



- (51) International Patent Classification:
H04B 1/7163 (2011.01)
- (21) International Application Number:
PCT/HR2013/000015
- (22) International Filing Date:
6 June 2013 (06.06.2013)
- (25) Filing Language: English
- (26) Publication Language: English
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,

BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- of inventorship (Rule 4.17(iv))

Published:

- with international search report (Art. 21(3))

- (54) Title: ENERGY-EFFICIENT SYSTEM FOR DISTANT MEASUREMENT OF ANALOGUE SIGNALS

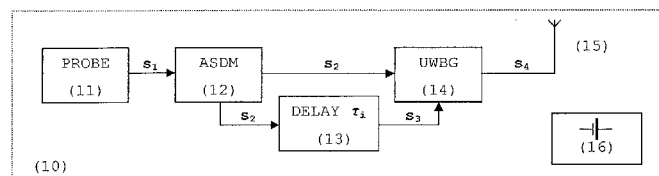
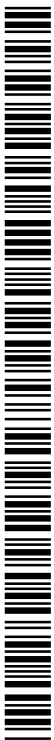


Fig. 1

- (57) Abstract: The invention discloses an energy-efficient system for wireless measurement comprising one or more measuring units (10). Each measuring unit (10) comprises measuring probe (11), an asynchronous sigma delta modulator (12), a delay circuit (13), ultra wide band pulse generator (14) transmission line (15) being preferably, antenna and a power supply (6). Said asynchronous sigma delta modulator (12) converts an analog signal received by the corresponding measuring probe (11) into digital pulsed signal. The signal formed by asynchronous sigma delta modulator (12) is delayed in a delay circuit (13) for the fraction of time that is unique for the said measuring unit (10) identifying uniquely the analog input received by the measuring probe (11). Signal formed by asynchronous sigma delta modulator (12) and the signal from the delay circuit (13) trigger corresponding ultra wide band pulse generator (14) by their pulse edges, resulting with two ultra wide band pulses per one asynchronous sigma delta modulator (12) signal edge. The invention is very useful for long term acquisition of analog signals, especially time varying signals.



ENERGY-EFFICIENT SYSTEM FOR DISTANT MEASUREMENT OF ANALOGUE SIGNALS

DESCRIPTION

Technical Field

The subject invention belongs to the technical field of analogue signals acquisition and conversion into digital form that can be sent across the transmission line to the receiver. More particularly, the subject invention belongs to the energy efficient system useful for long term acquisition of analog signals, especially time varying signals from one or more measuring probes.

Technical Problem

The first technical problem solved with the invention is construction of energy-efficient system for distant and reliable measurement of plurality of analogue signals that are transmitted in asynchronous manner to a receiving unit. Energy-efficient system has the meaning that the measuring units are capable to measure and transmit the measuring values over long time, where time is measured in a months or years of operation, without changing built-in power supply. Distant measuring means that the measuring information can be transmitted wirelessly or via standard wire to the receiving unit. Energy-efficiency is achieved during the process of forming the transmitted signals, i.e. no digital logic or computational means are used in the process of forming UWB (ultra wide band) signal carrying measuring information. In addition, no internal clock or counting module is necessary for the system to operate in a reliable manner that significantly preserves the energy consumption.

The second technical problem solved with the invention is that the number of measuring units that can operate together with one receiving unit can be theoretically very high due to the lack of any correlation between the transmissions of the measuring units among themselves or with the receiving unit.

The third technical problem solved with the invention is that measuring units are capable for the long term operation when measuring strongly varying signals in time, i.e. biological signals such as ECG (Electrocardiogram) or EEG (Electroencephalogram) electric signals.

Previous State of Art

Considering the importance of the data acquisition field the previous state of art is extremely reach regarding the solution of before mentioned technical problems.

The document "Asynchronous Signal Processing for Compressive Data Transmission" (Shuang Su), Master's Thesis, University of Pittsburgh, 2011; <http://d-scholarship.pitt.edu/8363/> teaches about a power-efficient procedure useful in the acquisition of biological data in digital form, without using high frequency samplers. The data is compressed so that transmission is limited to parts of the signal that are significant. The procedure uses an asynchronous sigma delta modulator (ASDM) together with a time-to-digital converter (TDC) to obtain binary data that is transmitted via orthogonal frequency division multiplexing (OFDM). The document uses ASDM connected to the popular scheme for wideband digital communication -- OFDM. However OFDM scheme requires significant computational power that leads inevitable to significant power consumption, higher than in the present invention. The document remains silent regarding the possible multiuser system achieved in the present invention by delay circuit built in measuring units. Considering the fact that the performance of the disclosed system was illustrated using an EEG signal, this document forms the closest document in the art.

The document Quek, T.Q.S.; Win, M.Z., "Analysis of UWB transmitted-reference communication systems in dense multipath channels", Selected Areas in Communications, IEEE Journal on , vol.23, no.9, pp.1863,1874, Sept. 2005 doi: 10.1109/JSAC.2005.853809, teaches

about transmitted-reference (TR) signaling, that in conjunction with an autocorrelation receiver (AcR) offers a low-complexity alternative to Rake reception in UWB systems. The present invention takes advantage of the transmitted reference signaling formed via delay circuits built into each of the measuring units.

The document WO 2008/061245 A2 „Multiple access techniques for a wireless communication medium“, (Ekbal A. et al) teaches about TR in UWB transmission for channel numbering, see paragraph no. 0050. However, by careful reading of paragraph 0008 and 0009 of the same document reveals that reference pulse is not equal to the data pulse shifted in time that is the core of the present invention.

Summary of invention

The invention discloses an energy-efficient system for distant measurement of analogue signals comprising one or more measuring units and a receiving unit. Each measuring unit comprises measuring probe, an asynchronous sigma delta modulator, a delay circuit, an ultra wide band pulse generator connected to the transmission line and a power supply. Said asynchronous sigma delta modulator converts an analog signal received by the corresponding measuring probe into digital pulsed signal with variable width.

Receiving unit comprises a receiving line, low noise amplifier, positive pulse detector, negative pulse detector, two monostable multivibrators, digital signal processing mean and a power supply.

The signal formed by asynchronous sigma delta modulator of the measuring unit is delayed in a delay circuit for the fraction of time τ_i that is unique for the said measuring unit identifying the analog input received by the measuring probe. Said signal from the asynchronous sigma delta modulator and the signal from the delay circuit trigger corresponding ultra wide band pulse generator by their pulse edges, resulting with two ultra wide band pulses separated in time by τ_i per one asynchronous sigma delta modulator

signal edge. The generated pulses are transmitted wirelessly or via "wire".

On the receiver side, the signal received by the receiving line is amplified in the low noise amplifier connected to the positive pulse detector and negative pulse detector. Each of pulse detectors is connected to the corresponding monostable multivibrator in order to reconstruct digital signal. Said signal is further processed via digital signal processing mean in order to discriminate the received information using characteristic times τ_i previously stored into said digital processing signal mean in the form of delay lines. Digital signal processing mean finally converts the received information into measured analogue or digital values received from each measuring unit.

Proposed scheme is useful for long term acquisition of analog signals such as biological signals, more particularly time varying biological signals such as ECG or EEG.

Brief Description of the Drawings

The present invention is represented via Figs. 1-5. Fig. 1 represents block-scheme of the measuring unit. Fig. 2 represents block scheme of the receiving unit. Fig. 3 represents sample of the signal processing performed by the measuring unit. Fig. 4 depicts blocks of the measuring units with the constitutive elements. Fig 5 represents circuitry of the digital signal processing mean.

Detailed Description

The present invention discloses energy-efficient system for distant measurement of analogue signals.

The term "system" refers to the one or more measuring units (10) and a corresponding receiving unit (20).

The term "energy-efficient" refers to that the measuring units (10) are capable to measure and transmit the measuring values over long time, where time is measured in a months or years of operation, without changing built-in power supply. This makes measuring units (10) suitable for various measuring processes with almost no maintenance required over the proposed lifetime. However, the present invention still need continued listening via receiving unit (20) of the transmissions of the measuring units (10), and the term "energy-efficient" is not applicable to the receiving unit (20) *per se*.

The term "probe" refers to any circuit that is capable to provide analogue voltage signal that varies in time. For instance, said voltage signal v_1 may depend to measured physical value converted via adequate sensor to the voltage signal in the manner that is well known in the previous art. We denoted the symbol s_1 for that voltage input v_1 that is normalised over the power supply voltage V_{cc} to be $s_1 = \frac{v_1}{V_{cc}}$. The values of the normalised input are within the interval $-1 \leq s_1 \leq 1$.

Each measuring unit (10) has its own probe (11), an asynchronous sigma delta modulator (ASDM) (12), a delay circuit (13), an ultra wide band (UWB) pulse generator (14), a transmission line (15) and a power supply (16).

The ASDM as used in the present invention is well known in the art, e.g. Ouzounov, S.; Engel Roza; Hegt, J.A.; Van Der Weide, G.; Van Roermund, A. H M, "Analysis and design of high-performance asynchronous sigma-delta Modulators with a binary quantizer," Solid-State Circuits, IEEE Journal of , vol.41, no.3, pp.588,596, March 2006. Its principal electrical scheme is presented in Fig. 4, and the maximum frequency of ASDM f_c is defined via the following formulae:

$$f_c = \frac{1}{T_c} = \frac{1}{4hT_p} \text{ where } h = \frac{R_{11}}{R_{11}+R_{12}}, T_p = R_1C_1 \text{ and } R_1 = R_2;$$

Where R_{11} , R_{12} , R_1 , R_2 and C_1 are the elements of the ASDM circuit depicted on Fig. 4. The maximum frequency f_C and the minimum period T_C is obtained when the input signal from the probe (11) $s_1 = 0$. Then, the ASDM output signal s_2 has the minimum period $T_C = T_{1min} + T_{0min}$ and $T_{1min} = T_{0min}$. During standard operation $s_1 \neq 0$ and the values T_1 and T_0 of a signal s_2 , in some hypothetical, scenario were represented on the Fig. 3.

During the standard operation conditions where the input signal $s_1(t)$ varies with the time in unpredictable manner associated with the measured physical value or any other loaded input voltage, the duty cycle α of the digital signal $s_2(t)$ is estimated via the following equation:

$$\alpha = \frac{T_1}{T_1 + T_0} = \frac{1}{2}(1 + s_1)$$

Actual frequency of the ASDM signal f_{ASDM} is defined via instant value of the input voltage signal s_1 and reads: $f_{ASDM} = f_C \cdot (1 - s_1^2)$. However, one condition has to be satisfied; the maximum frequency of the input signal $s_1(t)$ should be much less than actual frequency of the ASDM signal f_{ASDM} .

The signal s_2 generated via the asynchronous sigma delta modulator (ASDM) (12) is further processed by the delay circuit (13). The principal scheme of delay circuit (13) is depicted in Fig. 4 and is well known in the art, e.g.:

- Schidl, S.; Schweiger, K.; Gaberl, W.; Zimmermann, H., "Analogously tunable delay line for on-chip measurements with sub-picosecond resolution in 90 nm CMOS," Electronics Letters, vol.48, no.15, pp.910,911, July 19 2012;
- Schell, B.; Tsvividis, Y., "A Low Power Tunable Delay Element Suitable for Asynchronous Delays of Burst Information," Solid-

State Circuits, IEEE Journal of , vol.43, no.5, pp.1227,1234, May 2008.

The delay time τ_i of the i -th delay circuit embedded in i -th measuring unit (10) is defined by the RC constant, i.e. R_d and C_d , and reads: $\tau_i = R_d \cdot C_d \cdot \ln(2)$. Once the signal s_2 is processed through the delay circuit (13) the result is the signal s_3 which is signal s_2 shifted in time for the predetermined delay time τ_i , as presented on Fig. 3. The possible criteria for choosing the delay time τ_i will be discussed later. For the person skilled in the art it is evident that any other delay circuit can be effectively used instead the delay circuit presented by the Fig. 4. The core of invention is not affected by different selection of a delay circuit (13).

Both signals, i.e. signal s_2 and delayed signal s_3 , enters ultra wide band generator (14) and trigger corresponding ultra wide band pulse generators (14) by their pulse edges, resulting with two ultra wide band pulses s_4 separated in time by the time τ_i per one asynchronous sigma delta modulator (12) signal edge, Fig 3. The time separation of the s_4 pulses uniquely identifies measuring unit (10) and the measuring values of the probe (11) pertaining to the same measuring unit (10).

One of possible constructions of an ultra wide band generator (14) is presented by the Fig 4. Two step recovery diodes (SRD), for instance SMMD-840 or similar, are connected in antiparallel manner as the switching elements. The UWB pulses are defined by the values of the elements: R_{p1} , R_{p2} , C_{p1} , C_{p2} and the length of the microstrip that has in parallel connected resistor R_{p3} . Although is possible to perform various different shapes via variation in parameters, the preferred embodiment is when the values $R_{p1} = R_{p2}$ and $C_{p1} = C_{p2}$ ensuring almost perfectly identical pulses of the time width T_p . The shape discrepancy between two consecutive pulses has origin in a tolerance of the used electronic elements and thermal characteristic of the circuits. For the person skilled in the art it is evident

that any other ultra wide band generator can be effectively used instead the generator present in the Fig. 4 for achieving the same technical results.

The signal s_4 is further transmitted via transmission line (15). The transmission line (15) in preferred embodiment can be UWB antenna. In another embodiment the transmission line can be a wire. By term "wire" we understand any kind of direct electrical contact that includes also all types of waveguide or similar transmission lines capable of carrying an UWB signal to the receiving unit (20).

Considering the mass production of the measuring units (10), it is to be expected that only differences between two measuring units (10) are in different delay circuit (13), where P denotes the total number of identical measuring units (10). The core of the invention is that the ASDM signal s_2 is delayed in some i -th measuring unit (10) by some specific time τ_i thus forming signal s_3 where both signals triggers UWB generator (14), Fig. 3. Furthermore, considering the fact that there is no synchronization between the measuring units (10), i.e. they transmit in a pure asynchronous and uncorrelated manner; some restriction for minimizing possible reading errors should be set.

The restriction is necessary in some limiting cases, for instance when two measuring probes (11) recorded similar values - let say 0V, and being triggered by their corresponding ASDMs in the same time. Here, "in the same time" we mean within the time difference that corresponds to the UWB pulse duration T_p . Such events are rather rare, but have to be treated with care to improve the system. This can be resolved by choosing adequate scheme for delay times within the measuring system.

For the i -th measuring unit (10) tuned delay circuit (13) should be chosen in the way that:

(a) $\tau_i = T_p \cdot (P + i - 1)$; where $i \in N$; and

(b) $\tau_i < T_c/2$.

The similar TR scheme is cited in Tao Jia and Dong In Kim, "Analysis of Channel-Averaged SINR for Indoor UWB Rake and Transmitted Reference Systems", IEEE Trans. Commun., vol.55, no.10, pp.2022-2032, Oct. 2007.

Condition (a) ensures "coping over" and the condition (b) ensures adequate occurrences of the pulses bearing in mind what is the minimum period of the identical ASDM circuits T_c as explained earlier. Via condition (b) the delay times ensure reliable multiterminal coding performed by the measuring units (10).

Finally, the power supply (16) for powering measuring unit (10) may be external or internal. Due to the very low consumption of the described measuring unit (10), in the preferred embodiment the power supply (16) is battery build into the measuring unit (10). It is known in the art that UWB transmission scheme as well as the ASDM scheme is energy efficient with the meaning of "energy efficient" as set before.

The receiving unit (20) consists of a receiving line (21), low noise amplifier (22), positive pulse detector (23), negative pulse detector (24), monostable multivibrators (25, 26), digital processing mean (27), and power supply (28). The receiving line (21) can be UWB antenna, or "wire" with the meaning of "wire" as set before.

The preferred embodiment uses UWB antenna or a "wire". However, the hybrid solution is also possible if two or more low noise amplifiers (22) are combined together in the manner known in the art to produce signal capable for further processing. The signal consisting of series of UWB pulses received via one or more transmission lines (21) and adequately amplified via one or more low noise amplifiers (22) is processed via positive pulse detector (PPD) and negative

pulse detector (NPD). A PPT (23) and NPD (24) circuits are common in the art, e.g.:

- Rulikowski, P.; Sokol, V.; Barrett, J., "Low power consuming pulse detector," Ultra-Wideband, 2005. ICU 2005. 2005 IEEE International Conference on , vol., no., pp.4 pp., 5-8 Sept. 2005;
- Lechang Liu; Miyamoto, Y.; Zhiwei Zhou; Sakaida, K.; Ryu, J.; Ishida, K.; Takamiya, M.; Sakurai, T., "A 100Mbps, 0.19mW asynchronous threshold detector with DC power-free pulse discrimination for impulse UWB receiver," Design Automation Conference, 2009. ASP-DAC 2009. Asia and South Pacific , vol., no., pp.97,98, 19-22 Jan. 2009.

The roles of PPT (23) and NPD (24) are to detect the UWB pulses of both types, and to normalize the signals to be processed via pair of monostable multivibrators (25, 26). Each of monostable multivibrator (MM) finally reconstructs plurality of negative and positive UWB pulses into digital signal that is further processed by the digital signal processing mean (DSP). The role of DSP (27) is to reconstructs the signals from each measuring unit (10) via previously known delay times τ_i into digital or analogue information.

The final selection of pulse detectors (23, 24) and selection of adequate monostable multivibrators (25, 26) is left to the circuit designer.

The DSP (27) consist of two identical sets of delay circuits tuned to the delay times ($\tau_1, \tau_2, \dots, \tau_p$) adjusted to be the delay times of the corresponding measuring units (10), Fig. 5. Outputs from the monostable multivibrators (25, 26) are processed via corresponding delay circuit and multiplied with the original signal. Two branches, i.e. branch originated from the negative pulse detector (26) and branch originated from the positive pulse detector (25), processed via monostable multivibrators (25, 26) are then processed via edge combiner circuits that are common in the art, e.g.:

- Kuo-Hsing Cheng; Shu-Ming Chang; Shu-Yu Jiang; Wei-Bin Yang, "A 2GHz fully differential DLL-based frequency multiplier for high speed serial link circuit," Circuits and Systems, 2005. ISCAS 2005. IEEE International Symposium on , vol., no., pp.1174,1177 Vol. 2, 23-26 May 2005;
- Po-Chun Huang; Chi-Jih Shih; Yu-Chang Tsai; Kuo-Hsing Cheng, "A phase error calibration DLL with edge combiner for wide-range operation," New Circuits and Systems Conference (NEWCAS), 2011 IEEE 9th International , vol., no., pp.1,4, 26-29 June 2011.

The role of some particular edge combiner connected with the corresponding τ_i delay circuitry is to reconstruct only the s_{2i} signal received through the transmission line from some particular measuring unit (10) characterized by its delay circuit (13) characterized by the same delay time τ_i .

The built in logic then processes reconstructed s_{2i} signal into any desired form of digital information or convert it back to the analogue voltage signal via any convenient digital to analogue circuit, or directly to analog circuit, if necessary. This digital or analogue information resulted from some particular edge combiner and corresponding logic is delivered to final user i .

Industrial Applicability

Industrial applicability of the given invention is obvious and offers an energy-efficient system for distant measurement or transmission of analogue signals. The system is extremely useful for long term acquisition of analog signals such as biological signals, more particularly time varying biological signals such as ECG or EEG.

References

- 10 - measuring unit
- 11 - measuring probe

- 12 - asynchronous sigma delta modulator; or ASDM
- 13 - delay circuit
- 14 - ultra wide band pulse generator; or UWBG
- 15 - transmission line
- 16 - power supply
- 20 - receiving unit
- 21 - receiving line
- 22 - low noise amplifier; or LNA
- 23 - positive pulse detector; or PPD
- 24 - negative pulse detector; or NPD
- 25 - monostable multivibrator; or MM
- 26 - monostable multivirator; or MM
- 27 - digital signal processing mean; or DSP
- 28 - power supply

CLAIMS

1. An energy-efficient system for distant measurement of analogue signals comprising one or more measuring units (10) and a receiving unit (20);
 - each measuring unit (10) comprises measuring probe (11), an asynchronous sigma delta modulator (12), a delay circuit (13), ultra wide band pulse generator (14) connected to the transmission line (15) and a power supply (16); where said asynchronous sigma delta modulator (12) converts an analog signal s_1 received by the corresponding measuring probe (11) into digital pulsed signal s_2 with variable width; and
 - where receiving unit (20) comprising a receiving line (21), low noise amplifier (22), positive pulse detector (23), negative pulse detector (24), monostable multivibrators (25, 26), digital signal processing mean (27) and a power supply (28),

characterized by that:

- the signal s_2 formed by asynchronous sigma delta modulator (12) of the measuring unit (10) is delayed in a delay circuit (13) for the fraction of time τ_i that is unique for the said measuring unit (10) identifying the analog input received by the measuring probe (11);
 - where said signal s_2 and the signal s_3 from the delay circuit (13) trigger corresponding ultra wide band pulse generator (14) by their pulse edges, resulting with two ultra wide band pulses separated in time by τ_i per one asynchronous sigma delta modulator (12) signal edge.
2. The energy-efficient system for distant measurement of analogue signals according to claim 1, **characterized by that** each resulting signal s_4 from any of the ultra wide band pulse generators (14) situated within measuring units (10) are transmitted via transmission line (15) being antenna in unsynchronized manner with other measuring units of the same system.

3. The energy-efficient system for distant measurement of analogue signals according to claim 1, **characterized by that**, each resulting signal s_4 from any of the ultra wide band pulse generators (14) situated within measuring units (10) are transmitted via transmission line (15) being wire in unsynchronized manner with other measuring units of the same system.
4. The energy-efficient system for distant measurement of analogue signals according to any of the previous claims, **characterized by that** each delay circuit (13) has delay time τ_i adjusted in the manner that:
- (a) $\tau_i = T_p \cdot (P + i - 1)$; where $i \in N$; and
 - (b) $\tau_i < T_c/2$;
- T_c being minimum period of the digital pulsed signal s_2 ,
 T_p being ultra wide band pulse width,
 τ_i being delay time of the i -th measuring unit (10) having identically tuned asynchronous sigma delta modulator (12) as all other measuring units (10) of the same measuring system having P measuring units (10) for distant measurement of analogue signals.
5. The energy-efficient system for distant measurement of analogue signals according to any of the previous claims, **characterized by that** the power supply (16) is a battery integrated into measuring unit (10).
6. The energy-efficient system for distant measurement of analogue signals according to any of the previous claims, **characterized by that**:
- the signal received by the receiving line (21) is amplified in the low noise amplifier (21) connected to the positive pulse detector (23) and negative pulse detector (24);
 - each of pulse detectors (23, 24) being connected to the corresponding monostable multivibrator (25, 26) in order to

reconstruct digital signal that is further processed via digital signal processing mean (27) in order to discriminate the received information using characteristic times τ_i previously stored into said digital processing signal mean (27) in the form of delay circuits and convert the received information into measured analogue or digital values received from each measuring unit (10).

7. The energy-efficient system for distant measurement of analogue signals according to claim 6, **characterized by that**, the receiving line (21) is antenna.
8. The energy-efficient system for distant measurement of analogue signals according to claim 6, **characterized by that**, the receiving line (21) is wire directly connected to one or more measuring units (10).
9. The energy-efficient system for distant measurement of analogue signals according to claim 6, **characterized by that**, the receiving line (21) is of hybrid type consisting of antenna and wire connection.
10. Use of energy-efficient system for distant measurement of analogue signals according to any of the previous claims for long term acquisition of analog signals.
11. Use of energy-efficient system for distant measurement of analogue signals according to claim 10 where analog signals are biological signals.
12. Use of energy-efficient system for distant measurement of analogue signals according to claim 11 where biological signals are time varying biological signals such as ECG or EEG.

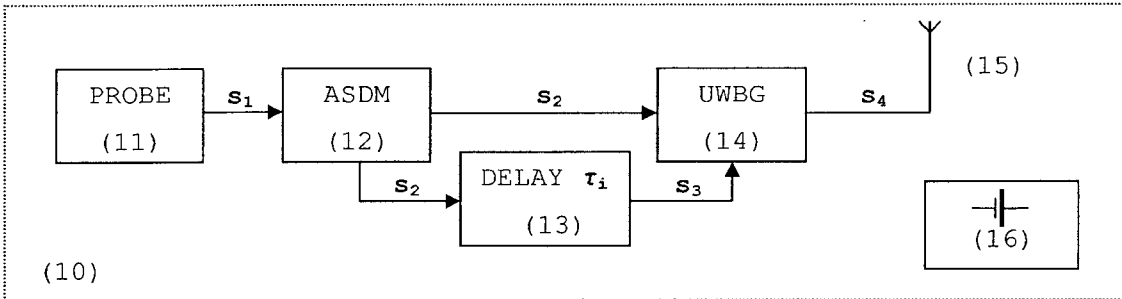


Fig. 1

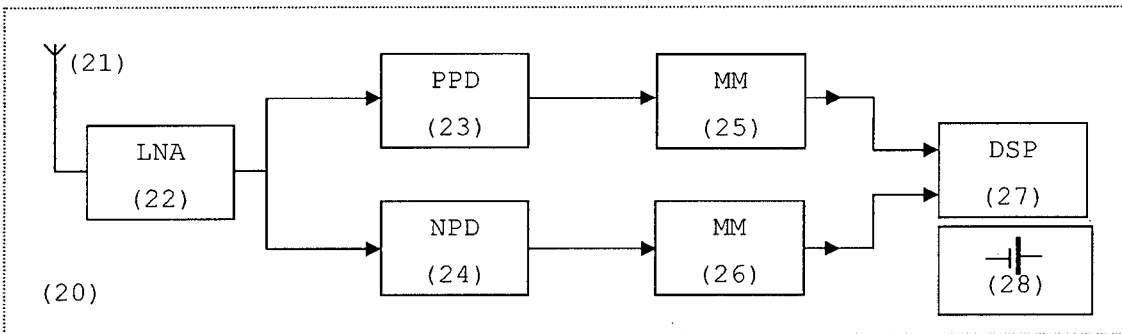


Fig. 2

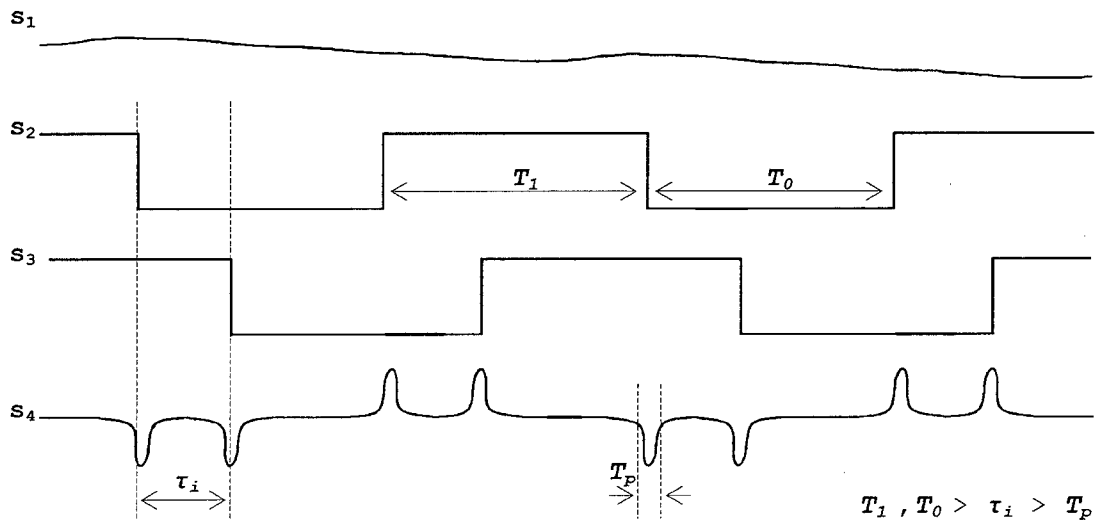


Fig. 3

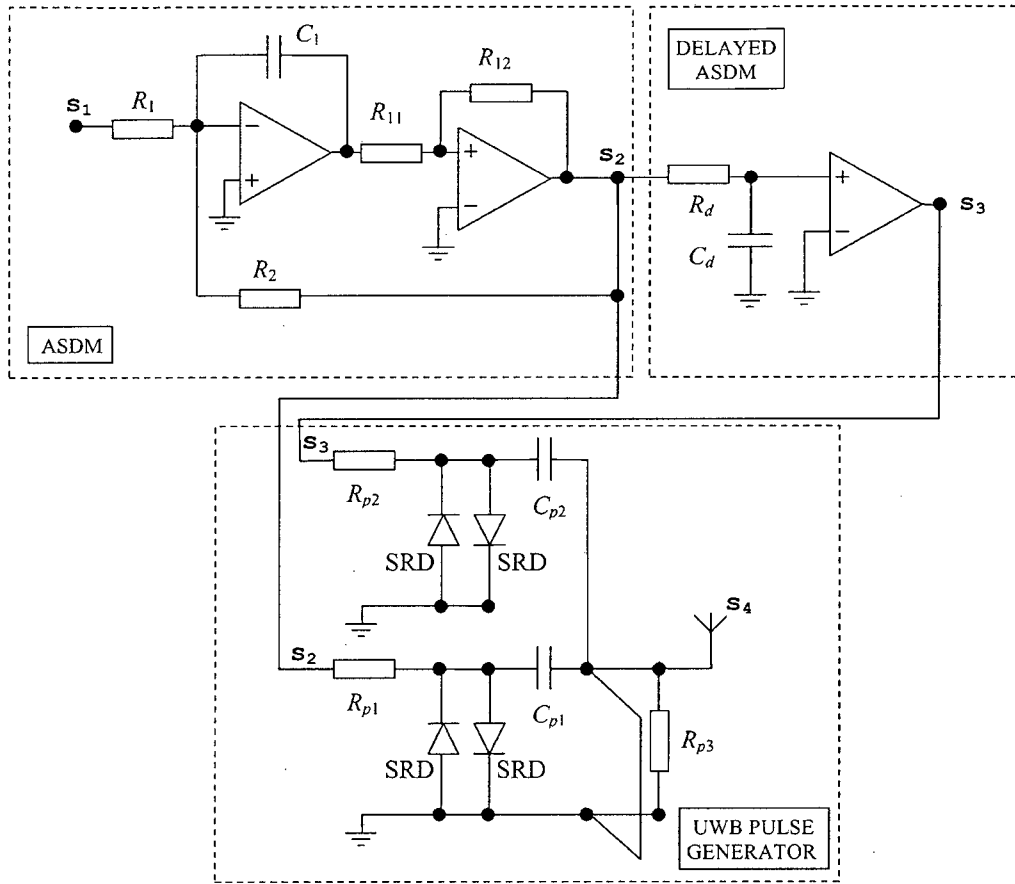


Fig. 4

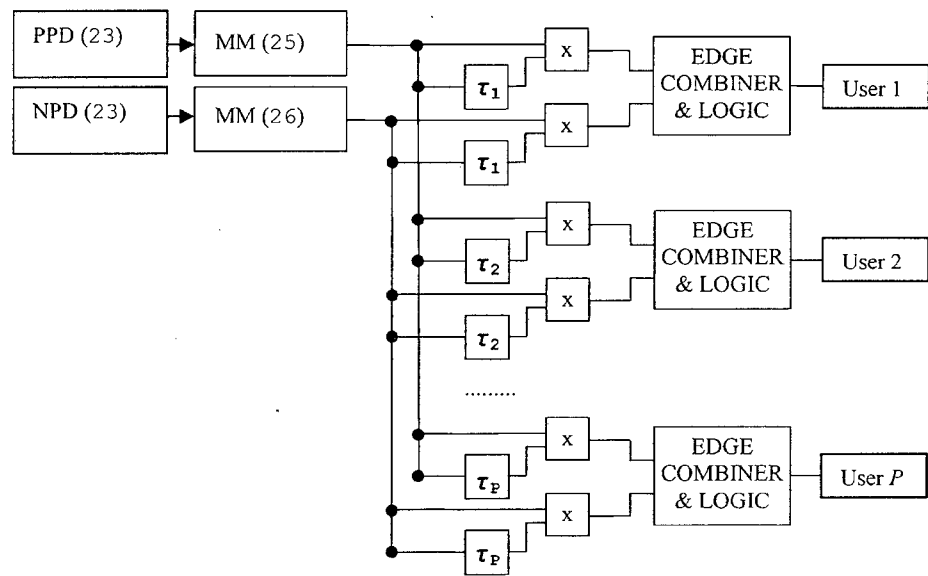


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/HR2013/000015

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B1/7163
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

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 practicable, search terms used)
EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SHUANG SU: "Asynchronous Signal Processing for Compressive Data Transmission", MASTER'S THESIS, UNIVERSITY OF PITTSBURGH, 2011, XP002720416, cited in the application the whole document -----	1-12
A	WO 2008/061245 A2 (QUALCOMM INC [US]; EKBAL AMAL [US]; LEE CHONG U [US]; JULIAN DAVID JON) 22 May 2008 (2008-05-22) cited in the application the whole document -----	1-12

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents :

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/HR2013/000015

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