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Accurate Power Measurement Using Power Line Communication

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ABSTRACT

It is of interest to know the power consumed when a particular hardware module or software application of a device-under-test (DUT) such as a smartphone is triggered and run. While the DUT can be controlled externally for timed triggering of modules or applications of interest, such triggering can contaminate power measurement. This disclosure describes techniques to synchronize power measurement with events within a device-under-test. A program within the DUT can temporarily increase or decrease slightly the power consumption of the DUT. A slight increase (decrease) in power consumption is interpreted by the power meter as a one (zero) bit. Prior to an event of interest, the DUT generates a specific bit pattern to herald the start of the event. At the end of the event, the DUT generates another bit pattern. Power consumption attributable to the event is included in the power-consumption waveform between the start and the stop bit-patterns.

KEYWORDS

- Device under test (DUT)
- Power measurement
- Observer effect
- Measurement error
- Power line communication (PLC)
- Test and validation
- Error-correcting code
- Frame synchronization
- Bit synchronization
- Manchester encoding

BACKGROUND

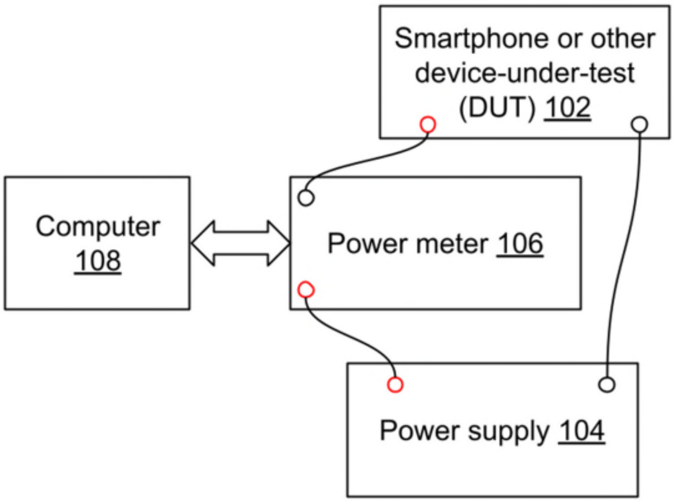

Fig.1: A typical set-up for power measurement

Fig. 1 illustrates a typical experimental set-up for power measurement. A device-under-test (DUT, 102), e.g., a smartphone, is connected to a power supply (104). In a series connection with the power supply and the DUT is a power meter (106) that measures the power consumed by the DUT. The power meter can measure instantaneous power consumption, e.g., at sampling intervals of 1 microsecond. The resulting power-consumption waveform can be captured and analyzed by a computer (108) connected to, and controlling, the power meter.

The DUT, e.g., a smartphone, typically has various hardware modules and software applications. It is of interest to know the power consumed when a particular module or application is triggered and run. The DUT can be controlled externally via USB, UART, or Bluetooth to enable the timed triggering of modules or applications of interest, but USB, Bluetooth, or other control channels themselves consume power and thereby contaminate power measurement. For example, earphone batteries typically have a 50mAh capacity, with the earphone typically running at 10mA/4V or thereabouts. Introducing USB/UART communications to time power measurement creates a power inaccuracy in the 3-5mA range, e.g., a measurement inaccuracy of 30-50%. Battery life estimates are correspondingly inaccurate.

DESCRIPTION

This disclosure describes techniques to synchronize power measurement with events within a device-under-test (DUT) without the need for external, power-consuming communications. As such, the raw power consumption waveform captured by the power meter and available at the computer has no markers indicating the starting or stopping of particular modules or applications. Per techniques described herein, the DUT is equipped with a small program that can temporarily increase slightly or decrease slightly the power consumption of the DUT. For example, executing different instruction sequences on the CPU can achieve such a change in the power consumption since some instructions use more power while others use less. A slight increase in power consumption is interpreted by the power meter as a high (1) bit. A slight decrease in power consumption is interpreted by the power meter as a low (0) bit. In effect, the power meter (and attached computer) serve as receiver to the unidirectional transmitter of the DUT. The duration of the bit can be controlled at the DUT using a hardware timer. Information transmission from the DUT to the power meter is thus established without the use of external, power-consuming techniques.

Prior to an event of interest, e.g., the running of a specific hardware module or software application within the DUT, the DUT generates a specific bit pattern to herald the start of the event. Immediately after the end of the event, the DUT generates another bit pattern to mark the end of the event. Effectively, the event is captured between timestamps; power consumption attributable to the event is included in the power-consumption waveform between the start and the stop bit patterns.

The slight decrease or increase in the power consumed by the DUT are such that their bit representations are achieved with sufficient signal-to-noise ratio (SNR) margin. To receive messages at the power meter that are free of errors, the techniques apply cyclic redundancy check (CRC) codes and forward error-correction codes (FEC). The messages sent by the DUT over the power line can be start-event markers, stop-event markers, or other messages, e.g., the identity of the power scenario being run, etc. The messages enable a developer to skip time-frames to focus on the scenario of interest and make accurate, event-based, power measurements. Power measurement can be done via current measurement, using, e.g., current-sensing resistors, magnetic techniques, etc.

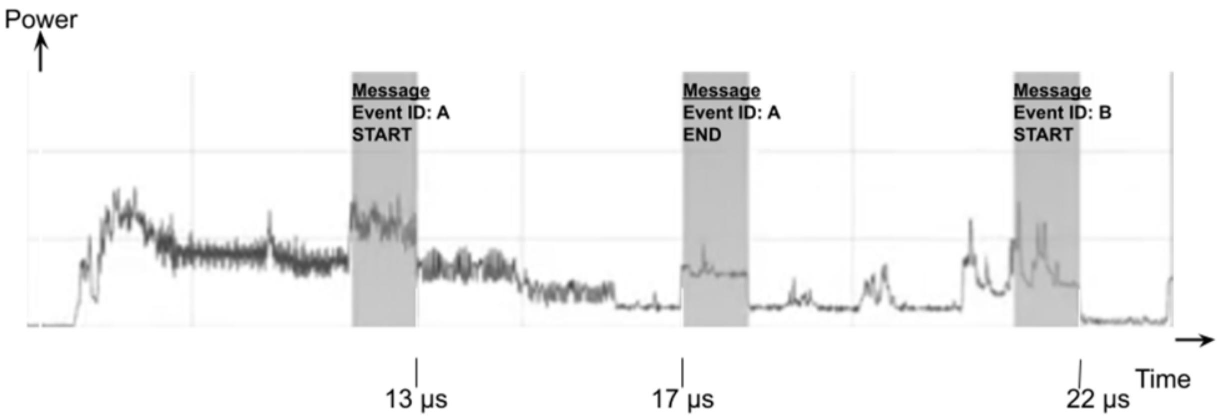

Fig. 2: Messages superimposed on a power-measurement waveform

Fig. 2 illustrates messages superimposed on a power-measurement waveform, e.g., as it is transmitted from the DUT, as captured by the power meter. A message can include, among other things, the identity of the event (or test scenario) it marks (A, B, etc., in the figure), whether it is a start-marker or an end-marker, etc. As the waveform is captured against a running clock, the timestamps of the messages, and hence of the events, can easily be determined by the power meter or the computer.

The inherent time variation of the underlying power waveform can potentially introduce interpretational errors in the bit pattern, e.g., a high bit superimposed on a naturally down-trending power waveform can be interpreted as a low bit, or vice-versa. To ensure accuracy of bit patterns, Manchester encoding of bits can be used, e.g., a bit “1” is a low-to-high transition, and a bit “0” is a high-to-low transition. Under Manchester coding, the bit value is better insulated from variations in the underlying power-measurement waveform.

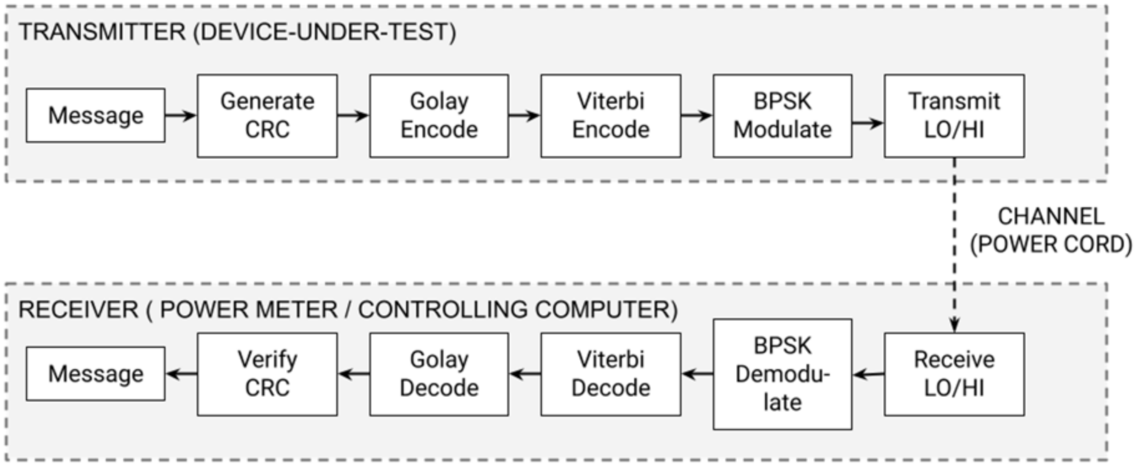

Fig. 3: An example transmit-receive chain

Fig. 3 illustrates an example transmit-receive chain. At the transmitter, e.g., the DUT, a message is appended with CRC bits; encoded, e.g., with an inner Golay code and an outer Viterbi code; and modulated using binary phase shift keying (BPSK). The resulting BPSK symbols are translated into a low-to-high or a high-to-low power transition (assuming Manchester encoding) and transmitted over the channel. As mentioned earlier, the channel is the power-supply cord - no additional communication medium, wired or wireless - is necessary for the purposes of communication. The receiver is the power meter, which in turn sends its received waveform to the controlling computer. At the receiver, the low-to-high or high-to-low transitions are demodulated as BPSK symbols, error-correction decoded, and CRC verified to recover the message.

Since the message is superimposed, e.g., added to or embedded within, a naturally time-varying power-measurement waveform at random time instants, it may be difficult for a receiver to determine the start of a message. To enable the receiver to determine message-start, a frame-synchronization sequence is introduced which can be, e.g., a sequence of a predetermined number of ones followed by a unique sequence with a very low probability of being randomly generated (such a sequence is known as a magic sequence). The frame-synchronization sequence is known to the receiver, and the receiver looks for it to detect message-start. Message-end can be declared a certain number of bits away from message-start.

In this manner, the problem of synchronizing power measurement with on-device events is solved. The described techniques enable the characterization of power models for wearable or handheld devices. Using the techniques, a developer can create different user scenarios to measure the power-usage profile and ensure that power consumption meets the battery life or power key performance indicators (KPI) requirements.

CONCLUSION

This disclosure describes techniques to synchronize power measurement with events within a device-under-test (DUT). A program within the DUT can temporarily increase or decrease slightly the current consumption of the DUT. A slight increase (decrease) in power consumption is interpreted by the power meter as a one (zero) bit. Prior to an event of interest, the DUT generates a specific bit pattern to herald the start of the event. At the end of the event, the DUT generates another bit pattern. Power consumption attributable to the event is included in the power-consumption waveform between the start and the stop bit-patterns.

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