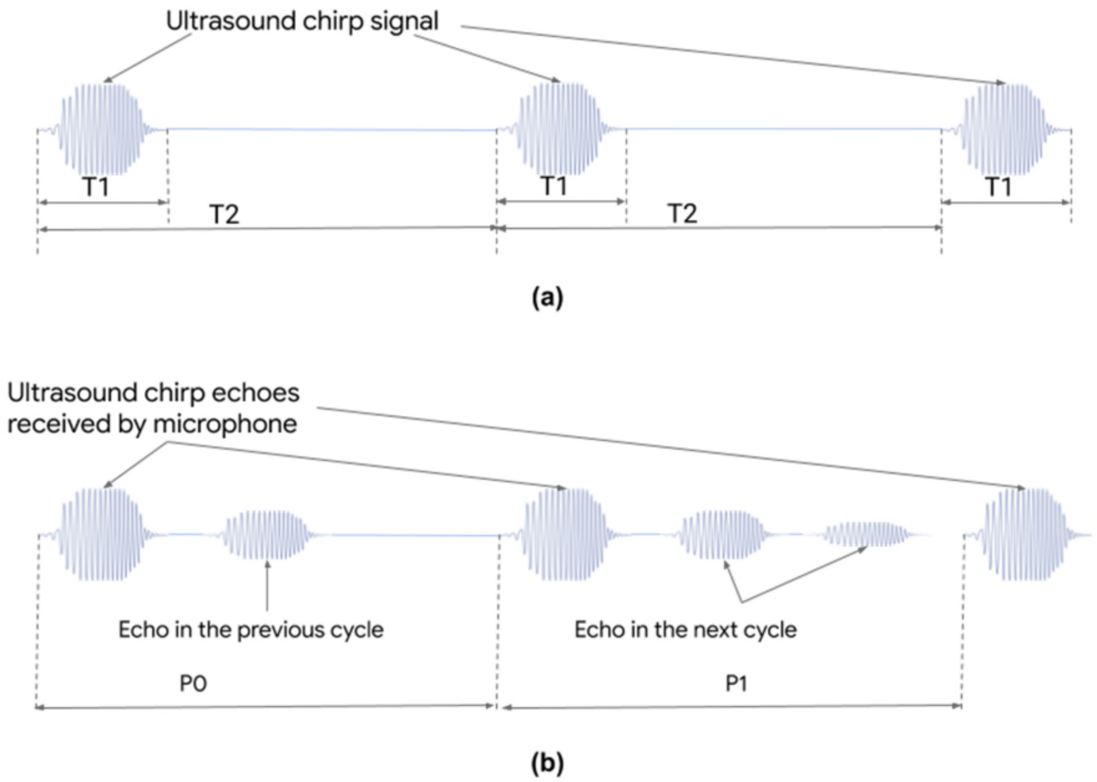

Fig. 1: Ultrasonic waves to detect a user's proximity to the device: (a) Transmitted ultrasonic signal; (b) Received ultrasonic echoes

As illustrated in Fig. 1, proximity sensing can be achieved by using the speaker of the device to send ultrasonic waves and by using the microphone of the device to detect echoes. Fig. 1(a) illustrates a series of ultrasonic chirp signals transmitted by the speaker of the device. A chirp signal is a signal whose instantaneous carrier frequency increases, e.g., from 18 kHz to 40 kHz. The amplitude of the carrier signal can be modulated by another lower frequency signal, e.g., to obtain low amplitude at the beginning and at the end of the chirp duration (T1). The speaker can send the modulated ultrasonic chirp at intervals T2 such that a duty cycle of, e.g., 5-20%, is achieved.

Fig. 1(b) illustrates ultrasonic echoes received by the device microphone. The transmitted chirp pattern can be identified by virtue of its known duration T1 and duty cycle T2. As shown, echoes bounced off objects (if any) in the region surrounding the device are received by the microphone. The time difference in the arrival of echoes between a cycle P0 and the following cycle P1 is calculated and translated into the distance between the device and object. A changing echo pattern indicates moving objects. The presence of objects within a certain distance, e.g., 10-45 cm, of the screen is indicative of user proximity.

In sleep mode, the device microphone is generally on; however, the speaker driver is not. Keeping the speaker driver on during sleep mode (as required for proximity detection) consumes substantial amounts of power which may be unacceptable in some device configurations.

DESCRIPTION

This disclosure describes power-efficient techniques of proximity detection using ultrasound for a device such as a tablet, laptop, etc. is in sleep mode. Device architectures herein described switch the speaker driver between the host application processor and an embedded controller. The host application processor drives the speaker when the device is on, whereas the embedded controller, which consumes much less power than the host application processor, drives the speaker with pre-programmed ultrasonic signals while the device is in sleep mode. If the embedded controller detects objects in the proximity of the device, e.g., based on reception of ultrasonic echoes at an appropriate delay, it sends a wake signal to the host application processor.

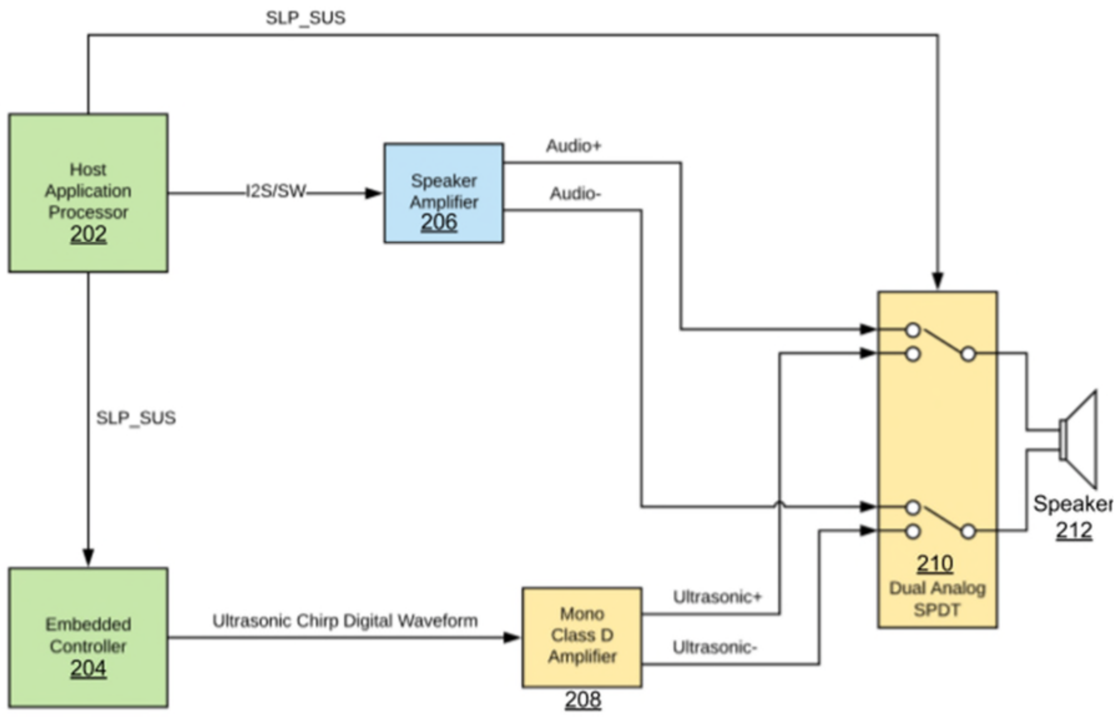

Fig. 2: Example 1 - power-efficient switching architecture for ultrasonic proximity sensing and device wake-up

Fig. 2 illustrates an example switching architecture for ultrasonic proximity sensing and device wake-up, per techniques of this disclosure. A host application processor (202), which is the main processor of the device, is coupled to a speaker amplifier (206), e.g., via an I2S interface. Through a switch (210), which can be a dual-analog, single-pole dual-throw (SPDT) switch, the speaker amplifier drives a speaker (212). Both the host application processor and the speaker amplifier consume substantial amounts of power, and, per the techniques, are active only when the device is in active mode.

A low power embedded controller (204) is coupled to an auxiliary, low-power speaker driver (208). Through the switch, the auxiliary low-power speaker driver, which can be, e.g., a mono-channel class-D amplifier, drives the speaker. The embedded controller and the auxiliary speaker driver both consume low amounts of power and are switched on while the device is in sleep mode. The switch (210) couples the speaker amplifier (206) to the speaker while the device is active and couples the auxiliary speaker driver (208) to the speaker while the device is in sleep mode.

The embedded controller stores in its memory a sampled ultrasonic chirp waveform, which it plays in a cycle while the device is in sleep mode. Ultrasonic chirps are thereby generated by the speaker while the device is in sleep mode, and echoes, if any, are received by the device microphone. If the echoes indicate human presence within a certain distance of the screen of the device, the embedded controller wakes up the host application processor and in turn, causes the device as a whole to wake up.

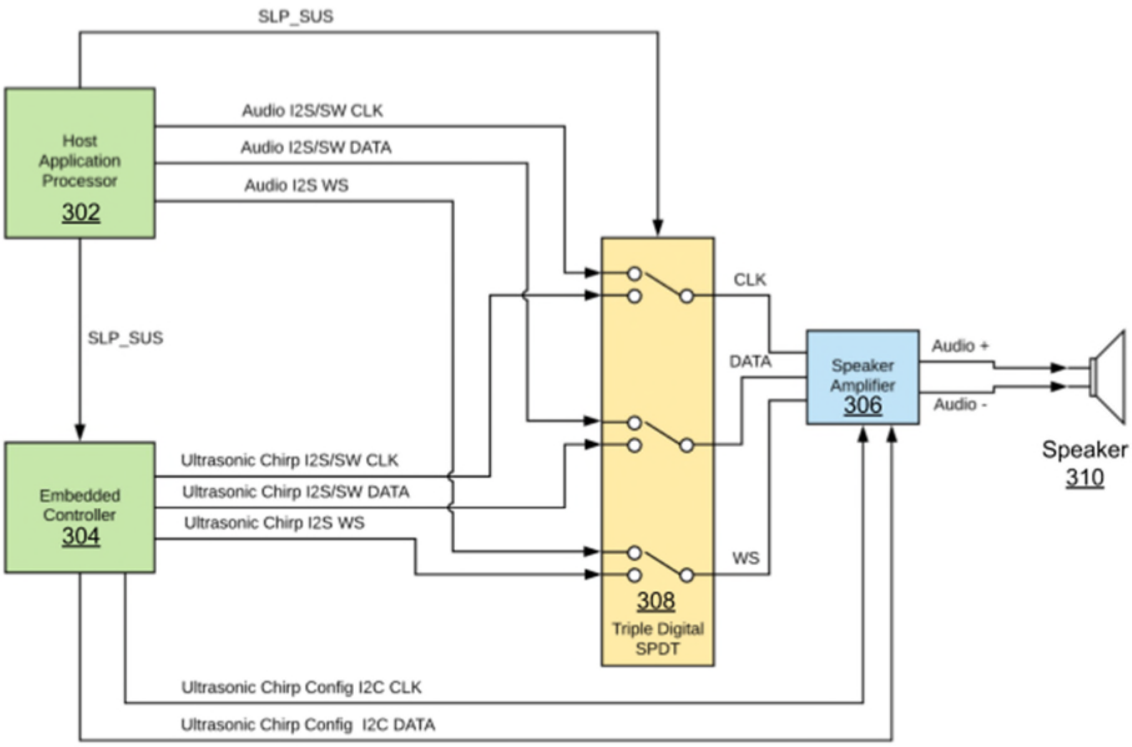

Fig. 3: Example 2 - power-efficient switching architecture for ultrasonic proximity sensing and device wake-up

Fig. 3 illustrates another example switching architecture for ultrasonic proximity sensing and device wake-up, per techniques of this disclosure. The host application processor (302) is coupled to and drives a speaker amplifier (306) through a switch (308), which can be, e.g., a triple-digital, single-pole dual-throw (SPDT) switch. The host application processor can be coupled to the speaker amplifier using, e.g., an I2S interface, such that I2S signals such as audio data, clock, and word-select (WS) are together routed by the triple-digital SPDT switch. When the device is active, the host application processor is on and can send audio signals to the speaker amplifier to drive the speaker (310).

An embedded controller (304) is coupled to and drives the speaker amplifier through the switch. The embedded controller can be coupled to the speaker amplifier using, e.g., an I2S interface, such that I2S signals such as audio data, clock, and word-select (WS) are together routed by the triple-digital SPDT switch. However, the embedded controller can directly configure the speaker amplifier for ultrasonic operations. The embedded controller, which consumes low amounts of power, is on while the device is in sleep mode. The switch couples the speaker amplifier to the host application processor while the device is active, and couples the speaker amplifier to the embedded controller while the device is in sleep mode.

The embedded controller stores in its memory a sampled ultrasonic chirp waveform, which it plays in a cycle while the device is in sleep mode. Ultrasonic chirps are thereby generated by the speaker while the device is in sleep mode, and echoes, if any, are received by the device microphone. If the echoes indicate human presence within a certain distance of the screen of the device, the embedded controller wakes up the host application processor and the device as a whole.

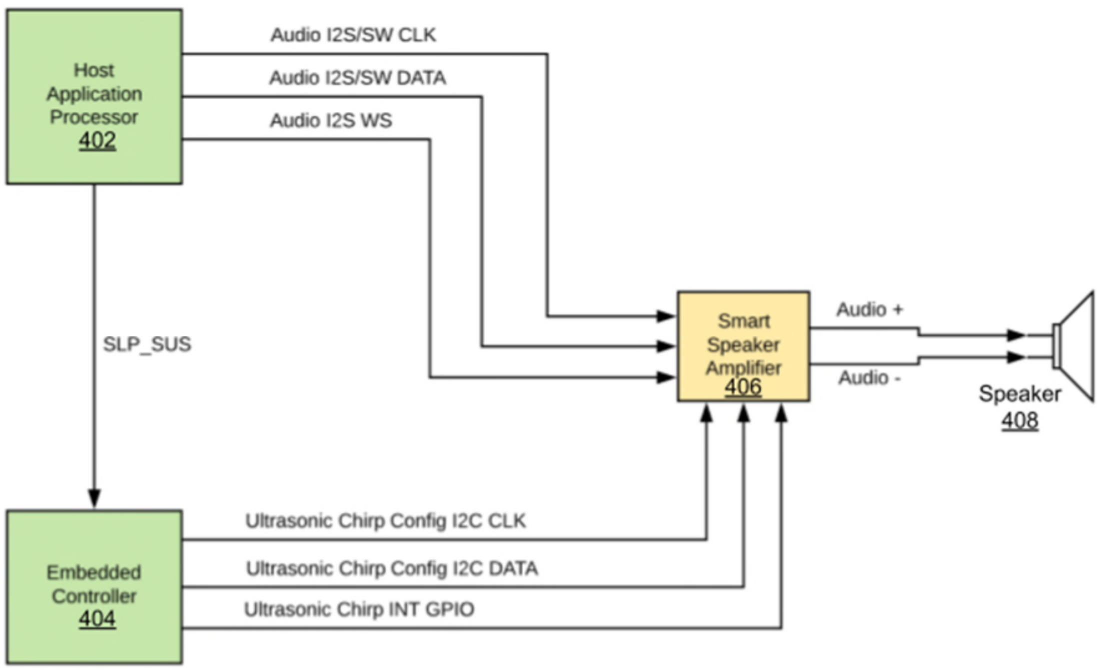

Fig. 4: Example 3 - power-efficient switching architecture for ultrasonic proximity sensing and device wake-up

Fig. 4 illustrates another example switching architecture for ultrasonic proximity sensing and device wake-up, per techniques of this disclosure. Both the host application processor (402) and the embedded controller (404) are coupled to and can drive a smart speaker amplifier (406). The host application to smart speaker coupling can be via an I2S interface, while the embedded controller to smart speaker coupling can be via an I2C interface.

The smart speaker amplifier is multiplexed between the host application processor and the embedded controller using software. While the device is active, the host application processor is on and can send audio signals to the speaker amplifier to drive the speaker (408). While the device is in sleep mode, the host application processor is off, and the embedded controller, which consumes low amounts of power, is on.

The embedded controller stores in its memory a sampled ultrasonic chirp waveform, which it plays in a cycle while the device is in sleep mode. Ultrasonic chirps are thereby generated by the speaker while the device is in sleep mode, and echoes, if any, are received by the device microphone. If the echoes indicate human presence within a certain distance of the screen of the device, the embedded controller wakes up the host application processor and the device as a whole.

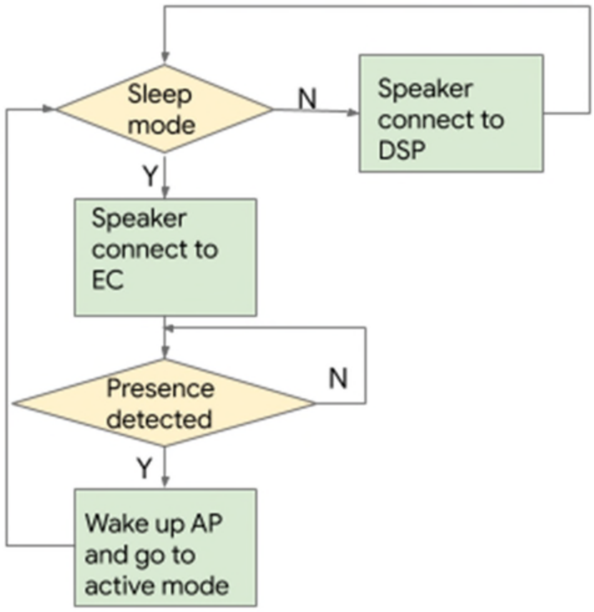

Fig. 5: Waking up a device based on ultrasonic proximity detection

Fig. 5 summarizes waking up a device based on ultrasonic proximity detection, per techniques of this disclosure. In active mode, the speaker is connected to the application processor, e.g., to an audio digital signal processor (DSP). In sleep mode, the low-power embedded controller (EC) is connected to the speaker. If human presence is detected, e.g., by the returning echo of ultrasonic signals generated by the EC, amplified by the low-power driver, and emitted by the speaker, the application processor (AP) is woken up and the device is placed into active mode.

In this manner, the switching architectures described herein use the existing speaker and microphone of the device and incorporate relatively inexpensive switching circuits to perform proximity sensing and device wake-up functions.

Ultrasonic proximity detection as described herein can be used in various devices. Users are provided with options regarding the use of proximity sensors and can elect to turn off the ultrasonic proximity detection feature. If the user chooses to turn off the feature, the circuits used for ultrasonic proximity detection (e.g., the embedded controller, speaker, microphone, etc.) are disabled while the device is in sleep mode. The user can wake up the device via other available mechanisms.

CONCLUSION

This disclosure describes power-efficient ultrasonic techniques for proximity detection and device wake-up from sleep mode. In sleep mode, the host application processor, e.g., the main device processor, is inactive. A low-power embedded controller remains on during sleep mode and generates an ultrasonic waveform that is amplified by a low-power speaker driver that also remains on during sleep mode. In some of the described architectures, a switch is provided that switches between the low-power speaker driver in sleep mode and a high-power speaker amplifier in active mode. A microphone captures echoes of reflected ultrasonic waves. Echoes arising from within a certain distance of the screen of the device are indicative of human presence and trigger the waking up of the device.