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(71) Applicant (for all designated States except US): **UNIVERSITY COLLEGE CORK - NATIONAL UNIVERSITY OF IRELAND, CORK** [IE/IE]; Western Road, Cork City (IE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **MARINKOVIC, Stevan** [RS/IE]; Apt. 2, 2 Adelaide Street, Cork City (IE). **POPOVICI, Emanuel** [IE/IE]; 148 West Avenue, Parkgate, Frankfield, Cork City (IE).

(74) Agent: **LUCEY, Michael**; Purdylucey, Intellectual Property, Suite 138/139, The Capel Building, Mary's Abbey, Dublin 7 (IE).

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(54) Title: LOW POWER WAKE-UP SYSTEM AND METHOD FOR WIRELESS BODY AREA NETWORKS

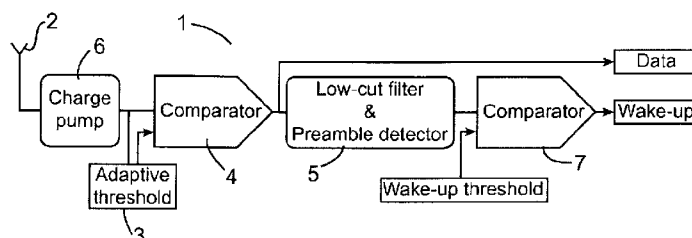


Figure 1

(57) Abstract: The invention provides a nano-power wake-up radio system to turn on a device for wireless body area networks, said system comprising means for receiving a signal, for example an OOK or GOOK signal; an adaptive threshold generator; a comparator adapted to communicate with said means for receiving and said adaptive threshold generator. A filter means at the output of the comparator comprising means for classifying the received signal to determine whether to turn on the device.

Title

Low Power Wake-Up System and Method for Wireless Body Area Networks

Field of the Invention

- 5 The invention relates to a wake up radio system and method. In particular the invention relates to a nano-power wake-up system and method for a Wireless Body Area Network.

Background to the Invention

- 10 Wireless Body Area Networks (WBAN) have been a popular research area in the recent years. Mostly, the trend in this area of research is about minimisation and low power. Since one of the bigger power consumers in a wireless sensor is the wireless transceiver, a number of protocols and methods have been devised to minimize the duty cycle of the transceiver. Whilst reducing the duty cycle helps to save power, it severely limits
15 network flexibility. The duty cycle can be defined as the percentage of time during which a transceiver is in an “active” state. But, once the transceiver is off, data cannot be sent nor received from/to the device or sensor. If it is needed for a sensor to listen idly on a channel, power consumed in such a case is equivalent or in some cases even larger than the one needed for transmission of the data.

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- Therefore, if there is a need for unsynchronised commands and events, initiated from the network coordinator, considerable amount of energy must be spent by a sensor on idle listening. Thus, there is a need for a ultra low power wireless receiver (Wake Up Radio, WUR) that can stay switched on while sensor is expecting an asynchronous
25 signal. Requirements for this type of receiver are not high communication-wise. It should either just wake up every sensor in proximity of the wake-up signal sender, to switch on a data receiver, or in better case, can receive a simple command to at least address the sensor that is needed. On the other hand, energy consumption requirements, for the WUR are critical. Since the device would sometimes be on for extended periods
30 of time, while the other components are in sleep mode or off, it's power consumption while idly listening should be of the same range as the power consumption of the other devices while in sleep mode, which can be approximately 1μW.

Because of such low power requirement, any circuit that will be used as a WUR must be very simple. For example, if possible there should not be any active filtering nor signal amplifications at the input. Therefore, ideal modulation for this type of a device is On-Off Keying (OOK). The problem with OOK signals usually leaves the radio vulnerable to signals from nearby devices with high transmit power, that can be misinterpreted as the wake up signal. This would require the sensor to falsely wake up and waste battery energy, which is undesirable.

In a normal WBAN, wake up signals that could happen from outside sources are quite frequent. For example mobile phone or laptop using a WiFi can be located in proximity of a sensor, and can trigger false wake up signals. Also, other wireless communication in a WBAN should not affect the wake up radio of a sensor that is in sleep mode. Therefore, a low power strategy must be developed to avoid these false wake-up signals, as much as possible.

There are number of approaches for Wake Up Radios. Most common are with zero-bias Schottky voltage doubler (voltage multiplier, envelope detector) such as those disclosed in the following publications:

- [1] L. Gu and J. A. Stankovic, "Radio-triggered wake-up for wireless sensor networks," *Real-Time Systems*, vol. 29, no. 2, pp. 157–182, 2005.
- [2] J. Ansari, D. Pankin, and P. Mahonen, "Radio-triggered wake-ups with addressing capabilities for extremely low power sensor network applications," *International Journal of Wireless Information Networks*, vol. 16, no. 3, pp. 118–130, 2009.
- [3] P. Le-Huy and S. Roy, "Low-Power Wake-Up radio for wireless sensor networks," *Mobile Networks and Applications*, pp. 1–11, 2010.
- [4] M. S. Durante and S. Mahlke, "An ultra low power wakeup receiver for wireless sensor nodes," in *Proceedings of the 2009 Third International Conference on Sensor Technologies and Applications-Volume 00*, 2009, pp. 167–170.

Gu et al. present and simulate a radio triggered hardware that extracts energy from the radio signals and provides wakeup signals to the network node without using internal power supply. But there is no addressing mechanism or selectivity of wake up signals.

Ansari et al. present a simple protocol for wake up signal transmission and a WUR that includes voltage multiplier and a digital comparator. Durante et al. present a solution with a Schottky voltage doubler followed by a programmable amplifier and integrator. Data rate and sensitivity is high, because of the amplification stage, on the expense of power consumption.

Another solution using OOK signals lead to increased power consumption , for example as disclosed in a paper by M. Malinowski, M. Moskwa, M. Feldmeier, M. Laibowitz, and J. A. Paradiso, "CargoNet: a low-cost micropower sensor node exploiting quasi-passive wakeup for adaptive asynchronous monitoring of exceptional events," in *Proceedings of the 5th international conference on Embedded networked sensor systems (SenSys)*, 2007, pp. 145–159 which presents a complete solution of micro power sensor node, with RF quasi-passive wakeup, with adjustable thresholds that adapt to dynamic environments. It is consisted of an envelope detector and an amplifier. This all adds up to increase power consumption.

There is therefore a need to provide a low power wake up system and method for use in wireless body area networks to overcome at least one of the above mentioned problems.

Summary of the Invention

According to the invention there is provided, as set out in the appended claims, a nano-power wake-up radio (WUR) system to turn on a device for wireless body area networks, said system comprising:

means for receiving a signal, for example an OOK or GOOK signal;

an adaptive threshold generator;

a comparator adapted to communicate with said means for receiving and said adaptive threshold generator; and

a filter means at the output of the comparator comprising means for classifying the received signal to determine whether to turn on the device.

In one embodiment the adaptive threshold increases dynamic range of the WUR, and provides equal mark-space ratio for logic '0' and '1' for weak, strong OOK or GOOK modulated signals.

In one embodiment the filter means comprises a low power filter or passive filter.

5 In one embodiment the filter means comprises a detector, for example a preamble detector, adapted to detect a wake-up preamble signal in a preselected or expected OOK or GOOK data rate range. Envelope detector demodulates OOK or GOOK modulated signal without power consumption.

10 In one embodiment a correct bit sequence of the received signal is formed using a comparator and/or the adaptive threshold generator.

In one embodiment a charge pump detects the received OOK or GOOK signal.

15 In one embodiment the charge pump comprises a two stage voltage doubler-multiplier.

In one embodiment there is provided means for receiving a wake-up packet wherein the wakeup packet comprises of a preamble sequence adapted to generate a wake-up signal and a payload that addresses the device that needs to be woken up.

20 In one embodiment the wake-up packet is transmitted as an OOK or GOOK modulated packet.

In one embodiment there is provided a second comparator, if the wake-up signal needs to have sharp transitions.

25 In one embodiment the means for receiving an OOK signal or GOOK signal comprises an antenna.

In one embodiment there is provided a Pulse Width Modulation decoder.

30 In one embodiment there is provided a Serial Peripheral Interface (SPI) adapter adapted for generating SPI compatible signals for data transfer to a processor of the device. Radio has SPI compatible interface for easier connection of the WUR in existing applications.

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In a further embodiment there is provided a nano-power wake-up radio (WUR) system to turn on a device for wireless body area networks, said system comprising:

- means for receiving a signal, for example an OOK or GOOK signal;
- a comparator adapted to communicate with said means for receiving; and
- 5 means for classifying the received signal to determine whether to turn on the device.

In another embodiment there is provided a nano-power wake-up radio (WUR) system to turn on a device for wireless body area networks, said system comprising:

- 10 means for receiving a signal, for example an OOK or GOOK signal;
- a comparator adapted to communicate with said means for receiving; and
- a filter means at the output of the comparator comprising means for classifying the received signal to determine whether to turn on the device.

- 15 There is also provided a computer program comprising program instructions for causing a computer program to carry out the above method which may be embodied on a record medium, carrier signal or read-only memory.

Brief Description of the Drawings

- 20 The invention will be more clearly understood from the following description of an embodiment thereof, given by way of example only, with reference to the accompanying drawings, in which:-

Fig. 1 illustrates a wake up radio overview according to one embodiment of the present invention;

- 25 Fig. 2a and 2b illustrate a detailed wake up radio electric scheme, according to a first and second embodiment of the invention;

Fig. 3 illustrates results of output signals obtained;

Fig. 4 illustrates result input signals obtained;

- 30 Fig. 5 illustrates data and wake up signals in the case of a GSM 3G data transfer interference;

Fig. 6 illustrates a wake up radio overview according to another embodiment of the invention;

Fig. 7 illustrate a detailed wake up radio electric scheme of Fig. 6;

Fig. 8 illustrates signals at the points a, b and PWM from Figure 6 for a GOOK modulated packet;

Fig. 9 illustrates signals PWM and WUp from Figure 6 for a full wake up packet;

5 Fig. 10 illustrates a SPI master output of the WUR (full packet);

Fig. 11 illustrates a SPI master output of the WUR (detailed start of the packet, start bit and pwm modulated '0' and '1');

Fig.12 illustrates a wake up case of a GSM call without input RF filtering, wake up does not reach interrupt threshold; and

10 Fig.13 illustrates interference rejection, measurement is done for the signal at 433.92Mhz with -45dBm power.

Detailed Description of the Invention

Referring now to Figure 1 the invention provides a system for nano-power wake-up radio circuit for wireless body area networks indicated generally by the reference numeral 1. The system comprises means for receiving, for example an antenna, an OOK signal 2 (or other suitable signal); an adaptive threshold generator 3; a comparator 4; and a filter and detector block 5 at the output of the comparator 4.

20 The filter 5 comprises a low power filter at the output of the comparator to filter signals that could generate false wakeups thus saving on power. The system of the invention allows it to work on any frequency, and can use the same antenna 2 as a normal transceiver in a wireless sensor. A charge pump 6 (for example a two stage voltage doubler-multiplier) detects the received OOK signal envelope. Then, the correct bit sequence of a received packet is formed using the comparator 4. Comparator threshold is not constant but adaptive threshold can be used. Preamble detector 5 detects the wake-up preamble, if it is generated in a preselected or expected OOK data rate range. This excludes unnecessary wake ups from common interferences in WBAN. There are a lot of wireless devices that are used by a person wearing a WBAN, such as a GSM
30 phone, WiFi device, Bluetooth device etc. An optional second comparator 7 can be provided for sharper transitions, the operation of which is described in more detail with respect to Figure 2b.

In order to keep the low power consumption the filter 5 should be passive. The optional second comparator 7 finally generates the wake-up signal if wakeup preamble sequence was received. But, this is optional, and in most cases would not be used in order to conserve energy, since microcontroller will generate interrupt when the wake up signal crosses $V_{dd}/2$ on standard CMOS input or $V_{dd}/3$ on a Schmitt-trigger input.

Wake up signal can be sent by a WBAN Coordinator node. That signal should be sensed by all of the sensors in the Network. This signal should wake up a microcontroller that controls the sensor, or a dedicated digital circuit to decide what to do with the signal. Then, the sensor which is meant for wake up turns on the transceiver, and packet is sent or sensor waits for a certain time to receive additional commands. The false wake up signals should be minimal.

Network coordinator broadcasts the wake-up packet. Wakeup packet consists of a preamble sequence that should generate wake-up signal and a payload that addresses the sensor that needs to be woken up and optionally, extra commands and instructions (requirement 2.b). This packet is transmitted as an OOK modulated packet. It will be appreciated that the invention only uses passive components to construct an efficient wake up radio with ultra low power consumption.

An electric scheme of the wake up radio according to the invention is shown in Fig. 2 according to one embodiment of the invention. Figure 2a shows two versions of the full WUR circuit. First part of the circuit (from the antenna) is the charge pump (C1-C4, D1-D4). It turns the Gaussian OOK (GOOK) modulated signal from the antenna (Fig. 4, top signal) in to the envelope signal, voltage dependent on the wireless signal strength (Fig.4, signal 'a'). Next part of the circuit (R1, R2, C5) is used for adaptive threshold generation (Fig.4, signal 'b'). Adaptive threshold has two advantages:

- 1) The threshold value for the comparator is always held at the same percentage of the 'a' signal level that changes with the wake up signal power. This is used to ensure the same length for '0' and '1' (Fig. 4, signal 'Data'), regardless if the received signal is weak or strong, and/or GOOK modulated (no sharp transitions).

- 2) There is no voltage divider at the second input of the comparator and energy from the antenna is used for the threshold generation, therefore static power is reduced. Fig. 5. Data and Wake Up signal in case of GSM 3G data transfer interference. After the comparator, next part of the circuit (R3, C6, C7, D5, D6) is used to generate wake up signal from the preamble.

This preamble detector is used for two reasons:

- 1) Getting the comparative threshold signal to the half of envelope detector signal (signals, 'a' and 'b', Fig.4).
 - 2) Significantly reducing interference from some other device. Only OOK modulated preamble with desired or higher data-rate will lower the WUp signal enough to trigger an interrupt. Other received signals are filtered using the preamble detector, that acts as a low cut filter. The data packets generated by a GSM, WiFi or some other wireless device are longer than one OOK modulated bit. One has to note that whole packet of data modulated by those schemes is seen as a bit in OOK modulation, since signal energy does not change. By studying the signals of those devices, this signal does not need to be filtered at RF front end (before the charge pump), but can be filtered after the comparator, with the same circuit that does preamble detection.
- For example, as seen in Fig. 5, GSM 3G data signal of a nearby phone consists of data bursts that are interpreted as lower data rate OOK. Circuit needs several short impulses to charge the C7 capacitor to lower the 'WUp' (Fig.2) signal, as it can be seen on Fig.3, and the frequency of GSM data packets is not high enough to generate wake up signal. Same can be proven for SMS send/receive, GSM Call, WiFi or Bluetooth.

A second comparator, as illustrated in Fig. 2(b), can be used if WUp signal needs to have sharp transitions, or can be used for measurements (Fig. 3). In most cases there is no need for it, therefore does not have to be used because it increases power consumption.

In one embodiment a full version of the wake up radio, using the SMD components can be built. Application of this radio would be to have circuit like this connected to the same antenna as the main transceiver on a sensor node, WUp output connected to the

microcontroller's (μ C) interrupt pin, and Data output connected to, for example UART, or some general purpose input-output (GPIO) pin. Principle of operation would be: μ C gets the interrupt signal when somebody transmits the preamble. Then, the microcontroller goes into the active state and reads the OOK command/address on the
5 UART or GPIO pin. It compares it, and decides if there is need to turn on the rest of the circuit, or go back into the sleep mode. This can be done by some dedicated device, however this consumes more static power, and can be proven that it is overall more power consuming, for regular WBAN applications with infrequent wake up signals, and low-power microcontrollers.

10

Testing of the WUR was performed on a carrier frequency of 433Mhz, using the ADF7020 transceiver's GOOK mode. But, since it doesn't have filtering at the input, it is intended to be used on any RF frequency. Ideally it is used in the same frequency band as the main transceiver, for antenna re-use, and possibility to use the main
15 transceiver as a transmitter of a Wake Up signal, without a need for a dedicated device. Data rate was 9600bit/s, and this is determined by the comparator propagation time. Generally, if high data rates are needed, faster but higher power consuming comparators must be used. Static power consumption of the presented circuit is solely determined by static power consumption of the comparator. Measurements show that static power
20 consumption of our wake up radio, based on LTC1540 comparator is 470nW at low voltage (2V). Dynamic power consumption, when receiving an OOK packet is determined by the values of C6, C7, R3 and data rate (C6=100pF, C7=330pF, R3=10M and data rate 9.6kbit/s in measurements made) and it is approximately 440nW at 2V. This would raise the total power consumption when receiving a packet to 910nW. It will
25 be raised also if it is sporadically interfered with the other wireless devices, but for an example in a realistic application where wake up packet is sent every second, this would raise average power just by 1% compared to static power consumption. The consumption would be much lower than any method for preamble detection or false wake up filtering based on ultra low power microcontrollers or FPGA.

30

In another embodiment of the invention shown in Figure 6, and similar to Figure 1, the invention provides a system for nano-power wake-up radio circuit for wireless body area networks, illustrated generally by the reference numeral 10. A charge pump 11, for

example a two-stage voltage doubler multiplier, is used as an OOK signal envelope detector. Then, the correct bit sequence for the received packet is formed using a data slicer 12 (comparator). The comparator 12 threshold is adaptive, rather than constant, and it is determined by the strength of the received signal. A Preamble Detector 13
 5 triggers the wake up interrupt if the preamble is in the expected OOK data rate range. The next part of the circuit is a Pulse-Width Modulation (PWM) decoder and the SPI (Serial Peripheral Interface) adapter 14. This part of the circuit first decodes a PWM encoded signal and generates SPI compatible signals for data transfer to the processor, now described in more detail with respect to Figure 7.

10

A detailed schematic circuit of the WUR according to the invention is shown in Fig. 7. The first part of the circuit is the envelope detector - a two-stage doubler (C1-C4, D1-D4). This extracts the envelope of the received GOOK signal (tracks the received signal power). Resulting signal is shown in Fig.8, signal 'a'. The next part of the circuit (R1,
 15 C5) is used for adaptive threshold generation (Fig.8, signal 'b'). The next part of the circuit (R2, C6, C7, D5, D6) is used to generate a wake up interrupt from the preamble. The preamble is an OOK signal of higher frequency than 2kHz in our implementation (Fig.9). This preamble is used for two purposes:

- 20 1) Sets the threshold signal ('b') to the mid-level of the envelope detector signal ('a'), Fig.8.
- 2) Significantly reduces interference from other communications. Only the OOK modulated preamble of higher than predetermined data-rate will raise the WUp-Int
 25 signal enough to trigger an interrupt. Lower data rate OOK signals do not trigger interrupts.

The wake up packet preamble raises this WUp-Int to generate the interrupt, as illustrated in Fig.9. On the other hand, the signal from a GSM mobile phone during a
 30 call does not trigger an interrupt. This figure shows how the WUR, without any RF filtering at the input, interprets a signal from a GSM mobile phone during a call. Note that the whole FSK modulated packet of data is seen as a high level impulse once it is OOK demodulated. This preamble detector drastically reduces false wake up interrupts

caused by spurious wireless FSK transmissions in the vicinity of a WBAN (particularly from GSM systems which are the strongest and most common).

The next part of the circuit (R3, R4, C8, D7 and 74HC132 Quad 2-input NAND Schmitt trigger) is used to decode the PWM signal and make it SPI compatible. First, the PWM signal is filtered using R3-C8, where only longer pulses (logical “1”) can raise input 5 of the 74HC132 to the Schmitt “1” level. This value (R3-C8) is data-rate dependant and should be changed if another data rate is used. The rest of the logic is used to generate the SPI data and SPI enable signals (Fig.10, channel 1 and 3). A high level of the WUP signal is needed to generate SPI data. An SPI enable signal is generated when the first bit in the packet arrives. This bit has to be “1” (start bit). Then, the SPI data is the PWM filtered signal (Fig. 11, middle signal), and the SPI clock is the raw PWM signal after the comparator (Fig. 11, top signal). The WUR acts as a SPI master. The working frequency is determined by the type of zero bias diode.

The Receiver sensitivity/data rate characteristic is determined by the RF characteristic of the Schottky diode, the OOK data-rate and the threshold level of the comparator-data slicer. A 100% AM test method was used for sensitivity measurement, with DC balanced data. This architecture is capable of working at data rates up to 80kbit/s, with proper changes in the component values for preamble detector/SPI adapter. The sensitivities are:

Data Rate (kbit/s)	1	2	5.5	10	30	50	80
Sensitivity (dBm)	-52.1	-51.4	-51	-46	-40	-36	-30

If input RF filtering is used (narrowband Surface Acoustic Wave (SAW) filter), input sensitivity is decreased by 3dBm due to the filter losses.

At higher data-rates, the comparator needs a higher voltage difference at the input to reduce the propagation time. Therefore reduction in the sensitivity is observed. A sensitivity of -51dBm (or -48dBm with SAW filtering) for 5.5kbit/s data rate, satisfies

the requirements of WBAN where the communication range is several meters. For the transmitter's output power of 10dBm, using the whip antennas (0dBi) 10m indoor range or more can be attained.

- 5 If there is a high power transmitter in the vicinity of a WUR, the envelope detector will detect the transmitted carrier wave. Around a WBAN, the most common high-power transmitter is the GSM phone. Its output power levels can reach up to +33dBm during a call. Any low power WUR based on the envelope detection method will be affected by these signals, if there is no filtering at the input, as it is shown in Fig.12. In this figure,
- 10 the comparator's output is shown, without input RF filtering, for a nearby phone during a call. Other common interferers will not be as critical as GSM, since their output power levels are not as high, and most of the WUR do not have great sensitivity. From an overall power consumption perspective (Requirement 1. b.) it is important how the receiver deals with these interferences. If the WUR generates a wake up interrupt every
- 15 time there is a packet being sent from some device, this would lead to high power consumption. The WUR of the present invention has the preamble detector to filter the most common interferences around a WBAN from generating a wake up interrupt, as explained earlier.
- 20 These interferences do not generate false wake up interrupts, but the communication can be interrupted if the interference happens during the transmission of the wake up packet, leading to corrupt data and packet dismissal after the cyclic redundancy check (CRC). This scenario occurs during a GSM call if no RF filtering is used. Therefore, in order to reduce the Packet Error Ratio, a SAW filter can be placed at the input. Interference
- 25 rejection performance is measured by applying a desired signal of power level D, along with an undesired (i.e. interfering) pulse signal of power I, injected into the RF input of the receiver. Undesired signal power is adjusted until the corruption happens in the signal at the output of the data slicer. The interference rejection performance is expressed as the ratio of the power of the desired signal and the power of the undesired
- 30 signal (D/I) at this threshold. Fig.13 shows the lowest possible D/I for the acceptable mark/space ratio during the interference pulse. Measurements were performed for the desired OOK signal with data rate of 5.5kbit/s at the working frequency of 433.92MHz and the power of -45dBm (3dB higher than the sensitivity). For the GSM 900 band the

rejection is approx. 55dB. For frequencies higher than 1.5GHz, the rejection becomes very high because of the diode characteristics.

A PWM coding scheme as presented in Fig.11 for communication in order to have very low power clock/data extraction and conversion to SPI compatible interface. The wake up packet is typically made of Preamble, Synchronisation bit, Data and CRC. The preamble is used to generate the wake up interrupt. The synchronisation bit is used to delimit the start of the message, and generate the SPI enable signal, for the microcontroller to start reading data. The data should be an address and/or some command defined by the MAC protocol, and the packet should also contain a CRC.

The static power consumption of the WUR is determined by the static power consumption of the comparator and the CMOS logic for the SPI. For this implementation, we used the NPS1101 CMOS comparator by NanoPower Solutions, Inc. (available at <http://www.npsi.jp/j/product/nps1101.pdf>) as the comparator with the lowest power consumption available on the market. Measurements show that the static current consumption of our WUR, based on NPS1101 comparator is 180nA at 1.5V. This figure is for the complete circuit including the SPI adapter based on HCMOS technology, for which the quiescent current is low (few nA at 25° C).

Therefore, the static power consumption (when listening on a channel) is 270nW. The dynamic power when receiving an OOK packet is dissipated on the preamble detector capacitances and the SPI adapter CMOS inputs. It is determined by the values of the capacitors C6, C7 and C8, power-dissipation capacitance of the NAND gates C_{pd} , and the data rate. The total measured energy per bit (Data slicer + Preamble detector + PWM decoder + SPI adapter) is 1.75nJ/bit. This does not vary much with the data rate, because higher data rates would have higher dynamic power consumption but lower time per bit, and vice-versa for the lower data rates. The average dynamic power dissipation is $P_{dyn} = f \times V_{cc} \times C_{sum}$. The energy per bit is then $E_b = P_{dyn} / f = V_{cc} \times C_{sum}$ (f is the data rate and C_{sum} is the sum of the external capacitances and power-dissipation capacitance of the SPI adapter). Therefore, E_b is data rate independent.

A comparison of the power consumption with the lowest power consuming radios was performed. Static power was only compared, only for the wake up radio since the works did not give average power consumptions when having the wake ups or when confronted with the false wake ups generated by external devices. Solutions with the closest idle listening power are [2] - 2.6 μ W, [5] - 4.8 μ W and [4] - 7.5 μ W, but these solutions filter the false Wake-ups with the microcontroller or dedicated FPGA. Therefore greater power consumption will happen if this is used in WBAN, because of the interference from the wireless devices around the person. These are listed in the Table 1 clearly shows the system and/or circuit of the present invention operates at much lower power (470nW) than other prior art systems available:

TABLE I
WAKE UP RADIO POWER CONSUMPTIONS

	WUR power	False wake-up filtering
This work	470 nW @ 2V	WUR
Ansari et al. [2]	2.6 μ W @ 3V	Microcontroller
Malinowski et al. [5]	4.8 μ W @ 3V	Microcontroller
Durante et al. [4]	7.5 μ W @ 1.5V	FPGA

It will be appreciated that since most of the devices in a WBAN have a very or ultra low energy consumption requirements, but will still need to have high flexibility, Wake Up Radio can be seen as one of the devices that will find its use in this type of sensors. The radios used in those sensors would need to have very low power consumption while idly listening on a channel for extended periods of time. They should be also easily integrated with the existing systems, and robust to interference by modern day wireless devices carried around a person. The invention provides a tested a low power, multi-frequency WUR, with common WBAN interference removal, to adhere to these requirements.

The wake up system of the present invention meets all the main requirements for a Wake Up Radio, which are:

- 1) Very low power consumption.

a) Very low WUR power consumption.

WUR should be switched on for extended periods of time, depending of the MAC protocol, when the rest of the node is in sleep mode.

b) Effect on the node power consumption.

5 WUR effect on the power consumption of the rest of the circuit should be minimal.

2) Reduced number of unneeded wakeup signals (in relation with 1.b.)

a) Low false wake-ups ratio.

10 Since every wake up must switch on at least a microprocessor circuit to analyse the reason for wake up, or in worse case switch on a power hungry receiver, expecting a longer command, it is important to keep these false wake-up signals to minimum.

b) Addressing Capabilities.

For added flexibility, WUR should be able to receive a addressing or some other type of MAC message besides just a wake up signal. Therefore, node will not switch on the receiver if the wake up signal was not intended for it.

15 3) Flexibility and usability

a) Antenna and frequency re-use

Because of the space and hardware limitations, WUR circuit should be easily integrated with the existing circuit, without adding too many components.

b) No need for a custom transmitter

20 If possible, wake up signals should be sent using the existing transmitter used in network.

c) Reasonable data-rate

25 If the WUR is capable of receiving data, and MAC is using this, it should have reasonable data-rate. Trying to adhere to all of these requirements, while still keeping the low power consumption (First, Second and Third requirement) is not trivial. Especially in a WBAN, where one has great number of strong wireless transmitter devices, that can be located in immediate vicinity of a sensor. Communication with the other sensors will also affect the WUR of a node in sleep mode, and this should not generate false wake-up signals.

30

It will be appreciated that the invention provides a full working Wake Up Radio (WUR), intended for use in Wireless Body Area Networks (WBAN) that operates in an ultra low power mode. The radio was tested regarding the power consumption and

robustness to communication interferences from a wireless device commonly found around the person carrying a WBAN. Results show that the wake up radio of the present invention has lower power consumption when idle listening than the other state of-the-art radios, and that the filtering method along with a preamble detection method can
5 significantly reduce power for false wake ups in a WBAN.

It will be further appreciated that nano-power wake-up radio system to turn on a device for Wireless Body Area Networks such as devices for Medical Applications, Sport/Fitness, Gaming/Entertainment and Wireless Sensor Networks: Automotive
10 applications, Structural/ambient monitoring, "smart" actuator systems. In other words any device operating in any wireless network that needs low latency and low power requirements.

The embodiments in the invention described with reference to the drawings comprise a
15 computer apparatus and/or processes performed in a computer apparatus. However, the invention also extends to computer programs, particularly computer programs stored on or in a carrier adapted to bring the invention into practice. The program may be in the form of source code, object code, or a code intermediate source and object code, such as in partially compiled form or in any other form suitable for use in the implementation of
20 the method according to the invention. The carrier may comprise a storage medium such as ROM, e.g. CD ROM, or magnetic recording medium, e.g. a floppy disk or hard disk. The carrier may be an electrical or optical signal which may be transmitted via an electrical or an optical cable or by radio or other means.

25 In the specification the terms "comprise, comprises, comprised and comprising" or any variation thereof and the terms include, includes, included and including" or any variation thereof are considered to be totally interchangeable and they should all be afforded the widest possible interpretation and vice versa.

30 The invention is not limited to the embodiments hereinbefore described but may be varied in both construction and detail.

Claims

1. A nano-power wake-up radio system to turn on a device for wireless body area networks, said system comprising:
 - means for receiving a signal, for example an OOK or GOOK signal;
 - 5 an adaptive threshold generator;
 - a comparator adapted to communicate with said means for receiving and said adaptive threshold generator; and
 - a filter means at the output of the comparator comprising means for classifying the received signal to determine whether to turn on the device.
- 10 2. The system of claim 1 wherein the filter means comprises a low power filter or passive filter.
3. The system of claim 1 or 2 wherein the filter means comprises a detector, for example a preamble detector, adapted to detect a wake-up preamble signal in a
15 preselected or expected OOK or GOOK data rate range.
4. The system as claimed in any preceding claim a correct bit sequence of the received signal is formed using a comparator and/or the adaptive threshold generator.
- 20 5. The system as claimed in any preceding claim wherein a charge pump detects the received OOK or GOOK signal.
6. The system as claimed in claim 5 wherein the charge pump comprises a two stage
25 voltage doubler-multiplier.
7. The system as claimed in any preceding claim comprising means for receiving a wake-up packet wherein the wakeup packet comprises of a preamble sequence adapted to generate a wake-up signal and a payload that addresses the device that
30 needs to be woken up.
8. The system as claimed in claim 7 wherein the wake-up packet is transmitted as an OOK or GOOK modulated packet.

9. The system as claimed in any preceding claim comprising a second comparator, if the wake-up signal needs to have sharp transitions.
10. The system as claimed in any preceding claim wherein the means for receiving an
5 OOK signal or GOOK signal comprises an antenna.
11. The system as claimed in any preceding claim comprising a Pulse Width Modulation decoder.
- 10 12. The system as claimed in any preceding claim comprising a Serial Peripheral Interface (SPI) adapter adapted for generating SPI compatible signals for data transfer to a processor of the device.
13. The system as claimed in any preceding claim wherein the adaptive threshold
15 generator comprises means for providing dynamic range of the wake up radio system.
14. The system as claimed in any preceding claim wherein the adaptive threshold generator is adapted to provide equal mark-space ratio for logic '0' and '1' for weak,
20 strong OOK or GOOK modulated signals.
15. A circuit comprising the wake up radio system as claimed in any of claims 1 to 14

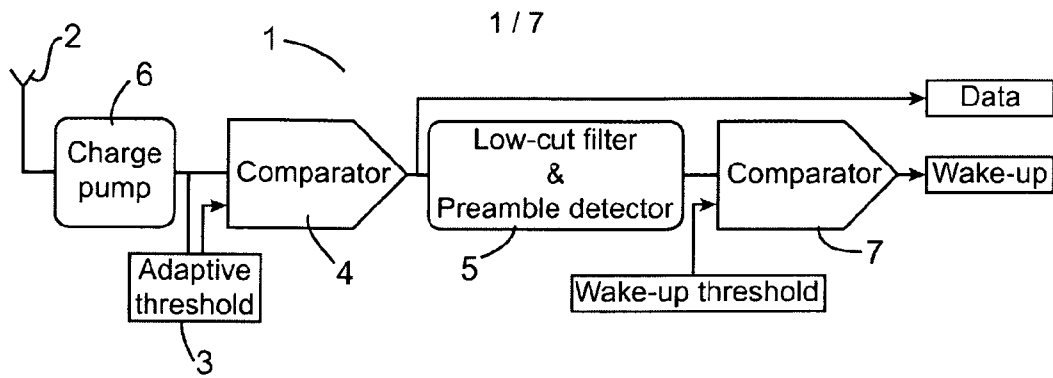


Figure 1

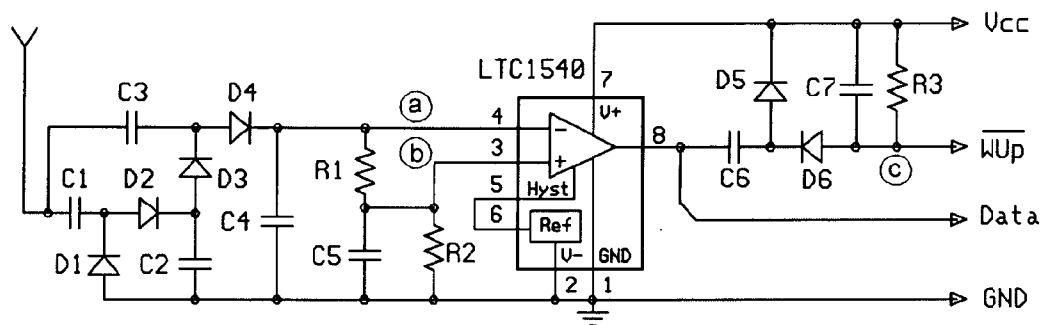


Figure 2a

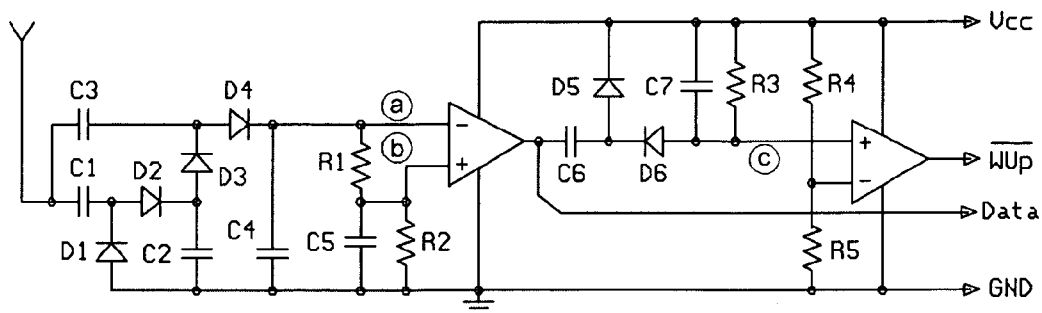


Figure 2b

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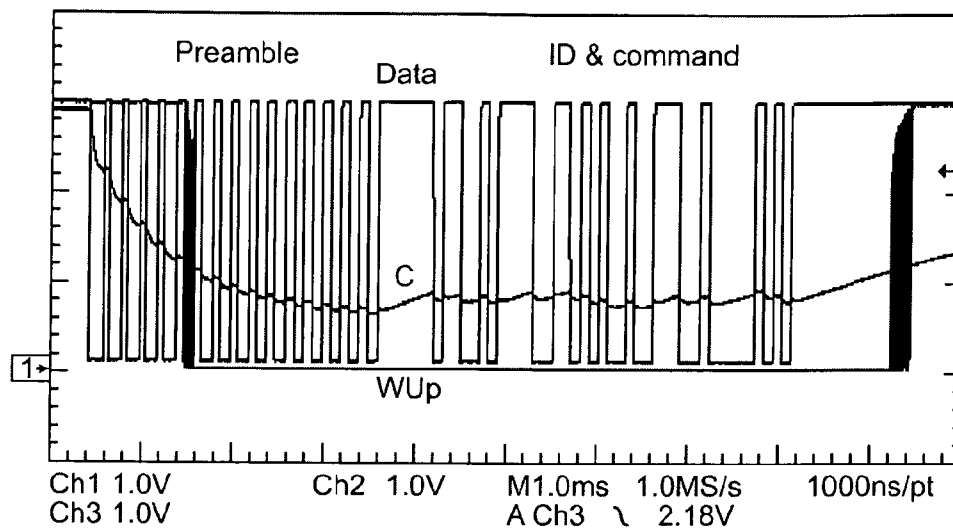


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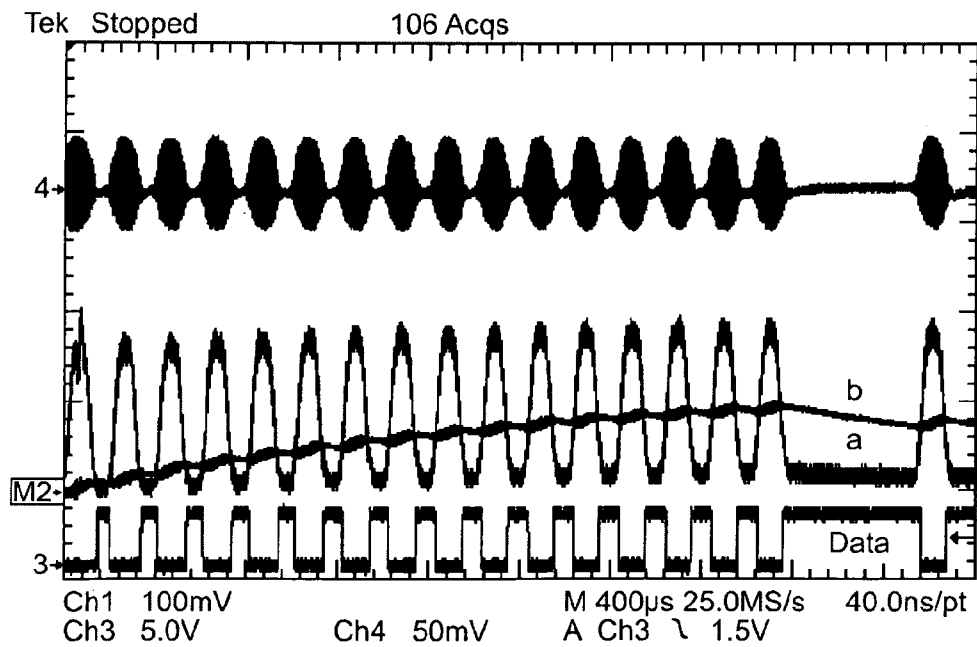


Figure 4

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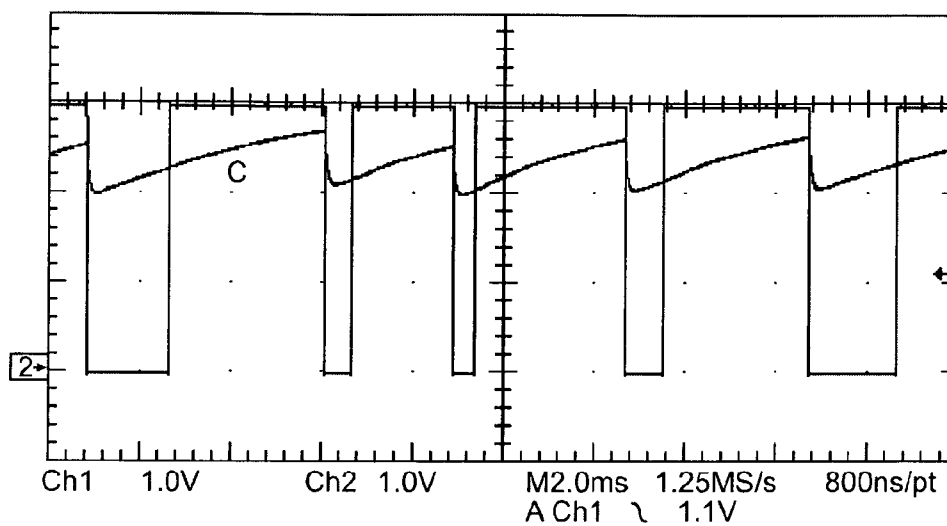


Figure 5

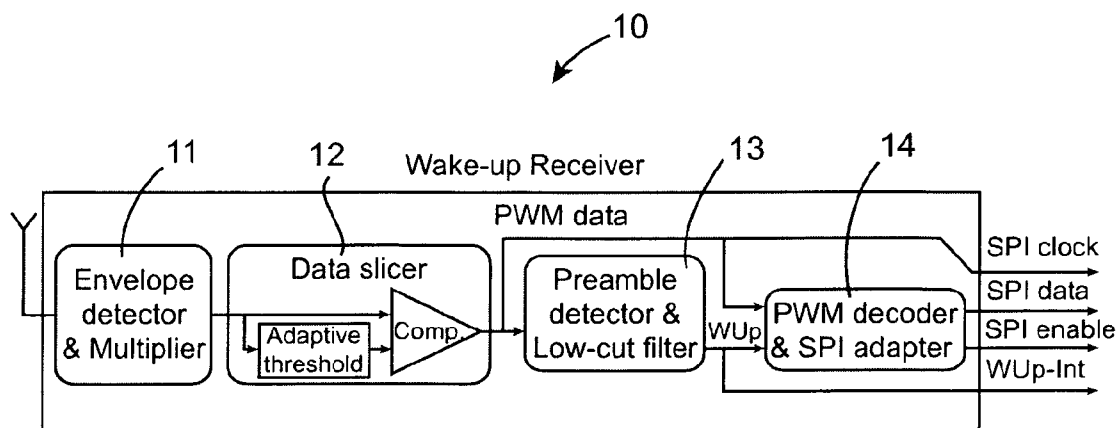


Figure 6

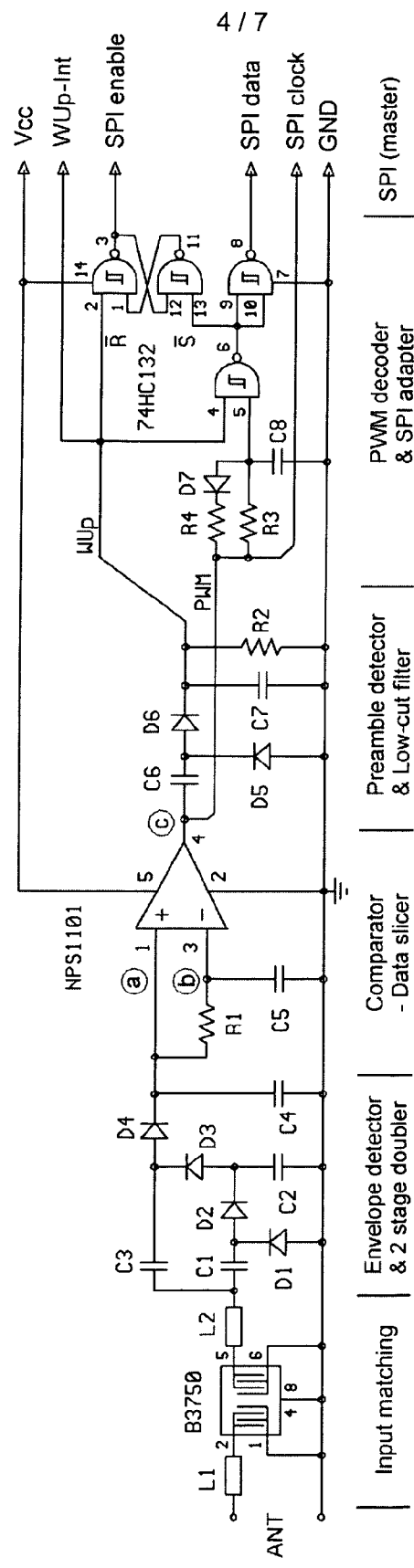


Figure 7

5 / 7

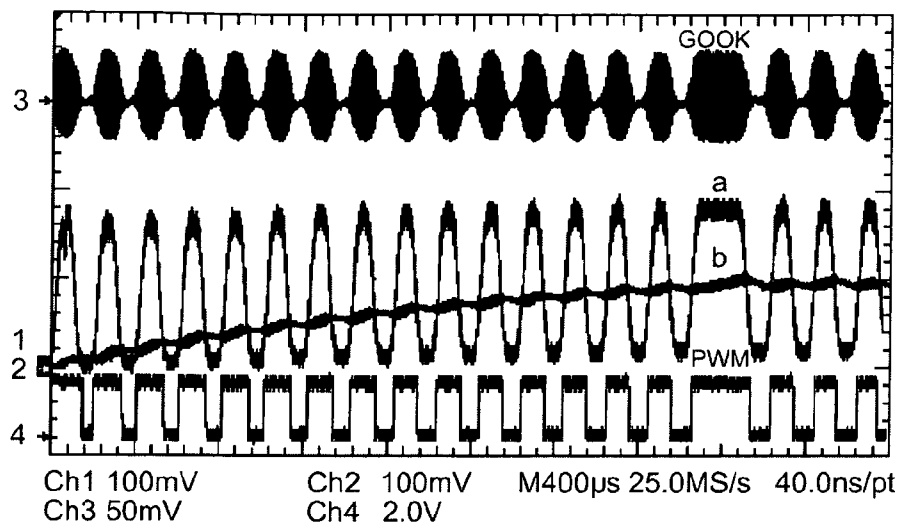


Figure 8

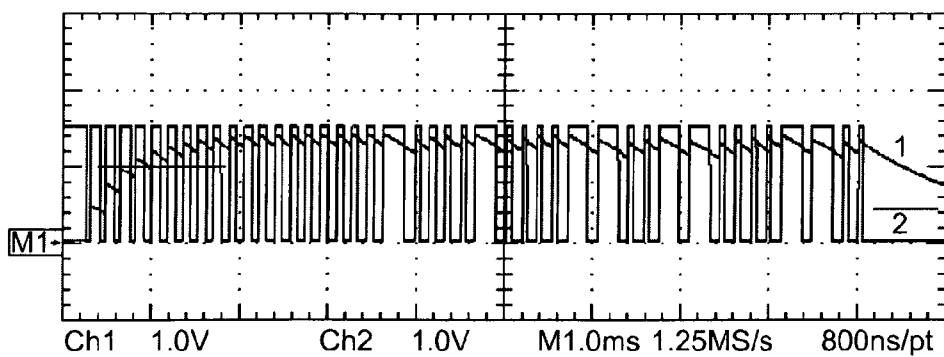


Figure 9

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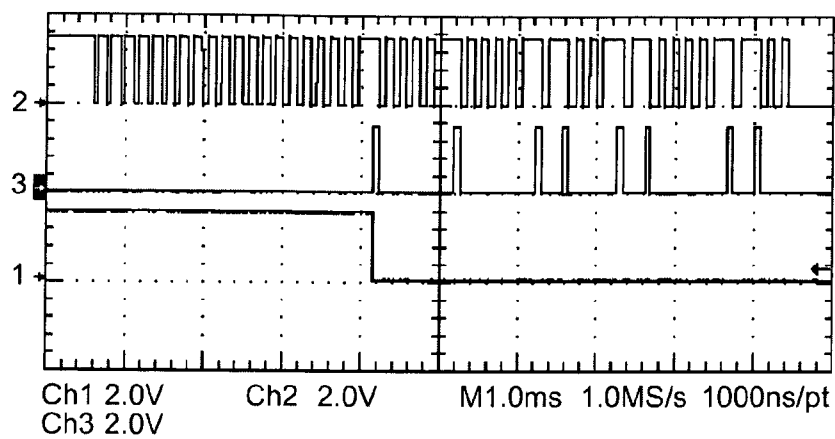


Figure 10

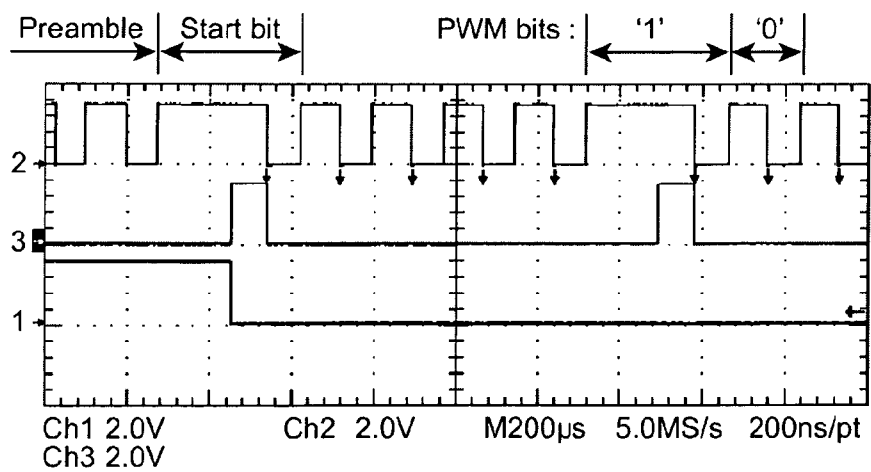


Figure 11

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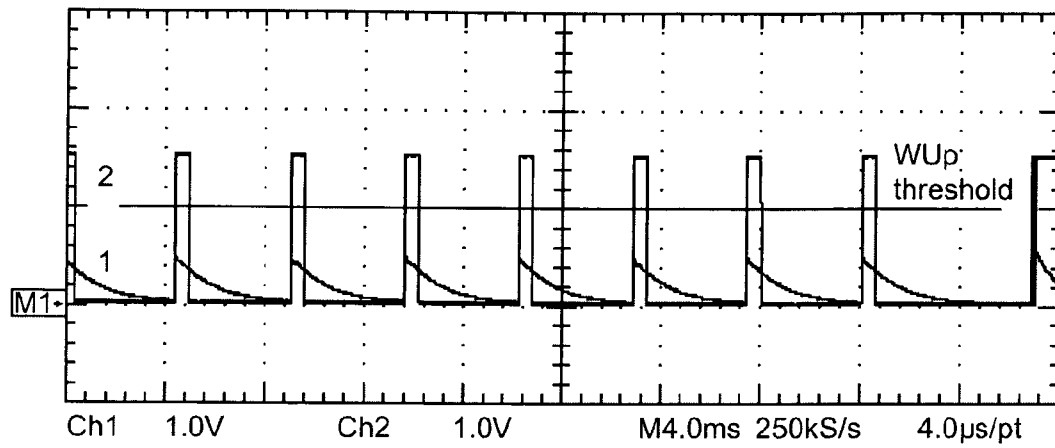


Figure 12

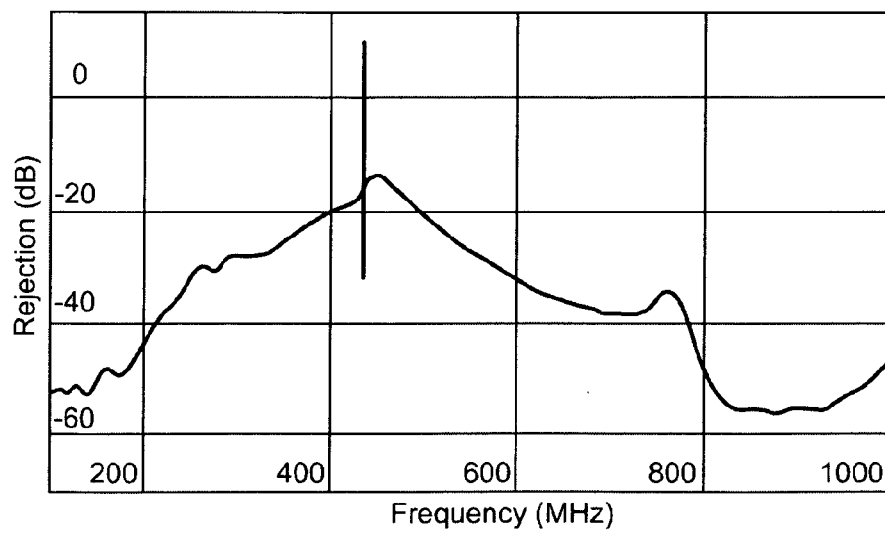


Figure 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/062583

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W52/02 H04B13/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B H04W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/080383 A1 (LOCCA TECH LTD [GB]; MCGIVERN SIMON [GB]) 19 July 2007 (2007-07-19) line 26 - page 5, line 7; figure 1 -----	1-15
X	US 2004/077383 A1 (LAPPETELAINEN ANTTI [FI] ET AL LAPPETELAEINEN ANTTI [FI] ET AL) 22 April 2004 (2004-04-22) paragraphs [0019], [0026]; figure 15 ----- -/--	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

9 December 2011

Date of mailing of the international search report

28/12/2011

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Lindberg, Per

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/062583

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	M. MALINOWSKI, M. MOSKWA, M. FELDMEIER, M. LAIBOWITZ, J. A. PARADISO: "CargoNet: a low-cost micropower sensor node exploiting quasi-passive wakeup for adaptive asynchronous monitoring of exceptional events", PROCEEDINGS OF THE 5TH INTERNATIONAL CONFERENCE ON EMBEDDED NETWORKED SENSOR SYSTEMS (SENSYS, 2007, pages 145-159, XP002665331, page 147, right-hand column, paragraph Sensor Hardware - page 152, right-hand column, paragraph Dynamic Thresholds; figures 3,4	1-15
A	----- JUNAID ANSARI ET AL: "Radio-triggered Wake-ups with Addressing Capabilities for Extremely Low Power Sensor Network Applications", INTERNATIONAL JOURNAL OF WIRELESS INFORMATION NETWORKS, KLUWER ACADEMIC PUBLISHERS-PLENUM PUBLISHERS, NE, vol. 16, no. 3, 8 July 2009 (2009-07-08), pages 118-130, XP019730117, ISSN: 1572-8129, DOI: 10.1007/S10776-009-0100-6 the whole document	1-15
A	----- LIN GU ET AL: "Radio-Triggered Wake-Up for Wireless Sensor Networks", REAL-TIME SYSTEMS, KLUWER ACADEMIC PUBLISHERS, BO, vol. 29, no. 2-3, 1 March 2005 (2005-03-01), pages 157-182, XP019216093, ISSN: 1573-1383, DOI: 10.1007/S11241-005-6883-Z the whole document -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2011/062583

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			US 2006270382 A1 30-11-2006
			WO 2004039102 A1 06-05-2004
