

Timer Synchronisation Using Radio Frequency Signal Offset

Technical Field

- 5 The present disclosure relates to a device comprising a counter and timer, and in particular to a device comprising correction logic for synchronising the timer with a timer of another device.

Background

- 10 A timer is a common function implemented in a device for measuring units of time very accurately based on a signal output by an oscillator of the device. The timer comprises a counter register that is incremented in response to each pulse of clock signal derived from the signal of the oscillator. Each time a certain threshold is reached, the timer
15 raises an interrupt. These interrupts may, for example, enable a software program to keep track of how long a program has been running or how much time has elapsed since the program started.

- 20 When multiple devices operate together within a system, time offset error may arise between these devices, even if the devices are operating at the same nominal oscillator frequency. Such time offset error occurs as a result of small unintended differences in oscillator frequency between the devices, which over time results in an increasing time offset between the devices. Typically, regular time-sensitive communications between the devices are needed to bring the time offset back close to
25 zero. However, such time-sensitive communication does not address the underlying issue causing the time offset error, so the time offset will continue to increase with time at the same rate as before, thus demanding a frequency of communications that is a function of the worst-case oscillator error and the desired maximum time offset.

- 30 Summary

There is a need for an approach of synchronising timers, so that the rate at which the time offset error increases over time is reduced.

According to a first aspect, there is provided a first device comprising: an oscillator configured to generate an oscillator signal having a predefined frequency; a timer comprising: a counter configured to store a counter value and increment the counter value based on the oscillator signal; and timer circuitry configured to repeatedly raise an interrupt in response to the counter value increasing by a threshold amount, radio receiver circuitry configured to: receive a radio frequency signal from a second device; and determine a frequency offset between a carrier frequency of the radio frequency signal and predefined frequency of the oscillator; and correction logic configured to adjust the threshold amount by an amount that is dependent upon the determined frequency offset so as to synchronise the timer with a further timer of the further device.

In a device for transmitting radio frequency (RF) signals, the oscillator that provides the signal for the timer function, additionally functions as the source for the signals generated by radio transmitters. The inventors have, therefore, realised that the timers of two devices may be synchronised to measure the same predefined time value by, at the receiver device, measuring the difference between the carrier frequency of the RF signal received at the device and the oscillator frequency of the device and adjusting the threshold amount at which interrupts occur. For example, if the device determines that the RF carrier signal received from a further device is of a higher frequency than the frequency of its own oscillator, then the device reduces the value of the threshold amount so that its timer circuitry raise interrupts more frequently. On the other hand, if the device determines that the RF carrier signal received from the further device is of a lower frequency than the frequency of its own oscillator, the device then increases the threshold amount so that its timer circuitry raise interrupts less frequently. In this way, the timers are synchronised such that the intervals between interrupts for both devices are made substantially the same.

According to a second aspect, there is provided a method implemented in a first device, the method comprising: generating an oscillator signal having a predefined frequency; storing a counter value and incrementing the counter value based on the oscillator signal; and raising an interrupt of a timer in response to the counter value increasing by a threshold amount, receiving a radio frequency signal from a second device; and determining a frequency offset between a carrier frequency of the radio frequency signal and the predefined frequency of the oscillator signal; and adjusting the threshold amount by an amount that is dependent upon the determined frequency offset so as to synchronise the timer with a further timer of the second device.

In some embodiments, the radio frequency signal encodes a value indicating a further threshold value for the further timer, wherein the correction logic is configured to adjust the threshold amount in proportion to the further threshold value.

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In some embodiments, the radio frequency signal encodes a first quality indicator associated with an oscillator of the second device, wherein the method comprises: receiving a further radio frequency signal from a third device, the further radio frequency signal encoding a second quality indicator associated with an oscillator of the third device; determining a further frequency offset between a carrier frequency of the further radio frequency signal and predefined frequency of the oscillator; and determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators.

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In some embodiments, the step of determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators comprises: in response to determining that the first quality indicator indicates a lower uncertainty in frequency of the oscillator of the second device, adjusting the threshold amount based upon the frequency offset.

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In some embodiments, the method comprises: using the oscillator signal to send a further radio frequency signal to the second device, the further radio frequency signal having a carrier frequency that is equal to the predefined frequency.

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According to a third aspect, there is provided a method implemented in a system comprising the first device and the second device. The method comprising: the method according to the second aspect implemented in the first device of the system; at the second device of the system, generating a further oscillator signal at the carrier frequency; and at the second device, generating the radio frequency signal based on the further oscillator signal and causing the radio frequency signal to be transmitted to the first device.

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In some embodiments, the method further comprises, at the second device; determining the further threshold value; and causing the further threshold value to be transmitted to the first device in the radio frequency signal.

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In some embodiments, the method further comprises, at the second device, determining the further threshold value based upon a frequency of a radio frequency signal from a global positioning system satellite.

- 5 In some embodiments, the method further comprises: at the second device, determining the first quality indicator based on one or more quantities held in storage of the second device; and at the third device, determining the second quality indicator based on one or more quantities held in storage of the third device.
- 10 In some embodiments, for each of the second device and the third device, the respective one or more quantities comprise at least one of: age of the respective device; a type of oscillator belonging to the respective device; a temperature detected at the respective device; and an indication as to whether or not a threshold value of a timer belonging to the respective device has been corrected.

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Brief Description of the Figures

Arrangements of the present invention will be understood and appreciated more fully from the following detailed description, made by way of example only and taken in conjunction with drawings in which:

- 20 Figure 1 illustrates a system comprising two devices in communication with one another;
- Figure 2 illustrates a receiving device of the two devices belonging to the system;
- Figure 3 illustrates the transmitting device according to an embodiment in which the transmitting device dispatches an updated timer threshold value to the receiving
- 25 device;
- Figure 4 illustrates the transmitting device according to an embodiment in which the transmitting device dispatches a quality indicator to the receiver device;
- Figure 5 illustrates a system in which a plurality of devices transmit quality indicators to a receiving device;
- 30 Figure 6A illustrates a first part of a method for synchronising timers;
- Figure 6B illustrates a second part of the method according to a first embodiment;
- Figure 6C illustrates a second part of the method according to a second embodiment;
- and
- Figure 6D illustrates a second part of the method according to a third embodiment.

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Detailed Description

Embodiments will be described in more detail with reference to the accompanying Figures.

5 Reference is made to Figure 1, which illustrates an example system 10 according to embodiments. The system 10 comprises two devices 100A, 100B that are in communication with one another. The devices 100A, 100B communicate via radio frequency (RF) communications sent over an air interface between the devices 100A, 100B. Both of the devices 100A, 100B each comprise an antenna 140 enabling RF
10 communications to be sent/received over the air interface between the two devices 100A, 100B.

In the example of Figure 1, the device 100B comprise transmitter circuitry 130 for producing RF signals for sending to the device 100A, whilst the device 100A comprises
15 receiver circuitry 135 for receiving and demodulating those signals. However, in some embodiments, both devices 100A, 100B may be equipped with transceiver circuitry configured to perform both the transmission functions described herein as being performed by the transmitter circuitry 130 and reception functions described herein as being performed by the receiver circuitry 135. In such embodiments, the transceiver
20 circuitry of the device 100A may produce RF signals for sending to the device 100B, whilst the transceiver circuitry of the device 100B may produce RF signals for sending to the device 100A.

The transmitter circuitry 130 is configured to produce signals to drive the antenna 140,
25 so as to send communications to the device 100A. Each of the devices 100A, 100B comprises an oscillator 160 configured to produces an RF signal, which in device 100B provides the carrier wave for the RF communications. The transmitter circuitry 130 may be configured to encode information in the carrier wave using frequency-shift keying (FSK). The transmitter circuitry 130 comprises frequency synthesizer circuitry 150 and
30 mixer circuitry 155. The frequency synthesizer circuitry 150 is configured to receive the signal from the oscillator 160 and, based on the oscillator signal, synthesize a plurality of signals in a range of frequencies. The mixer 155 is configure to mix together the plurality of signals to produce the RF signal in which data is encoded. The data to be encoded is provided to the transmitter circuitry 130 by the processing circuitry 120. The
35 transmitter circuitry 130 drives the antenna 140 to cause the antenna 140 to send the RF signal over the air interface to the device 100A.

The receiver circuitry 135 of each of the device 100A is configured to receive RF signals sent from the device 100B over the air interface. The receiver circuitry 135 is configured to demodulate the received RF signals and to provide the data extracted
5 therefrom to the processing circuitry 120 of the device 100A.

In each device 100A, 100B, the signal output from the oscillator 160 is used by the clock source 165 to derive the clock signal for clocking the processing circuitry 120. The oscillator signal output by the oscillator 160 may be a sinusoidal wave. The clock
10 signal derived from the oscillator signal by the clock source 165 may be a digital signal that oscillates between a high and low state at the same frequency as the oscillator signal. The oscillators 160 in different devices 100A, 100B are associated with the same nominal frequency at which they are arranged to operate. However, due to imperfections in the oscillators 160, there is uncertainty in the true oscillation frequency
15 of the oscillators 160 and the oscillators 160 may each operate at different frequencies which deviate from the nominal frequency.

The processing circuitry 120 of each of the devices 100A, 100B may comprise one or more processors configured to execute computer readable instructions. Additionally or
20 alternatively, the processing circuitry 120 may comprise circuitry configured to implement functions in hardware. For example, the processing circuitry 120 may comprise a field programmable gate array (FPGA) and application specific integrated circuit (ASIC). The processing circuitry 120 may be part of a microcontroller of the relevant device 100A, 100B. The processing circuitry 120 operates according to a clock
25 signal that is derived from the signal output by the oscillator 160 by a clock source 165. The processing circuitry 120 also periodically receives an interrupt from a timer 110 of the device 100A, 100B. The interrupt enables the tracking of time by the processing circuitry 120. The processing circuitry 120 of device 100B is configured to provide data to the transmitter circuitry 130 for sending to the device 100A.

30 Reference is made to Figure 2, which illustrates circuitry of the device 100A in more detail. The elements having the same reference numerals as elements of Figure 1 have already been described above with reference to Figure 1, and the description of those elements is not repeated. As shown in Figure 2, the receiver circuitry 135
35 comprises circuitry 210, which may be referred to as the carrier frequency offset estimate (CFOE) module 210, for determining the frequency offset (i.e. the difference in

frequency) between the oscillator signal output by the oscillator 160 of the device 100A and the radio frequency signal received from the device 100B. The frequency offset determined by the carried frequency offset module 210 may be an estimate of the frequency offset. The carrier frequency offset estimate module 210 may be part of the demodulator 170 and may enable the demodulator 170 to compensate for the frequency differences between the frequency of the received carrier wave and the frequency of the oscillator 160 for the purposes of coherent demodulation. Having determined the frequency offset, the CFOE 210 provides the determined frequency offset to correction logic 235 that is associated with the timer 110.

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As shown in Figure 2, the timer may be part of a microcontroller 215. The microcontroller 215 comprises processing circuitry 220. The processing circuitry 220 may be the same as, or a part of, the processing circuitry 120 of the device 100A shown in Figure 1.

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Figure 2 illustrates the timer 110 of the device 100A in more detail. The timer 110 comprises a counter register 225. Circuitry of the timer 110 receives the clock signal from the clock source 165 and increments the value held in the counter register 225 in response to an edge in each cycle of the clock signal. For example, the circuitry may increment the value held in the counter register 225 by one in response to each rising edge of the clock signal. In embodiments, the counter register 225 may be a 32-bit register. The timer 110 further comprises timer circuitry 230, which is configured to monitor the value held in the counter register 225 and raise an interrupt each time the value held in the counter register 225 is incremented by a threshold amount. The threshold amount may be referred to as the counter target. The threshold amount may be stored in a register of the timer circuitry 230. For example, if the threshold amount is 1000, the timer circuitry 230 may raise a first interrupt when the value in the counter register 225 becomes equal to 1000, raise a second interrupt when the value of the counter register 225 becomes 2000, raise a third interrupt when the value of the counter register 225 becomes 3000, and so on. The intervals between interrupts represents a predefined period of time (e.g. 1ms). The counter resolution (i.e. the threshold amount) is set greater than the maximum desired relative oscillator frequency error. For example, if the desired maximum error is ± 1 ppm, and the timer 110 is a 1ms Timer, the threshold amount at which interrupts are raised must be at least 1000.

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The timer 110 is associated with the correction logic 235, which is configured to adjust the threshold amount applied by the timer circuitry 230, in dependence upon the frequency offset determined by the CFOE circuitry 210. The correction logic 235 adjusts the value of the threshold amount by an amount that is proportional to the frequency offset. The correction logic 235 adjusts the threshold amount, such that the interval between interrupts issued by the timer circuitry 230 of device 100A is the substantially the same as the interval between interrupts issued by the timer circuitry 230 of device 100B. In this way, the timers 110 of the devices 100A, 100B are synchronised and the increase in time offset between the two devices 100A, 100B over time is reduced. To achieve this, the correction logic 235 may determine an adjusted threshold amount (TA) by setting it equal to:

$$\text{Adjusted TA} = \text{Initial TA} * \left(1 + \frac{\text{Frequency Offset}}{\text{Nominal Frequency}} \right) \quad \text{Equation 1}$$

Where the “initial TA” is a default value for the threshold amount, and “Nominal Frequency” is the nominal frequency of the oscillator 160 of the device 100A. This nominal frequency value may be stored in storage of the device 100A that is accessible to the correction logic 235. The true frequency of the oscillator 160 signal may, in both devices 100A, 100B, differ from this nominal value due to imperfections associated with the oscillator 160, hence resulting in the frequency offset.

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The “Frequency Offset” in equation 1 is given by:

$$\text{Frequency Offset} = \text{Oscillator frequency} - \text{RF frequency} \quad \text{Equation 2}$$

Where “Oscillator frequency” is the frequency of the signal output by the oscillator 160 of device 100A and “RF frequency” is the carrier frequency of the RF signal received from the device 100B.

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The correction logic 235, therefore, scales the initial value of the threshold amount in proportion to the frequency offset between the oscillator signal of its own device 100A and the received RF signal. The correction logic 235 provides this updated value of the threshold amount to the timer circuitry 230, which then applies this to provide interrupts to the processing circuitry 220 each time the value in the counter register 225 increases by the updated value of the threshold amount.

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In some embodiments, the timer 110 of the transmitting device 100B may perform a correction to the value of its own threshold amount. Reference is made to Figure 3, which illustrates the device 100B according to an embodiment. The device 100B comprises a timer 215 and correction logic 235, which may be the same as the timer 215 and correction logic 235 belonging to the first device 100A. In this embodiment, the circuitry 130 is transceiver circuitry 130.

This correction performed to the device's 100B threshold amount may be based on a global positioning system (GPS) signal, for example. In this case, transceiver circuitry 130 of the device 100B is configured to determine a frequency offset between a carrier frequency of the GPS satellite signal and the frequency of the device's 100B oscillator signal and correction logic 235 of the device 100B to adjust the threshold amount in proportion to this frequency offset. For example, the correction logic 235 may perform the adjustment of the threshold amount by applying equation 1, where the "Frequency Offset" is the frequency offset between a frequency of the GPS satellite signal and the frequency of the oscillators 160 signal of the device 100B.

Alternatively, the correction may be based on an RF signal received from a third device having the same components as the first and second devices 100A, 100B already discussed. In this case, transceiver circuitry 130 of the device 100B is configured to determine a frequency offset between a carrier frequency of the RF signal received from the third device and the frequency of the device's 100B oscillator signal, and correction logic 235 of the device 100B is configured to adjust the threshold amount in proportion to this frequency offset. For example, the correction logic 235 may perform the adjustment of the threshold amount by applying equation 1, where the "Frequency Offset" is the frequency offset between the carrier frequency of the RF signal of the third device and the frequency of the oscillators 160 signal of the device 100B.

When the device 100B has corrected its own threshold amount, the device 100B is configured to dispatch as data in the RF communication, an indication of the adjusted value of the threshold amount. When the correction logic 235 determines an adjusted value of the threshold amount, the correction logic 235 provides this value to processing circuitry 120. In response, the processing circuitry 120 performs processing to provide an indication of the adjusted value as part of data that is provided in a suitable format (e.g. as a data packet) to the transmitter circuitry 130. The transceiver

circuitry 130 causes the data 300 to be sent to the device 100A in the form of the radio frequency communications.

Referring back to Figure 2, when the RF signal encoding the data 300 is received at the device 100A, the correction logic 235 receives from the receiver circuitry 135, the indication of the adjusted value that was included in the data 300. The correction logic 235 receives this indication of the adjusted value in addition to the frequency offset received from the CFOE circuitry 210. The correction logic 235 then determines an adjusted threshold amount for its own associated timer circuitry 230 of device 100A in dependence upon both the frequency offset and the adjusted threshold amount of the device 100B. The correction logic 235 may determine the adjusted threshold amount (Adjusted TA_1) for the device 100A by setting it equal to:

$$\text{Adjusted } TA_1 = \text{Adjusted } TA_2 * \left(1 + \frac{\text{Frequency Offset}}{\text{Nominal Frequency}} \right) \quad \text{Equation 3}$$

Where the “Adjusted TA_2 ” refers to the adjusted threshold amount determined and applied at device 100B. Therefore, in the case that the indication of the adjusted value is received from the device 100B, the “Adjusted TA_2 ” takes the place of the “initial TA ”, which was used in Equation 1.

In some embodiments, the device 100A receives RF communications from a plurality of different devices. In this case, the RF communications received from different devices may each be provided with a different carrier frequency. To enable the recipient device 100A to determine how to correct its threshold amount, each transmitting device may transmit a quality indicator, which indicates a level of uncertainty associated with the frequency of the oscillator 160 of the relevant transmitting device. The level of uncertainty provides an estimate of the deviation of the frequency of the respective oscillator 160 from the nominal frequency for the oscillators 160 in the system 10. In response, to receipt of the quality indicators, the recipient device 100A then performs the adjustment of the threshold amount based on the quality indicators.

Reference is made to Figure 4, which illustrates a further example of a device 100B according to embodiments. The device 100B comprises at least one storage 410, which may store one or more quantities that are used to determine the quality indicator for the device’s 100B oscillator. The one or more quantities may comprise an indication

of the type of the oscillator 160. For example, the indication of the type of the oscillator 160 may indicate that the oscillator 160 is a crystal oscillator and more specifically may indicate that the oscillator 160 is a temperature control crystal oscillator (TCXO). The one or more quantities may comprise an indication of the time elapsed since the time of calibration of the oscillator 160 or the time of manufacture of the oscillator 160, since the frequency error of the oscillator 160 may increase with the age of the oscillator 160. The one or more quantities may comprise the measured temperature at the device 100B. In this case, the device 100B may comprise a temperature sensor 420 for measuring the temperature at the device 100B. The one or more quantities may comprise an indication as to whether the threshold amount of the device 100B has already been updated, e.g. based on a high accuracy signal such as GPS.

The processing circuitry 120 is configured to determine a quality indicator in dependence upon the one or more quantities and provide this quality indicator (QI) to the transmitter circuitry 130 for transmission as data 400 in the RF communications sent by device 100B.

Reference is made to Figure 5, which illustrates a system 500 in which a plurality of devices 100B, 100C, 100D transmit their associated quality indicator to the device 100A in RF communications. Each of the devices 100C, 100D comprise the same components and operate in the same manner as device 100B to determine their respective quality indicators and transmit them to the device 100A. Although in Figure 5, three devices 100B, 100C, 100D are shown transmitting quality indicators to the device 100A, in some embodiments, there may be only two such devices 100B, 100C.

Referring again to Figure 2, when the quality indicators are received from the devices 100B, 100C, 100D, these quality indicators (labelled as QI) are provided by processing circuitry 220 to the correction logic 235. In addition, the circuitry 210 determines the frequency offset (i.e. difference between carrier frequency and the device's 100A oscillator frequency) for the RF communications from each of the devices 100B, 100C, and 100D. The correction logic 235 determines the updated threshold value in dependence upon the quality indicators. For example, in response to receiving a plurality of items of data, each comprising a different quality indicator from a different one of the devices 100B, 100C, and 100D, the correction logic 235 may determine which of these quality indicators is highest (i.e. indicates the lowest uncertainty in the oscillator frequency). The correction logic 235 then determines the updated threshold

value based on the carrier frequency of the RF communications in which that highest quality indicator was received. In this way, the timer 110 is calibrated based upon the oscillator 160 in the system 500 that has the lowest expected error.

5 The correction logic 235 may determine the updated threshold value by applying equation 1 to the frequency offset associated with the one of the devices 100B, 100C, 100D that provides the highest quality indicator. Alternatively, the embodiment described with respect to Figures 4 and 5 and the embodiment described with respect to Figure 3 may be combined in which case, one or more of the devices 100B, 100C,
10 100D may, in addition to providing a quality indicator as data in its RF transmission, also provide as part of this data, an indication of an adjusted threshold applied to its own timer 110 (as described with respect to Figure 3). In this case, if the correction logic 235 applies the carrier frequency of RF communications from a device providing an adjusted threshold value to determine its own updated threshold value, then the
15 the correction logic 235 also determines its own updated threshold value on the basis of the adjusted threshold value received from that device.

Reference is made to Figures 6A to 6D, which illustrates a method according to embodiments of the application. It would be appreciated that some of the steps of the
20 method may be optional. Figure 6A shows a first part 600 of the method according to embodiments of the application. The steps of the first part 600 are performed by all of the devices (e.g. devices 100A-D) belonging to the system.

At S602, the oscillator 160 generates an oscillator signal having a predefined
25 frequency. This step continues to be performed throughout the method.

At S604, the counter value of the counter 225 is incremented based on the oscillator signal generated at S602. The counter value is incremented at S604 in response to clock cycles of a clock signal derived from the oscillator signal. S604 is performed in
30 response to each edge in the clock cycle.

At S606, the timer circuitry 230 determines whether the counter value has been increased by a threshold amount since the last interrupt was raised. If not, the method proceeds to S604. If so, the method proceeds to S608, at which the timer circuitry 230
35 causes an interrupt to be raised to the processing circuitry 220. The method then proceeds again to S604.

Reference is made to Figure 6B, which illustrates a second part 610 of the method according to a first embodiment. The second part 610 of the method is performed in parallel (i.e. at the same time as) the first part 600 of the method.

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At S612, a second device 100B transmits an RF signal to the first device 100A. This step is performed by the transmitter circuitry 130 and antenna 140. The carrier frequency of the RF signal is equal to the frequency of the oscillator 160 of the second device 100B.

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At S614, the first device 100A receives the RF signal from the second device 100B.

At S616, the receiving circuitry 135 of the first device 100A determines the frequency offset between the carrier frequency of the received RF signal and the frequency of the oscillator signal of the first device 100A.

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At S618, the correction logic 235 determines an updated value of the threshold amount based on the frequency offset estimated at S616. The updated value is proportional to the frequency offset, and more specifically is proportional to a ratio between the frequency offset and the nominal frequency. The updated threshold value may be given by equation 1.

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Reference is made to Figure 6C, which illustrates the second part 620 of the method according to a second embodiment. This second part 620 may be performed in parallel with the first part 610 of the method.

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At S622, the threshold value at the second device 100B is updated by the correction logic 235 at that device 100B. This update may be performed based upon frequency of a received GPS signal.

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At S624, the processing circuitry 120 causes the threshold value updated at S622 to be transmitted to the first device 100A in RF communications. The RF signal is sent from the second device 100B to the first device 100A.

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At S614, the first device 100A receives the RF signal from the second device 100B.

At S616, the receiving circuitry 135 of the first device 100A determines the frequency offset between the carrier frequency of the received RF signal and the frequency of the oscillator signal of the first device 100A.

5 At S630, the correction logic 235 adjusts the threshold amount of the timer 110 of the device 100A in dependence upon the determined frequency offset determined at S616 and in dependence upon the updated threshold value received in the RF signal. The correction logic 235 adjusts the threshold amount in proportion to each of these quantities. The correction logic 235 may adjust the threshold amount by applying
10 equation 3.

Reference is made to Figure 6D, which illustrates a second part 630 of the method according to a third embodiment. This second part 630 may be performed in parallel with the first part 610 of the method.

15 At S632, the second device 100B transmits a radio frequency signal. The processing circuitry 120 of the second device 100B causes the radio frequency signal to be encoded with a first quality indicator of the oscillator 160 of the second device 100B.

20 At S614, the first device 100A receives the RF signal from the second device 100B.

At S616, the receiving circuitry 135 of the first device 100A determines the offset of the carrier frequency of the RF signal received at S614 from the frequency of the signal output by the oscillator 160 of the first device 100A.

25 At S634, the first quality indicator transmitted in the radio frequency signal at S632 is stored in storage at the first device 100A.

30 At S636, the third device 100C transmits a radio frequency signal to the first device 100A. The processing circuitry 120 of the third device 100C causes the radio frequency signal to be encoded with a second quality indicator of the oscillator 160 of the third device 100C.

35 At S638, the first device 100A receives the RF signal from the third device 100C.

At S640, the receiving circuitry 135 of the first device 100A determines the offset of the carrier frequency of the RF signal received at S638 from the frequency of the signal output by the oscillator 160 of the first device 100A.

5 At S642, the correction logic 235 compares the first quality indicator and the second quality indicator. For example, the correction logic 235 may determine which of these quality indicators indicates a lower uncertainty in oscillator frequency.

10 At S644, the correction logic 235 adjusts the threshold amount in dependence upon the result of comparison of the quality indicators at S642 and in dependence upon at least one of the frequency offsets determined at S616 and S640. For example, the correction logic 235 may select the frequency offset associated with one of the devices 100B, 100C from which the quality indicator indicating the lower estimated oscillator uncertainty was received. The correction logic 235 may then use this selected
15 frequency offset to determine an updated value for the threshold amount (e.g. by applying equation 1).

The steps of the second part 620 according to the second embodiment, and the steps of the third part 630 according to the third embodiment may be combined.
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In the description of the above embodiments, it has been described that the first device 100A receives RF communications from the second device 100B and adjusts its threshold value. However, the first device 100A may additionally be configured to transmit RF signals to the second device 100B, which is configured to adjust its
25 threshold value. In this case, the first device 100A and second device 100B are each configured with transceiver circuitry to send and receive RF communications. The second device 100B performs the same operations described above as being performed by the first device 100A to correct its timer threshold value.

30 Implementations of the subject matter and the operations described in this specification can be realized in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. For instance, hardware may include processors, microprocessors, electronic circuitry, electronic components,
35 integrated circuits, etc. Implementations of the subject matter described in this specification can be realized using one or more computer programs, i.e., one or more

modules of computer program instructions, encoded on computer storage medium for execution by, or to control the operation of, data processing apparatus. Alternatively or in addition, the program instructions can be encoded on an artificially-generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. A computer storage medium can be, or be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, or a combination of one or more of them. Moreover, while a computer storage medium is not a propagated signal, a computer storage medium can be a source or destination of computer program instructions encoded in an artificially-generated propagated signal. The computer storage medium can also be, or be included in, one or more separate physical components or media (e.g., multiple CDs, disks, or other storage devices).

While certain arrangements have been described, the arrangements have been presented by way of example only, and are not intended to limit the scope of protection. The inventive concepts described herein may be implemented in a variety of other forms. In addition, various omissions, substitutions and changes to the specific implementations described herein may be made without departing from the scope of protection defined in the following claims.

ANNEX A

The present invention can also be defined by reference to the following clauses:

- Clause 1. A first device comprising:
- 5 an oscillator configured to generate an oscillator signal having a predefined frequency;
- a timer comprising:
- a counter configured to store a counter value and increment the counter value based on the oscillator signal; and
- 10 timer circuitry configured to raise an interrupt in response to the counter value increasing by a threshold amount,
- radio receiver circuitry configured to:
- receive a radio frequency signal from a second device; and
- determine a frequency offset between a carrier frequency of the radio
- 15 frequency signal and the predefined frequency of the oscillator signal; and
- correction logic configured to adjust the threshold amount by an amount that is dependent upon the determined frequency offset so as to synchronise the timer with a further timer of the second device.
- 20 Clause 2. A first device as in clause 1, wherein the radio frequency signal encodes a value indicating a further threshold value for the further timer, wherein the correction logic is configured to adjust the threshold amount in proportion to the further threshold value.
- 25 Clause 3. A first device as in clause 1 or clause 2, wherein the radio frequency signal encodes a first quality indicator associated with an oscillator of the second device, wherein the radio receiver circuitry is configured to:
- receive a further radio frequency signal from a third device, the further radio frequency signal encoding a second quality indicator associated with an oscillator of
- 30 the third device; and
- determine a further frequency offset between a carrier frequency of the further radio frequency signal and predefined frequency of the oscillator,
- wherein the correction logic is configured to:
- determine the amount by which to adjust the threshold amount in
- 35 dependence upon the first and second quality indicators.

Clause 4. A first device as in clause 3, wherein the step of determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators comprises:

5 in response to determining that the first quality indicator indicates a lower uncertainty in frequency of the oscillator of the second device, adjusting the threshold amount based upon the frequency offset.

Clause 5. A first device as in any preceding clause, wherein the first device comprises transceiver circuitry comprising the receiver circuitry,

10 wherein the transceiver circuitry is configured to use the oscillator signal to send a further radio frequency signal to the second device, the further radio frequency signal having a carrier frequency that is equal to the predefined frequency.

Clause 6. A system comprising:

the first device as in any preceding clause; and

the second device, wherein the second device comprises:

a further oscillator configured to generate a further oscillator signal at the carrier frequency; and

20 transmitter circuitry configured to generate the radio frequency signal based on the further oscillator signal and cause the radio frequency signal to be transmitted to the first device.

Clause 7. A system as in clause 6, wherein the radio frequency signal encodes a value indicating a further threshold value for the further timer, wherein the correction logic is configured to adjust the threshold amount in proportion to the further threshold value, wherein the second device comprises:

25 further correction logic configured to determine the further threshold value; and

processing circuitry configured to cause the further threshold value to be

30 transmitted to the first device in the radio frequency signal.

Clause 8. A system as in clause 7, wherein the further correction logic is configured to determine the further threshold value based upon a frequency of a radio frequency signal from a global positioning system satellite.

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Clause 9. A system as in any of clauses 6 to 8, wherein the system further comprises the third device, wherein the radio frequency signal encodes a first quality indicator associated with an oscillator of the second device, wherein the radio receiver circuitry is configured to:

- 5 receive a further radio frequency signal from the third device, the further radio frequency signal encoding a second quality indicator associated with an oscillator of the third device; and
- determine a further frequency offset between a carrier frequency of the further radio frequency signal and predefined frequency of the oscillator,
- 10 wherein the correction logic is configured to determine the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators,
- wherein the second device comprises processing circuitry configured to determine the first quality indicator based on one or more quantities held in storage of the second device,
- 15 wherein the third device comprises processing circuitry configured to determine the second quality indicator based on one or more quantities held in storage of the third device.

- 20 Clause 10. A system as in clause 9, wherein for each of the second device and the third device, the respective one or more quantities comprise at least one of:
- age of the respective device;
- a type of oscillator belonging to the respective device;
- a temperature detected at the respective device; and
- 25 an indication as to whether or not a threshold value of a timer belonging to the respective device has been corrected.

- Clause 11. A method implemented in a first device, the method comprising:
- generating an oscillator signal having a predefined frequency;
- 30 storing a counter value and incrementing the counter value based on the oscillator signal; and
- raising an interrupt of a timer in response to the counter value increasing by a threshold amount,
- receiving a radio frequency signal from a second device; and
- 35 determining a frequency offset between a carrier frequency of the radio frequency signal and the predefined frequency of the oscillator signal; and

adjusting the threshold amount by an amount that is dependent upon the determined frequency offset so as to synchronise the timer with a further timer of the second device.

- 5 Clause 12. A method as in clause 11, wherein the radio frequency signal encodes a value indicating a further threshold value for the further timer, wherein the correction logic is configured to adjust the threshold amount in proportion to the further threshold value.
- 10 Clause 13. A method as in clause 11 or clause 12, wherein the radio frequency signal encodes a first quality indicator associated with an oscillator of the second device, wherein the method comprises:
- 15 receiving a further radio frequency signal from a third device, the further radio frequency signal encoding a second quality indicator associated with an oscillator of the third device;
- determining a further frequency offset between a carrier frequency of the further radio frequency signal and predefined frequency of the oscillator; and
- determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators.
- 20 Clause 14. A method as in clause 13, wherein the step of determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators comprises:
- in response to determining that the first quality indicator indicates a lower
- 25 uncertainty in frequency of the oscillator of the second device, adjusting the threshold amount based upon the frequency offset.
- Clause 15. A method as in any of clauses 11 to 14, further comprising:
- using the oscillator signal to send a further radio frequency signal to the second
- 30 device, the further radio frequency signal having a carrier frequency that is equal to the predefined frequency.

CLAIMS:

1. A first device comprising:
an oscillator configured to generate an oscillator signal having a predefined
5 frequency;
a timer comprising:
a counter configured to store a counter value and increment the counter
value based on the oscillator signal; and
timer circuitry configured to raise an interrupt in response to the counter
10 value increasing by a threshold amount,
radio receiver circuitry configured to:
receive a radio frequency signal from a second device; and
determine a frequency offset between a carrier frequency of the radio
frequency signal and the predefined frequency of the oscillator signal; and
15 correction logic configured to adjust the threshold amount by an amount that is
dependent upon the determined frequency offset so as to synchronise the timer with a
further timer of the second device.
2. A first device as claimed in claim 1, wherein the radio frequency signal encodes
20 a value indicating a further threshold value for the further timer, wherein the correction
logic is configured to adjust the threshold amount in proportion to the further threshold
value.
3. A first device as claimed in claim 1, wherein the radio frequency signal encodes
25 a first quality indicator associated with an oscillator of the second device, wherein the
radio receiver circuitry is configured to:
receive a further radio frequency signal from a third device, the further radio
frequency signal encoding a second quality indicator associated with an oscillator of
the third device; and
30 determine a further frequency offset between a carrier frequency of the further
radio frequency signal and predefined frequency of the oscillator,
wherein the correction logic is configured to:
determine the amount by which to adjust the threshold amount in
dependence upon the first and second quality indicators.

4. A first device as claimed in claim 3, wherein the step of determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators comprises:
- 5 in response to determining that the first quality indicator indicates a lower uncertainty in frequency of the oscillator of the second device, adjusting the threshold amount based upon the frequency offset.
5. A first device as claimed in claim 1, wherein the first device comprises
- 10 transceiver circuitry comprising the receiver circuitry,
- wherein the transceiver circuitry is configured to use the oscillator signal to send a further radio frequency signal to the second device, the further radio frequency signal having a carrier frequency that is equal to the predefined frequency.
- 15 6. A system comprising:
- the first device as claimed in claim 1; and
- the second device, wherein the second device comprises:
- a further oscillator configured to generate a further oscillator signal at the carrier frequency; and
- 20 transmitter circuitry configured to generate the radio frequency signal based on the further oscillator signal and cause the radio frequency signal to be transmitted to the first device.
7. A system as claimed in claim 6, wherein the radio frequency signal encodes a
- 25 value indicating a further threshold value for the further timer, wherein the correction logic is configured to adjust the threshold amount in proportion to the further threshold value, wherein the second device comprises:
- further correction logic configured to determine the further threshold value; and
- processing circuitry configured to cause the further threshold value to be
- 30 transmitted to the first device in the radio frequency signal.
8. A system as claimed in claim 7, wherein the further correction logic is configured to determine the further threshold value based upon a frequency of a radio frequency signal from a global positioning system satellite.

9. A system as claimed in claim 6, wherein the system further comprises the third device, wherein the radio frequency signal encodes a first quality indicator associated with an oscillator of the second device, wherein the radio receiver circuitry is configured to:

5 receive a further radio frequency signal from the third device, the further radio frequency signal encoding a second quality indicator associated with an oscillator of the third device; and

determine a further frequency offset between a carrier frequency of the further radio frequency signal and predefined frequency of the oscillator,

10 wherein the correction logic is configured to determine the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators,

wherein the second device comprises processing circuitry configured to determine the first quality indicator based on one or more quantities held in storage of the second device,

15 wherein the third device comprises processing circuitry configured to determine the second quality indicator based on one or more quantities held in storage of the third device.

20 10. A system as claimed in claim 9, wherein for each of the second device and the third device, the respective one or more quantities comprise at least one of:

age of the respective device;

a type of oscillator belonging to the respective device;

a temperature detected at the respective device; and

25 an indication as to whether or not a threshold value of a timer belonging to the respective device has been corrected.

11. A method implemented in a first device, the method comprising:

generating an oscillator signal having a predefined frequency;

30 storing a counter value and incrementing the counter value based on the oscillator signal; and

raising an interrupt of a timer in response to the counter value increasing by a threshold amount,

receiving a radio frequency signal from a second device; and

35 determining a frequency offset between a carrier frequency of the radio frequency signal and the predefined frequency of the oscillator signal; and

adjusting the threshold amount by an amount that is dependent upon the determined frequency offset so as to synchronise the timer with a further timer of the second device.

- 5 12. A method as claimed in claim 11, wherein the radio frequency signal encodes a value indicating a further threshold value for the further timer, wherein the correction logic is configured to adjust the threshold amount in proportion to the further threshold value.
- 10 13. A method as claimed in claim 11, wherein the radio frequency signal encodes a first quality indicator associated with an oscillator of the second device, wherein the method comprises:
- 15 receiving a further radio frequency signal from a third device, the further radio frequency signal encoding a second quality indicator associated with an oscillator of the third device;
- 20 determining a further frequency offset between a carrier frequency of the further radio frequency signal and predefined frequency of the oscillator; and
- 25 determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators.
- 30 14. A method as claimed in claim 13, wherein the step of determining the amount by which to adjust the threshold amount in dependence upon the first and second quality indicators comprises:
- 35 in response to determining that the first quality indicator indicates a lower uncertainty in frequency of the oscillator of the second device, adjusting the threshold amount based upon the frequency offset.
- 40 15. A method as claimed in claim 11, further comprising:
- 45 using the oscillator signal to send a further radio frequency signal to the second device, the further radio frequency signal having a carrier frequency that is equal to the predefined frequency.