(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 November 2015 (19.11.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/174879 A1

(51) International Patent Classification:
G01S 7/00 (2006.01) *G01S 7/41* (2006.01)
G01S 7/03 (2006.01) *G01S 13/58* (2006.01)
G01S 7/35 (2006.01) *G01S 13/88* (2006.01)

(21) International Application Number: PCT/RS2015/000011

(22) International Filing Date: 15 April 2015 (15.04.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
P-2014/0247 14 May 2014 (14.05.2014) RS

(71) Applicant: NOVELIC D.O.O. [RS/RS]; Omladinskih brigada 86p, 11070 Belgrade (RS).

(72) Inventors: SAVIĆ, Milan; Gandijeva 31a/51, 11000 Belgrade (RS). BRANKOVIĆ, Veselin; Bačvanska 21, 11000 Belgrade (RS). TASOVAC, Darko; Bul Zorana Djindjića 205, 11000 Belgrade (RS). GRUJIĆ, Dušan; Krfska 11, 11000 Belgrade (RS). MIHAJLOVIĆ, Veljko; Matice Srpske 97a, 11000 Belgrade (RS). JOVANOVIĆ, Pavle; Gandijeva 130v/50, 11000 Belgrade (RS).

(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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, 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, SA, 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, ST, 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))*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) Title: MM-WAVE RADAR VITAL SIGNS DETECTION APPARATUS AND METHOD OF OPERATION

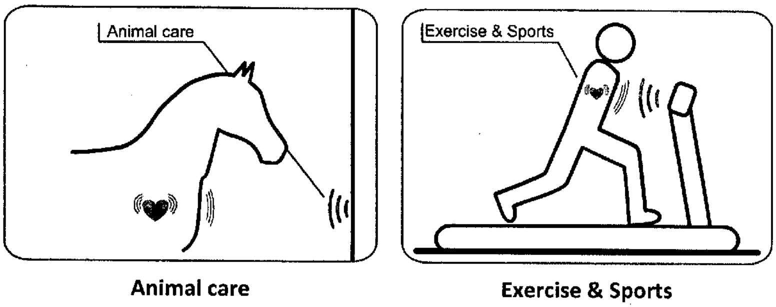


Fig. 1

(57) Abstract: The present invention discloses mm-wave radar sensor to be applied for detection of the vital signs of humans, particularly babies, as well as animals, in clinical and daily life environments. The key system relevant elements are the utilization of mm-wave integrated radar system, with specific planar high-gain antenna radiation pattern, with separate receive and transmit antennas, and detection of the following biomarkers: heartbeat and respiratory dynamics. The method of operation calculates the probability of a number of possible events. In case that probability is above a predefined threshold, the interaction with end user or end system is initiated, typically by using arbitrary wireless communication. Corresponding event related predefined actions are performed in that case. Preferably, the system is using 60 GHz integrated radar front end working in Doppler operation mode, with 4 x 4 TX and RX planar radiation elements, with physical size typically in the range 4 x 2 x 1 cm, or smaller.

WO 2015/174879 A1

Description

MM-wave Radar Vital Signs Detection Apparatus and Method of Operation

Technical Field

The present invention relates to a contactless vital signs sensor apparatus and method of operation comprising mm-wave radio radar with two planar high-gain antenna systems, one for transmitting and one for receiving mm-wave radio signals, utilizing information extracted from processing of both human heartbeat and breathing dynamics. In particular, this solution addresses monitoring babies and humans in general in medical, assistive living and leisure & sports environments.

Background Art

According to Centers for Medicare & Medicaid Services (CMS), which is an agency within the US Department of Health & Human Services, data extracted from Medicare patient discharge records between 2005 through 2007, respiratory failure and failure to rescue (prevent a clinically important deterioration) were two of the three medical indicators with the highest incidence, accounting for 26% of the 97,755 reported deaths and over $1.82 billion in excess costs.

To reduce mortality, enable fast intervention, and finally to reduce the cost, the specific strategies in clinical environment are required, imposing the need for early detection of patient's condition deterioration. Practical technical and organizational solutions in clinical environment are required to meet this ultimate goal. The trends in clinical environment are that the technologies previously utilized in critical care and emergency environments are adapted to non-critical care areas in hospitals. Teams are organized to react upon early warning indicators, including changes in heartbeat and respiratory dynamics.

On the other side, solutions are needed for monitoring babies in incubators, cribs, beds, carriages, and carriers. The system allows noncontact vital signs monitoring. In case of baby incubators this would enable fast reactions of the medical staff when required. In other cases, permanent observation of the baby's vital signs is often required by the parents, as essential for proper reaction in abnormal conditions, such as sudden infant death syndrome (SIDS).

Furthermore, observing the vital signs of the elderly people as a part of their assistive living programs, people in medical recovery, or during exercise and sports activities requires contactless vital signs sensors. Additionally, systems for wireless monitoring of animals' vital signs during pregnancies or illness are needed.

The required system should be usable in various application scenarios. Ideally, advanced heartbeat and respiratory rate sensor system is needed, being non-invasive, ideally contactless, easy to deploy, practical, user friendly, and low-cost.

The following application scenarios will be addressed by the proposed innovative solution:

- Contactless monitoring of baby's vital signs in incubators.
- Contactless monitoring of baby's vital signs in their cribs, beds, carriages, carriers, and generally in their living environment.
- Contactless vital signs monitoring of the people in hospital beds.
- Contactless vital signs monitoring of people in their medical recovery, assistive living, or generally living environment.
- Contactless vital signs monitoring of animals.

The state-of-the-art solutions for vital signs monitoring are based on one of the following two approaches: contact and contactless. The first group includes systems with sensors in direct contact with the human or animal body, which is in many cases impractical. There are several products available on the market based on the contact approach. The second group solutions are proposed by research papers and patents, currently without available products. Proposed systems are based on contactless optical, video or radio approach. The invention proposed here relates to the radio based contactless vital signs detection concept, with clear innovative differentiation to the state-of-the-art in this segment.

It was published in different scientific articles that microwave radar sensor, in the frequency range 3–30GHz, may be used to detect the vital signs. Especially 2.4, 3–10, 24 and 60 GHz vital sign demonstrators have been publicly reported.

Patents and patent applications published in last several years show the relevance of the topic and the state-of-the-art, and will be presented in the following.

The following patents propose the systems based on contact detection of vital signs.

US 20130324860, "Optical Power Modulation Vital Sign Detection Method and Measurement Device", of Tarilian Laser Technologies, introduces optical system for vital signs detection.

EP 1214904, "Wrist-worn vital sign detection device", of Omron Healthcare, introduces system with contact to the human body.

EP 1350460, "Vital sign detection sensor and sensor controlling device", of Matsushita Electric Industrial Co., introduces system attached to human body.

WO 2003024325, "Vital sign detector" introduces the system attached to human body with attached communication circuits.

US 20110087080, "Detection Device For Vital Signs", of Nanoident Technologies Ag, introduces body attached system which detects blood oxygen content, body temperature, skin moisture, skin conductivity and the heartbeat.

WO 2013027027, "Remote monitoring of vital signs", of Isis Innovation Limited, proposes a method of remote monitoring of vital signs by detecting the PPG (photoplethysmogram) signal in an image of a subject taken by a video camera.

WO 2010040452, "Apparatus for recording and monitoring at least one vital sign of a person in a motor vehicle", of Fraunhofer, introduces optoelectronic sensor arrangement for recording at least one vital sign by means of light reflection.

DE 102011112226, "Multi-model multi-sensor device for contact-less detection and monitoring of physiological signals of resting or active working people, has sensors for simultaneous capacitive and optoelectronic detection of physiological signals", of LifeTAix GmbH, introduces multi-model multi-sensor device comprising sensors for simultaneous capacitive and optoelectronic detection and monitoring of significant physiological signals.

The following patents propose the systems based on contactless detection of vital signs.

US 20100198083, "Random Body Movement Cancellation for Non-Contact Vital Sign Detection", of University Of Florida Research Foundation, introduces system for cancelation of the body movements by utilizing vital sign detection based on two transceivers utilizing different frequencies.

US 3796208, "Movement monitoring apparatus", of Memco Ltd, discloses an apparatus for monitoring patient movements utilizing Doppler effect with microwave radar.

US 20120209087, "Non-Contact Vital Sign Sensing System and Sensing Method Using the Same", of National Sun Yat-Sen University, Industrial Technology Research Institute, introduces a non-contact vital sign sensing system and method which sense a vital sign according to a self-injection locking (SIL) and cancel body movement interference according to a mutual injection locking (MIL).

CN 102509419, "Wireless driver fatigue monitoring device" is published, disclosing wireless monitoring device for driver fatigue, including microwave signal transmission for respiratory conditions detection of the driver, using 24 GHz radio. The system analyses the driver's breathing using wireless signal, and then converts it to a respiratory frequency. This information is compared to a preset threshold value in order to determine the fatigue.

US 4958638, "Non-contact vital signs monitor", of Georgia Tech Research Corporation, introduces basic Doppler detection principle by using single antenna radar system for TX and RX functionality combined by circulator and isolator structures, targeting microwave region, particularly 3 and 10 GHz frequency bands.

US 7811234, "Remote-sensing method and device", of California Institute of Technology, proposes system comprising the signal source and the detector which extracts from the reflected signal beam the variations in amplitude indicative of motion of the illuminated tissue or indicative of time dependent variations in the permittivity of the illuminated tissue associated with the electrical activity of the subject's heart.

Recent patent application **US 20130245437**, "System and method for facilitating reflectometric detection of physiologic activity", of Advanced Telesensors, relates in various aspects to systems and methods involving reflectometric detection of physiologic activity.

Summary of Invention

This invention proposes the apparatus **100** and method of operation for contactless vital sign detection, i.e. heartbeat and respiratory dynamics. The detection of the vital signs is followed by the dedicated, specific event-related actions, initiated by the same Apparatus **100**. The proposed solution can save the lives of humans, particularly babies, as well as of the animals.

The key system relevant components of the proposed apparatus **100** are:

- High-gain planar antenna system, realized by the plurality of the technologies, with each of the transmit **21** and receiving **22** parts having more than one antenna radiation element and the radiation diagram in the direction of the subject being observed.
- Millimeter-wave radar with integrated front end on silicon **10**, providing analog processing of the mm-wave signal, and the provision of the analog to digital conversion functionality;
- Digital signal processing functionality **40**, having wireless communication interface with plurality of the realization;
- Mechanical assembly with power supply interface, containing mechanically integrated antenna, digital and analog functionalities and having mechanical connection to the baby incubator, crib, bed, carriage, or carrier, to the bed of the patient in the hospital, or to the wall or ceiling of the areas populated by the subject being observed.
- Supporting circuitry **50** as a part of apparatus **100** may include functionalities like loudspeaker and light warning source, by the plurality of the realization options.

Millimeter-wave front end preferably operates in 60 GHz ISM Band. The usage of higher mm-wave ISM bands is also proposed. The RX and TX antennas preferably have 4 x 4 elements, to explore the tradeoff between the size of the antenna, having impacts on the system cost and integration in the environment, and obtaining the narrow antenna beam. The narrow antenna beam, associated with explicit high-gain antenna approach is essential part of the system, providing limited possibility that the biometric data, i.e. heartbeats or respirations, from the subjects in the vicinity of the subject being observed is sensed. This is one of the essential innovative approaches, because it dramatically decreases the complexity of the digital processing, providing simple, compact, and low-cost apparatus. This is also an essential system-related factor, which imposes the use of mm-wave signals for vital signs detections, as opposed to the state-of-the-art where utilization of microwave frequencies 3–30 GHz is proposed.

Using mm-wave frequency band, preferably the 60 GHz ISM band, allows several major system related advantages compared to the state-of-the-art utilizing microwave frequencies, for example to the 24 GHz ISM band approach proposed in **CN 102509419 B**:

- The capability to have smaller dimensions of the high-gain antenna systems, meaning that, for the same radiation characteristics, 6 times less antenna surface is needed. This reduces the cost and greatly improves the compactness, hence almost eliminating practical use of the system proposed in **CN 102509419 B**.
- The advantage of the proposed innovation is that the utilization of the higher frequency increases the resolution of the target micro displacements, in this case a human body heartbeat and respiratory dynamics. The proposed system provides at least 3 times better resolution compared to **CN 102509419 B**. Moreover, micro displacement may be analyzed with increased accuracy if the IQ outputs are available, as proposed.
- The advantage of the proposed innovation is that the mm-wave frequency band signals, in applications where humans are irradiated, do not penetrate the human skin. The penetration depth is significantly lower compared to the microwave frequency band, typically 3 times shallower than in the case of state of the art **CN 102509419 B**.

In contrast to the state-of-the-art solutions utilizing single antenna for transmission and reception, such as **US 4958638** and **CN 102509419 B**, innovative approach proposed here explicitly operates with separate antenna systems, one for TX chain and one for RX chain, connected to the same integrated mm-wave front end **10**. This allows omitting typical radio & radar system components such as circulators and isolators, which are fully impractical for any type of integration due to the size and specific realization technologies, hence prohibiting low-cost and compact product.

Presented drawbacks of the proposed solutions explain why basic principles of Doppler radar application in human and animal vital signs detection have not turned into a product, almost 30 years after the first demonstrations.

US 20100198083 and **US 20120209087** proposes utilization of two transceivers operating with two distinct frequencies in order to cancel the impact of the random body movement on the vital signs detection. These systems require high complexity hardware and complex signal processing.

Smaller size of the module allows easier physical integration in the application environment. Position of the apparatus may be chosen such that it provides the direct path to the subject being observed and also allows easier manufacturing. System utilizing lower frequencies would either have larger dimensions or wider radiation beams which would allow system to "pick up" unwanted reflections.

Moreover, present invention has innovative approach of integrating complete RF functionalities of the mm-wave radar (30 – 300 GHz) within a single front end chip, including complete mm-wave frequency synthesis, fabricated in standard silicon process. This is possible because the separate antenna systems for TX and RX are used, hence avoiding the need for circulators and potentially isolators. These elements have acceptable performance only when realized using special technologies, which are inherently expensive and cannot be integrated in silicon. In contrast to **CN 102509419 B** and **US 4958638** the presented innovation introduces digital signal processing which allows significant system advantage of using single digital processing HW for simultaneous processing of both heartbeat and respiratory dynamics. Proposed **CN 102509419 B** topology would require twice the processing HW complexity to process both biomarkers, has no inherent signal processing capability to filter out signals from two sources, and cannot add specific adjustments in averaging procedures, which may be required for system customization for the particular application environment.

As a significant innovation step, in contrast to the state-of-the-art, the proposed system analyses both biomarkers simultaneously, thereby providing significantly more information to the user.

The proposed apparatus **100** has significant advantages compared to the state-of-the-art, in at least of one of the following features:

- There is no physical contact to the subject of subject's clothes.
- The system functions independently of the light conditions.
- The system is inherently low-cost allowing the complete HW solution in the range less than 10$ for large quantities.
- The system is compact with inherently small thickness of typically less than 1 cm, allowing easy integration, which reduces assembly cost in the vehicle manufacturing, and allows aftermarket deployment
- The system analyzes two essential biomarkers simultaneously: heartbeat and respiratory dynamics, and therefore provides more information. This allows simultaneous analysis of both heartbeat and respiratory dynamics, providing the means for better prediction and diagnose, which may save lives.
- Proposed utilization of mm-wave frequency, such as 60 GHz ISM band or higher, do not penetrate the human body, in contrast to microwave frequency signals.
- In the applications where a number of radar sensors need to operate in the vicinity of each other sharing the same frequency, there is a problem of a sensor detecting the reflected signal which was transmitted by another sensor. This problem can be largely alleviated by utilizing highest possible frequencies, as proposed here, since those frequencies have strong propagation losses and allow high directivity of the transmitted beam.

The proposed system may function with several meters distance between the subject being observed and the apparatus, depending on the antenna arrangement, transmit power, and receiver sensitivity. The transmit power is, however, reduced to the minimum needed, for the reasons of having minimum power consumption, minimum thermal dissipation, and minimum reflection clutters, which will further simplify digital processing algorithms and further reduce the power consumption and thermal dissipation. The digital part has typical wireless interface **63**, with plurality of its realizations allowing easy connection to the infrastructure accessed by the user.

Apparatus **100** could be also realized with one high gain planar antenna and isolator functionality. This may reduce the size of the system but in the same time increase the technical requirements on isolator functionality, which is difficult to release in the low cost and miniature manner.

Instead of the down conversion mixer in the integrated mm-wave chip functionality **10**, the IQ demodulator may be integrated, providing some extra features in the digital signal processing.

Brief Description of Drawings

Fig. 1 presents apparatus in the specific application scenarios

Fig. 2 presents apparatus functional block diagram

Fig. 3 presents apparatus digital processing functional blocks

Fig. 4 presents the block diagram of the integrated mm-wave front end

Fig. 5 presents antenna TX and RX system options with 4 and 8 dipoles

Fig. 6 presents antenna element arrangement and chip connection to the antenna feeding arrangement

Fig. 7 presents event detection functional block

Fig. 8 presents preferable integrated module 3D topology based on apparatus **100**, top and lateral view, with polymer integration approach

Fig. 9 presents communication of the vital signs and event detection information to mobile device by wireless means

Fig. 10a) presents apparatus functional block diagram with one high gain antenna for both transmitting and receiving mm-wave radio signals, isolator functionality and IQ demodulator in mm-wave chip functionality **10**

Fig. 10b) presents apparatus functional block diagram with one high gain antenna for both transmitting and receiving mm-wave radio signals, isolator functionality and single mixer in mm-wave chip functionality **10**

Description of Embodiments

Integration of the apparatus **100** is application dependent, as illustrated in Fig. 1, and may be:

- Within the baby incubator enclosure such that the antenna is directed towards the baby
- Within the baby bed enclosure such that the antenna is directed towards the baby
- Within the baby transportation means enclosure, such as baby carriage, carrier, or car seat, such that the antenna is directed towards the baby
- Within the patient bed enclosure such that the antenna is directed towards the patient
- Within the environment enclosure in which the subject being observed resides, such as emergency car cabin, hospital, living rooms, placed e.g. on the wall or ceiling, such that the antenna is directed towards the subject being observed

Due to advantageously proposed mm-wave radar application, the size of the high-gain Antenna System for RX **21** and for TX **22** is small enough to allow practical use of the apparatus in the application environment while maintaining high-gain antenna features. Taking into account proposed 60 GHz ISM band operation, and 4 x 4 antenna elements for **21** and **22**, the approximate size of the device may be less than 4 x 2 x 1 cm, which would inherently allow practical use of the system.

The crucial block of the proposed apparatus **100** is the Integrated mm-wave front end, -System on Chip- **10**. It contains the complete RF functionality, and includes power amplifier functionality attached to the antenna system **22**, low noise amplifier attached to antenna system **21**, integrated PLL, used both for up-conversion in transmit and down-conversion in receive, one analog pre filtered an amplified signal or providing two analog pre-filtered and amplified signals as IQ outputs to A/D conversion functionality **30**. The entity **10** has test functionality, voltage regulation, and digital interface to the Controlling functionality **41**, which is a part of the Digital Processing functionality **40**. More detailed structure of the integrated front end **10** is given in Fig. 4, with IQ outputs. The realization with one down conversion mixer and one signal conditioning part compromising amplification and filtering, would require less space in the entity **10** and therefore less cost. The use of the integrated front end **10** allows the system to be compact and have low-cost assembly, enabling the use in the real product. Integration of the complete frequency synthesis and complete analog functionality in a single chip allows considerable reduction of the cost, which is not the case in published mm-wave systems. The entity **10** is preferably realized using SiGe BiCMOS technology that provides high performance. Alternatively CMOS technology may be used. AD (analog to digital) conversion functionality **30** converts the analog conditioned signal or two quadrature signals, I and Q, of the entity **10**, and feeds digital representation of signal or signals to the Digital processing functionality **40** for further processing. Entity **30** is realized by plurality of the realization options, with sampling frequency typically under 1 MHz and typically at least 8 bit resolution for the vital signs detection applications. Entity **30** may be integrated on the same chip as Entity **10**. Entity **30** may be integrated on the same chip as Entity **40**. Entities **40**, **10**, and **30** may be all integrated on a single chip. Entity **60** is providing interface to the infrastructure by using general wired interfaces **61**, and/or standardized interfaces **62**, such as Home Automation, CAN or LIN standards, and/or wireless interface **63**. Wireless interface **63** allows the proposed apparatus **100** to be integrated into the "internet of things" approach.

Wireless interface **63** may be realized by one of the plurality of possible wireless communication technologies for both short- and wide-range communication, in particular:

1. Cellular long-range communication means, allowing connection to personal smart phones and their applications, using one or more than one of the plurality of possible communication standards, such as UMTS, LTE, GSM, GPRS, as well as connection to a cloud application accessible via the WEB. This later connection would allow simultaneous monitoring of the set of systems, e.g. monitoring of all patients in a hospital.
2. Short range communication means, allowing connections typically up to 100 meters, by using: a) low data rate wireless systems like Bluetooth, ZigBee, ISM band communication systems in 433, 915 MHz, 2.4 and 5.8 GHz range, and b) Wireless LAN typical applications in 2.4, 5 – 6 GHz, and 60 GHz range. Those connections may be established to the concentrators, which further communicate with the web/cloud based applications, and/or to the smart mobile devices. One possible scenario is that the information from a number of vital signal sensors is gathered, e.g. in a hospital, and transferred to the web and/or to the medical staff via smart phones. In another possible scenario the vital signs information from a sensor monitoring a baby in a crib is directly communicated to a parent's smart phone, e.g. via WLAN.

Supporting circuitry **50** optionally includes additional memory, manual switching, power supply related circuitry, mechanical support, and any additional functionality required for easy integration. Power supply related circuitry in **50** enables one of the realization options: autonomous power supply provided by the battery, or the connection to the external power supply. The mechanical support structure for integration of all functionality is preferably provided using advanced polymer technologies. Optionally, entity **50** may also include a loudspeaker or indication/warning light source/display, allowing autonomous operation.

Digital processing functionality **40** may be realized by the plurality of technologies, such as: advanced CPUs, FPGAs, advanced µC, DSP, or ASIC, or their combinations, where the digital processing may be performed by "soft" approach or by hard-wired approach or by their combination. Preferably functionalities **60** and **40** are integrated on a simple ASIC, having CPU on one digital SOC. Digital processing functionality **40** includes functionalities **41, 421–429** and **70–71** as described in Fig. 3. The goal is to perform remote and contactless detection of the driver body movement. Important information is the micro-movement of the driver's body; therefore, the simplest approach like Doppler radar system may be used. The entity **10** sends mm-wave CW signal by Tx antenna entity **22** towards the driver's body. The radio signal of mm-wave frequency does not penetrate the clothes and the human body. Heartbeat and respirations cause body micro-movements. According to Doppler effect those movements are causing frequency modulation of the radio signal received by the antenna entity **21**. After the downconversion or IQ demodulation, i.e. mixing with the quadrature of the transmitted signal, and subsequent filtering, and amplification performed in the entity **10**, the low-frequency baseband signal or signals are provided to the entity **30**. These analog signal or two analog signals are converted into corresponding one or two digital streams by the entity **30** and fed into the entity **40**. In entity **421** additional low-pass digital filtering may be performed. Data is further provided to entities **422** and **423**, which perform appropriate digital band-pass filtering such that the expected heartbeat and respiratory rates are in-band. Filter characteristics must account for the expected variations of the appropriate biomarkers which reflect normal and pathologic conditions. Filtering characteristics may be set based on the live object biomarkers history and statistics, previously stored in memory. Entities **426** and **427** perform the calculations of the heartbeat and respiration rates respectively. Filtered signals are first converted in the frequency domain. The corresponding heartbeat and respiratory rates are detected as peaks in signal spectrum. The position of the peaks determines the corresponding rate. One or the combination of the plurality of possible peak detection methods may be utilized, with corresponding digital signal processing realizations of various possible averaging, smoothing, windowing, and peak position estimation techniques. In entities **428** and **429**, the calculated rates are further processed by calculating the rate of the change of the heartbeat and respiratory rates, which may be mathematically expressed as derivatives of the corresponding biometric rates, where various averaging techniques may be applied. This information is provided to the entity **70**, which is responsible for event detection.

With proposed Method of operation one or more of the following events may be detected:

- Subject is alive, justified by the presence of heartbeat and/or respirations
- Subject is alive and in normal condition, confirmed by the vital signs behavior within the predefined range indicating normal condition
- Subject condition is changing, based on detection of the specified variations of the vital signs, such as detected rates outside of specific range, or specified behavior of the vital signs related to their rate of change. These events can be divided in the categories, related to the high probability that the subject is:
    - falling to sleep;
    - waking up;
    - getting excited;
    - getting relaxed;
    - undergoing significant health condition, such as immediately preceding giving birth, characterized by the increased heartbeat and respiratory rates, e.g. in animals;
    - undergoing abnormal health condition, such as respiratory irregularities in sleep;
    - undergoing emergency health condition, such as abrupt abnormal change of the heartbeat and/or respiratory rates, e.g. in case of SIDS.

In entities **711** and **712** respective rates are compared with the set of previously detected values, or predefined thresholds, which are provided by entities **715** and **716**. All information is provided to the entity **720**. Entities **715** and **716** are updated with the new rates and corresponding rates of change. Entities **715** and **716** contain the history of the subject biomarkers information, particularly including:

- Rate information in specific predefined time steps;
- Averaged information of rate over at least one predefined period;
- Rate of change information in specific predefined time steps;
- Averaged information of rate of change over at least one predefined period;
- Comparison thresholds for rate;
- Comparison thresholds for rate of change.

Comparison thresholds may be predefined or statistically calculated based on the stored data.

In particular, the entities **715** and **716** have models and ranges for biomarkers rates and biomarkers rates of change, representing high probability of specific events.

Time information entity **717** is providing additional information to entity **720**, including current local time information, which is used in the event calculation.

Event calculation entity **720** is calculating the event score based on a weighted sum of the following information set:

- Heartbeat rate value reduced below calculated or predefined threshold.
- Rate of change of the heartbeat rate achieved calculated or predefined threshold.
- Respiratory rate value reduced below calculated or predefined threshold.
- Rate of change of the respiratory rate achieved calculated or predefined threshold.

- Duration of the continuous values above calculated or predefined thresholds.
- Part of the day: morning, daytime, evening, night, late night.

The weighting factors are predefined or determined based on the information set, predefined values and subject's behavior statistics. If the score is above the threshold, the appropriate event category is determined. This information is communicated to the entity **71**. Based on this information, the entity **71** is initiating predefined actions using entity **60** and/or entity **50** where optional audio and visual indication/alert capability is included.

These actions may be:

- Sending the heartbeat and/or respiratory related information such as:
  - Appearance or disappearance;
  - Rates;
  - Rates outside of the specified range;
  - Rate of change of the rates;
  - Rate of change of the rates outside of the specified range.
- Sending the corresponding time-stamp information.
- Activating audio and/or visual indication/alert functionality.

This information may be sent to:

- Cloud-based web service for vital signs monitoring;
- User mobile device, such as smart phone;
- Fixed monitoring infrastructure.

In Fig. 5 two antenna high-gain arrangements are shown. Systems **21** and **22** are on the left and right side of the integrated front end entity **10**. The arrangement 2 may be considered as the preferred embodiment, providing preferable tradeoff in size and performance, having the front size dimensions of the complete apparatus **100** of 4 x 2 cm or less for the 60 GHz ISM band operation. The antenna system is preferably realized as the planar printed dipoles with ellipsoid-like antenna shapes, with the two parts printed on the opposite sides of the dielectric layer, which also provides mechanical support. Prints on the opposite side of the dielectric are depicted using dashed lines in the Fig. 5. Cross section presented in Fig. 6 shows antenna printed on the opposite sides of the dielectric layer, as well as metalized reflector at the distance of approximately one quarter of the signal wavelength. The space between the reflector and the antenna may be empty or filled with foam. The antenna parts **21** and **22** are fed by the symmetrical lines printed on both sides of the dielectric approaching dipoles perpendicularly to their arrangement, as shown in the Fig. 5. Symmetrical strip line may be advantageously connected to differential mm-wave inputs and outputs of the entity **10** by using micro-vias produced by an advanced polymer technology. This is illustrated in of Fig. 6.

Supporting circuitry **50** as a part of the apparatus **100** may include loudspeaker and/or visual indication/alert functionality having plurality of possible realizations.

Alternatively instead of using two high gain antennas one for Tx **22** and one for Rx **21**, the proposed system may be realized by one high gain antenna for both Rx and Tx functionality, **24** like in Fig, 9a) and Fig. 9b) and isolator functionality **23**. This approach has several system disadvantages of the difficult practical realization of the entity **23** providing sufficient isolation between Rx and TX inputs of the entity **10**. Also entity **23** inherently includes unwanted signal attenuation of the TX signal toward antenna and received signal from antenna toward the RX input of the entity **10**. This imposes more power consumption of the system, more thermal dissipation, and more system cost on isolator entity **23** realization. Entity **23** could be preferably realized by rat race planner coupler structures, also on the IC level within the entity **10** or on the PCB level, where the entity **10** is assembled in the

Apparatus **100**. The only potential system related sensor advantage would be the reduced size of the apparatus **100**, where the one planar high gain antenna would need to be integrated instead of two.

The usage of the IQ demodulator instead of signal mixer in entity **10**, would provide the two analog baseband down converted quadrature signals to the entity **30**. Having two signals in the signal processing path additional information about phase changes between two signal may be used. This may increase the accuracy in the digital signal processing and some redundancy, by the expense of the more chip size of entity **10** and more processing efforts of the entity **40**. The method of operation may use the straight forward information obtained from the one down conversion chain from I or from Q chain, and do not process the information from other chain, as long there is no need in more accurate information extraction. The existence of the both chains, with 90 degrees moved zero crossings, may have practical advantages. By evaluating the phase changes of the IQ signals, with the typical accuracy of 1-2 degrees resolution, micro movements of the objects may be evaluated with more accuracy, within one wave length typically in µm region. This may increase the capability of the frequency extraction.

Claim 1: Mm-wave Radar Driver Vital Signs Sensor Apparatus and Method of Operation **100,** where mm-wave declares operation between 30 and 300 GHz, is including:

1. High-gain planar antenna for transmitting mm-wave radio signals **22**, where the high-gain planar antenna has at least two radiation elements;
2. High-gain planar antenna for receiving mm-wave radio signals **21**, where the high-gain planar antenna has at least two radiation elements;
3. Integrated mm-wave radio front end **10**, implemented in arbitrary semiconductor technology, having on-chip integrated mm-wave voltage controlled oscillator, mm-wave power amplifier, mm-wave low noise amplifier, mm-wave down conversion mixer, digital control interface, power supply circuitry and PLL;
4. Analog to digital conversion entity **30**;
5. Digital processing functionality **40** including controlling functionality **41** and calculation and memory capacity for performing digital signal processing by arbitrary type of the realization options;
6. Supporting circuitry **50**, including mechanical interface to the environment and supporting power supply related circuitry.

where apparatus **100** is integrated in the baby incubator, facing the baby, which is the subject under observation, with a direct line-of-sight operation and where Method of Operation includes:

- Transmission of mm-wave signals generated in **10** using **22**;
- Receiving mm-wave signals reflected from subject's body using **21**;
- Amplification of the reflected signal in **10**;
- Down-conversion of the signals by mixing with the same signal of the same frequency as the transmitted signal in **10**;
- Amplification of the converted signal after mixer in **10**;
- Analog filtering of the signals after amplification in **10**;
- Signal conditioning in **10** for subsequent analog to digital conversion performed by **30**;
- Digital processing of the signal in **40**, by:
    - Extracting the heartbeat rate from the previous arbitrary processed signal;
    - Extracting the rate of change of the heartbeat rate from the previous arbitrary processed signal;
    - Extracting the respiratory rate from the previous arbitrary processed signal;
    - Extracting the rate of change of the respiratory rate from the previous arbitrary processed signal;
    - Digital processing in vital signs event decision functionality **70** which includes the following steps:
        - Evaluation if the heartbeat rate is within the specified range **711**;
        - Evaluation if the respiratory rate is within the specified range **712**;
        - Evaluation if the rate of change of the heartbeat rate is within specified range **713**;
        - Evaluation if the rate of change of the respiratory rate is within specified range **714**;
        - Statistical evaluation of the subject's heartbeat rate data history **715**;
        - Statistical evaluation of the subject's respiratory rate data history **716**;
        - Provision of the current heartbeat rate by the entity **711** and the current rate of change of the heartbeat rate by the entity **713** to the subject's statistical heartbeat rate model entity **715**;
        - Provision of the current respiratory rate by the entity **716** and the current rate of change of the respiratory rate by the entity **713** to the subject's statistical respiratory rate model entity **716**;
        - Digital processing in vital signs event calculation decision functionality **720** is performed, which:

- Calculates the score by processing the information provided through entities **711–717** weighted by the specified coefficients, where the score is related to the probability of the corresponding vital signs event;
- In case that the calculated score is above predefined threshold, decision on positive vital signs event is made;
- In case of the positive vital signs event the entity **720** sends the decision information and the corresponding score to the entity **71**;
- In case of the positive vital signs event the entity **71** initiates appropriate specified actions of the entity **60** and/or entity **50**.

where the vital signs event is: the stop of the subject's vital activity.

Claim 2: System according to Claim 1, in which the apparatus **100** is mechanically attached to the baby bed, instead of being integrated in baby incubator.

Claim 3: System according to Claim 1, in which the apparatus **100** is mechanically attached to the baby carriage, instead of being integrated in baby incubator.

Claim 4: System according to Claim 1, in which the apparatus **100** is mechanically attached to the patient bed in medical care environment, instead of being integrated in baby incubator, and where the complete method of operation is related to the patient as the subject under observation.

Claim 5: System according to Claim 1, in which apparatus **100** is positioned in the area in which the subject under observation resides, instead of being integrated in baby incubator, and where the complete method of operation is related to the subject under observation.

Claim 6: System according to Claim 1, in which the apparatus **100** is mechanically attached to an exercise machine, instead of being integrated in baby incubator, and where the complete method of operation is related to the person using the exercise machine as the subject under observation.

Claim 7: System according to Claim 1, in which the apparatus **100** is positioned in the area in which the animal under observation resides, instead of being integrated in baby incubator, and where the complete method of operation is related to the animal as the subject under observation.

Claim 8: System according to Claims 1 to 7, where the vital signs event is: change of the subject's vital signs.

Claim 9: System according to Claims 1 to 7, where the vital signs event is: change pattern of the vital signs of the subject under observation, where the pattern is defined by the:

a) specific value thresholds,

b) specific rate of change value thresholds,

where each is in specific time window.

Claim 10: System according to Claims 1 to 9, where wireless interface **63**, which implements one or more than one wireless communication standards, is part of the Apparatus **100**;

Claim 11: System according to Claim 10, where wireless interface **63**, which implements one or more than one wireless communication standards, is used for communication with the user's mobile device.

Claim 12: System according to Claim 10, where wireless interface **63**, which implements one or more than one wireless communication standards, is used for communication with cloud-based web service application.

Claim 13: System according to Claim 10 where wireless interface **63**, which implements one or more than one wireless communication standards, is used for communication with the health related emergency service.

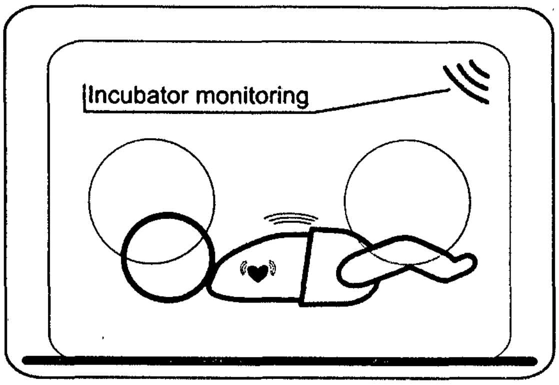
Claim 14: System according to previous Claims, in which the supporting circuitry **50** contains audio and/or visual alerting capabilities of arbitrary realization, which are activated in case the vital signs event is detected by the entity **71**.

Claim 15: System according to previous Claims, in which the mm-wave frequency is within 60 GHz ISM band.

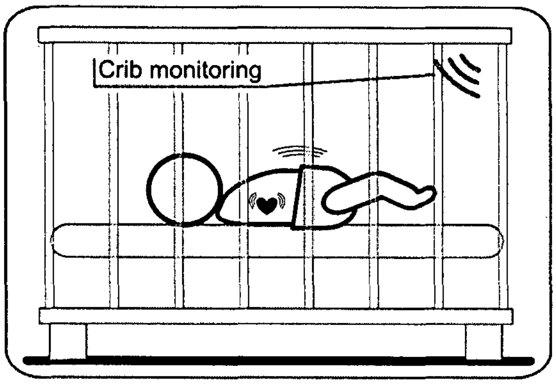
Claim 16. System according to previous Claims, in which the sensor apparatus and method of operation **100** has only one high gain antenna for transmitting and receiving mm-wave radio signals **24**, where the high-gain planar antenna has at least two radiation elements and isolator functionality **23** being released by plurality of the realization option, providing isolation between Rx and Tx chains, and related Rx and Tx connection to high gain antenna 24.

Claim 17. System according to previous Claims, in which the sensor apparatus and method of operation **100** has entity **10** having instead of mm-wave down conversion mixer, the IQ Demodulator, and two signal conditioning chains instead of one.

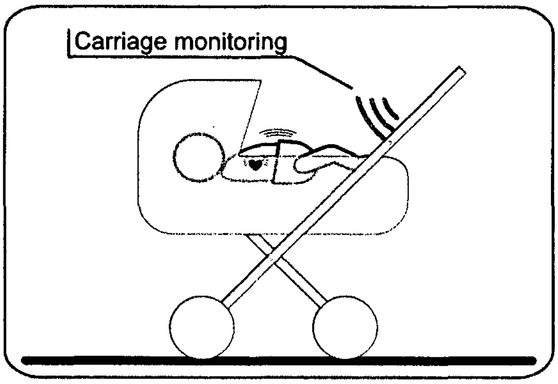
Drawings



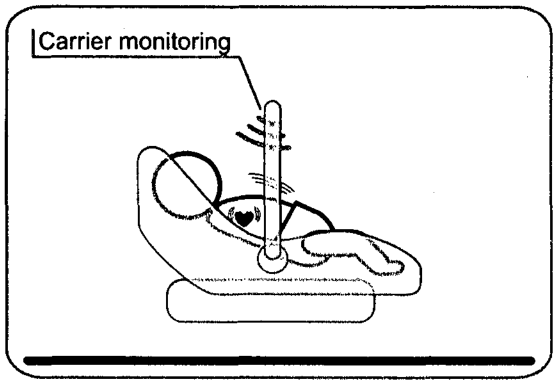
Baby in Incubator



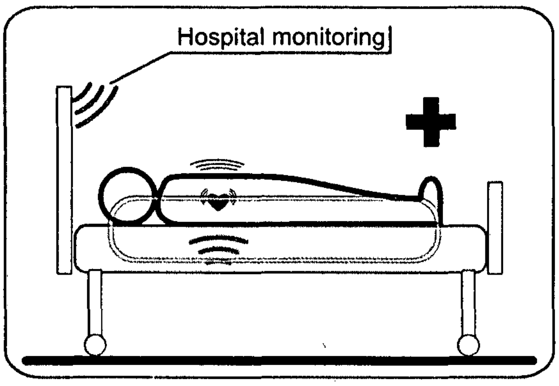
Baby in Crib



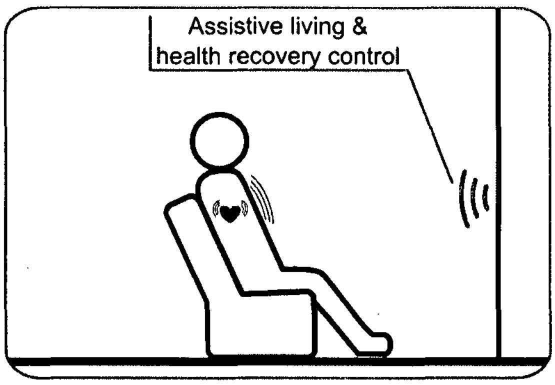
Baby in Carriage



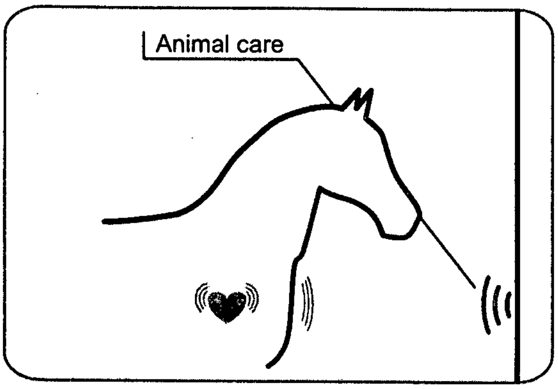
Baby in Carrier



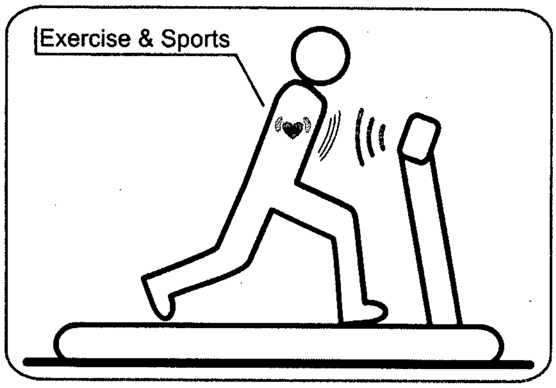
Patient in Hospital



Assistive living &
health recovery control



Animal care



Exercise & Sports

Fig. 1

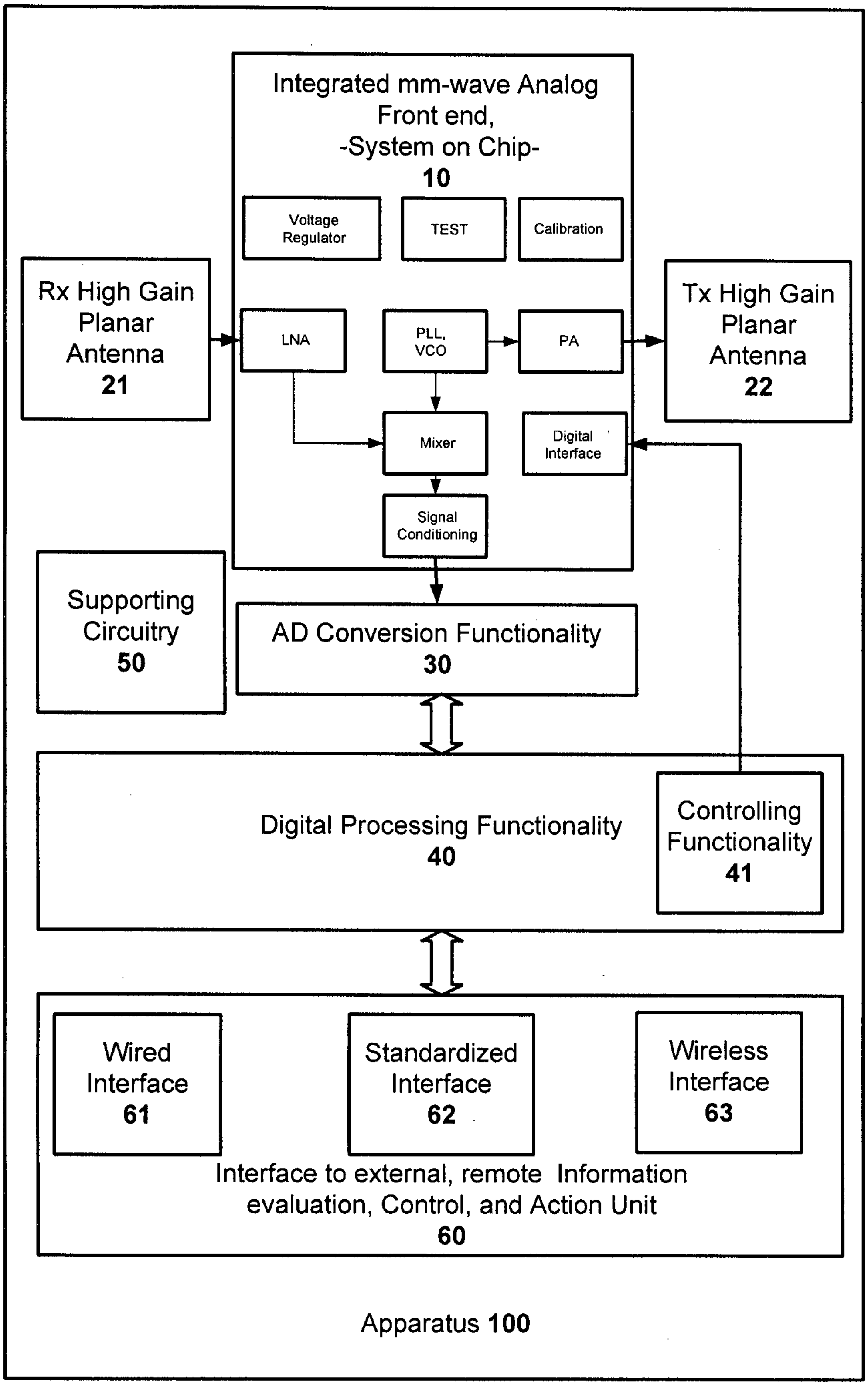

Integrated mm-wave Analog Front end, -System on Chip- 10
Voltage Regulator
TEST
Calibration
Rx High Gain Planar Antenna 21
LNA
PLL, VCO
PA
Tx High Gain Planar Antenna 22
Mixer
Digital Interface
Signal Conditioning
Supporting Circuitry 50
AD Conversion Functionality 30
Digital Processing Functionality 40
Controlling Functionality 41
Wired Interface 61
Standardized Interface 62
Wireless Interface 63
Interface to external, remote Information evaluation, Control, and Action Unit 60
Apparatus 100

Fig. 2

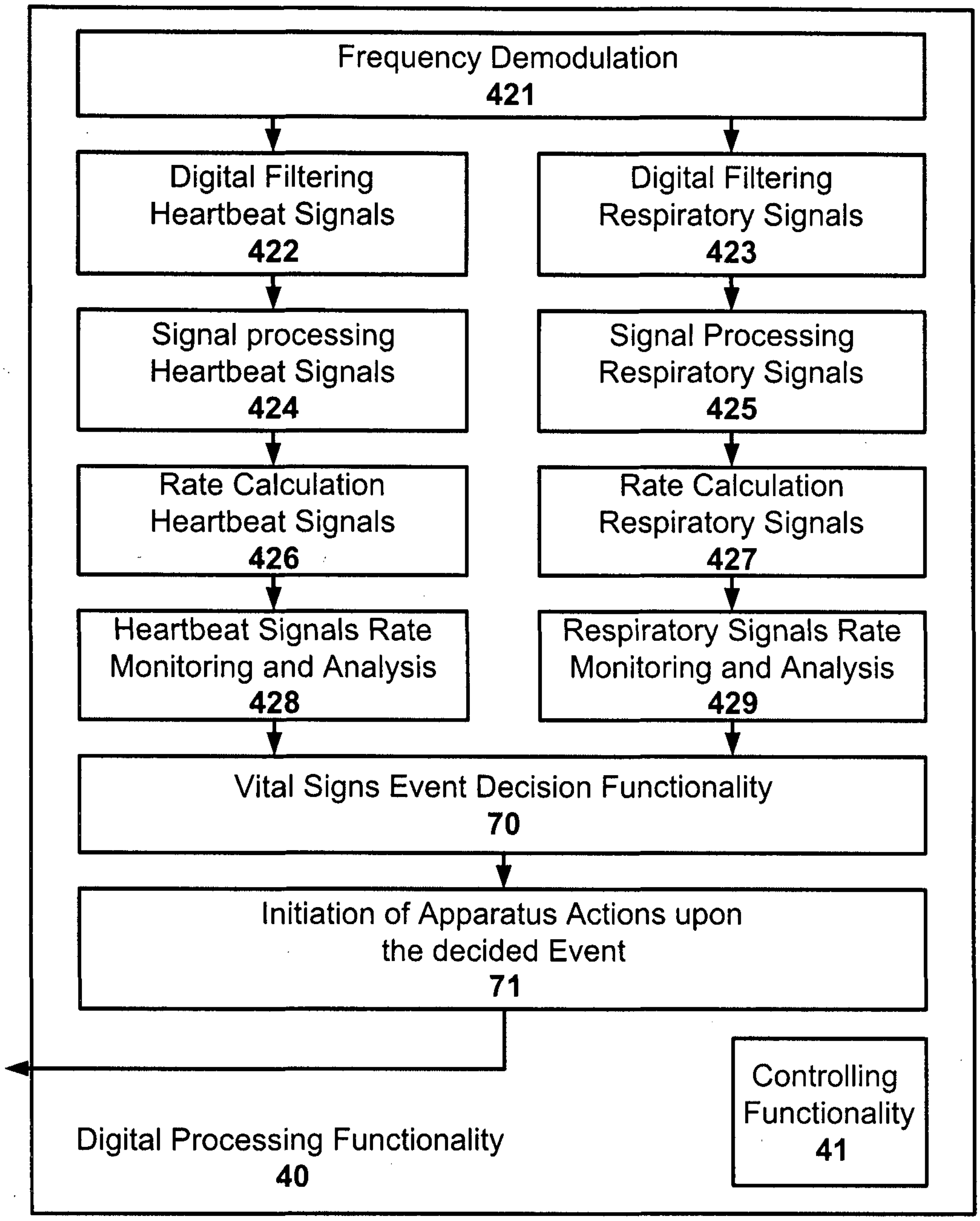

Frequency Demodulation
421
Digital Filtering
Heartbeat Signals
422
Digital Filtering
Respiratory Signals
423
Signal processing
Heartbeat Signals
424
Signal Processing
Respiratory Signals
425
Rate Calculation
Heartbeat Signals
426
Rate Calculation
Respiratory Signals
427
Heartbeat Signals Rate
Monitoring and Analysis
428
Respiratory Signals Rate
Monitoring and Analysis
429
Vital Signs Event Decision Functionality
70
Initiation of Apparatus Actions upon
the decided Event
71
Controlling
Functionality
41
Digital Processing Functionality
40

Fig. 3

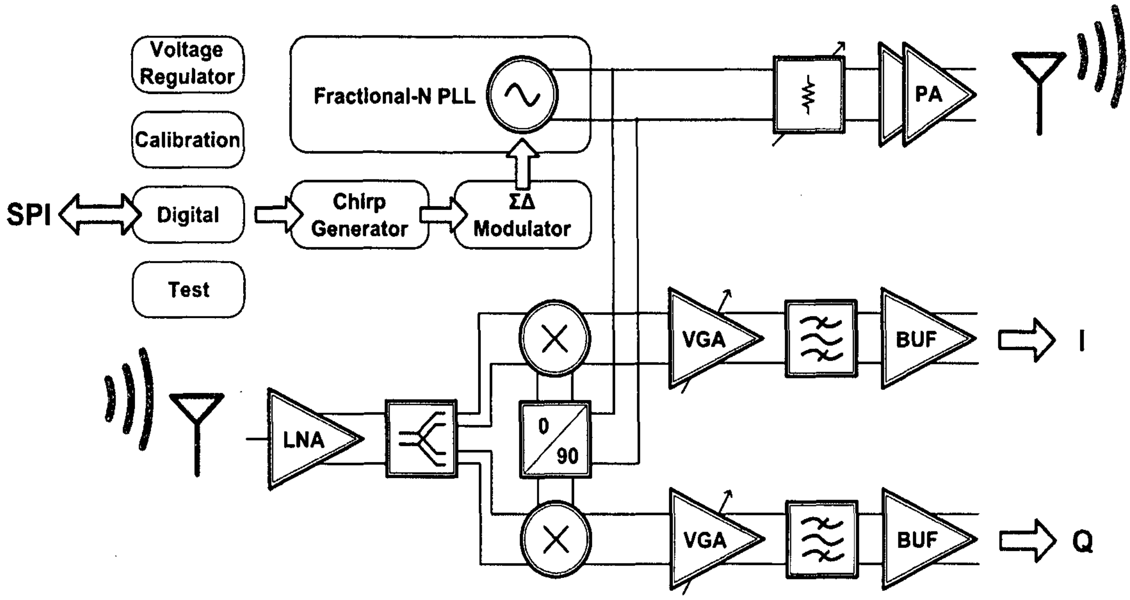
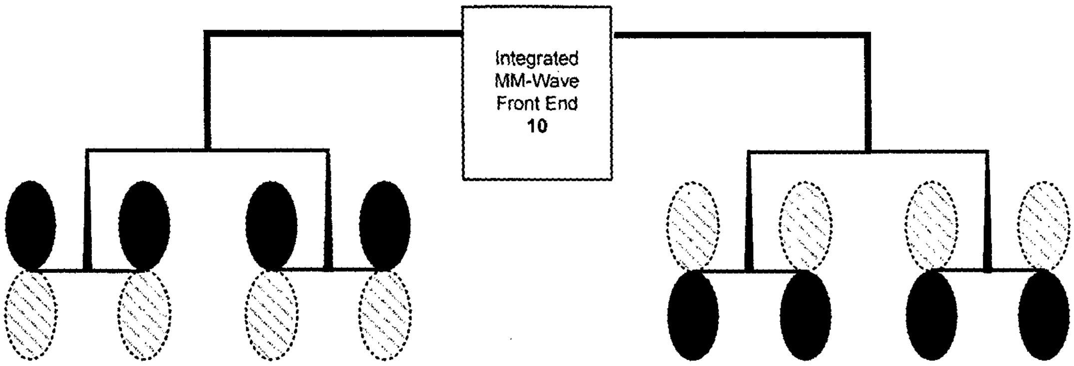
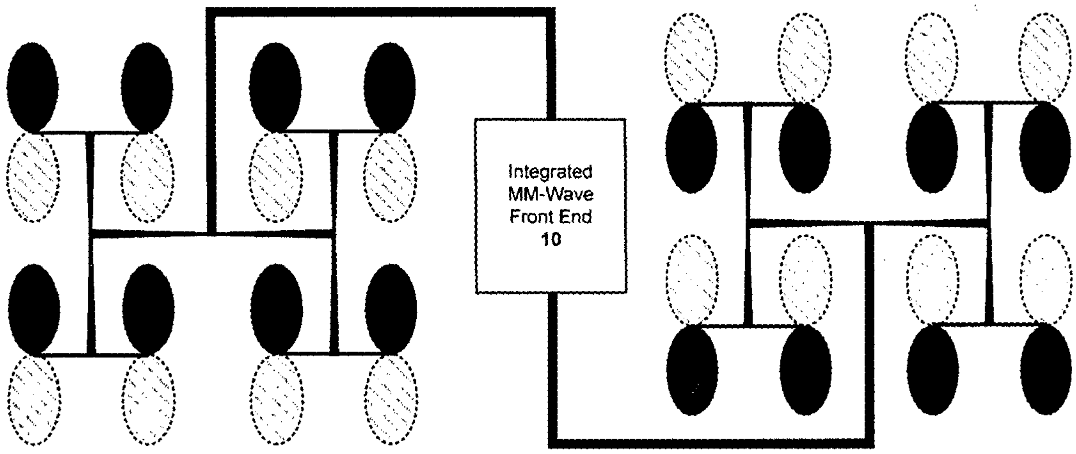

Voltage Regulator
Calibration
SPI
Digital
Test
Fractional-N PLL
Chirp Generator
ΣΔ Modulator
PA
VGA
BUF
I
LNA
0
90
VGA
BUF
Q

Fig. 4

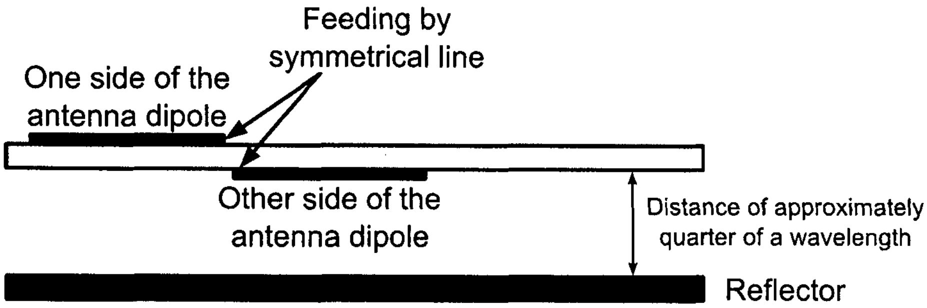


Arrangement 1

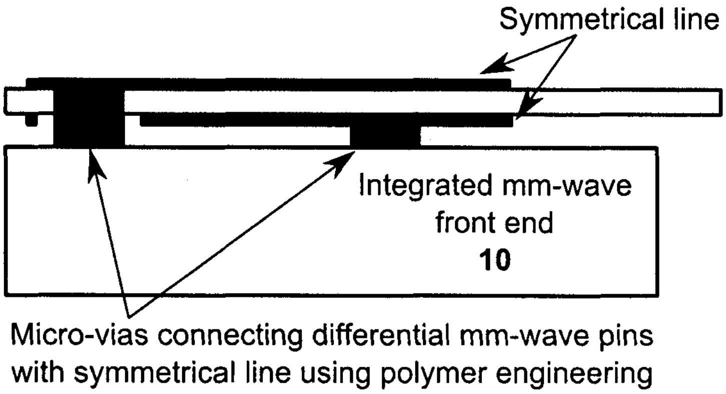


Arrangement 2

Fig. 5



Dipoles, arrangement and reflector



Chip connection without bond wires

Fig. 6

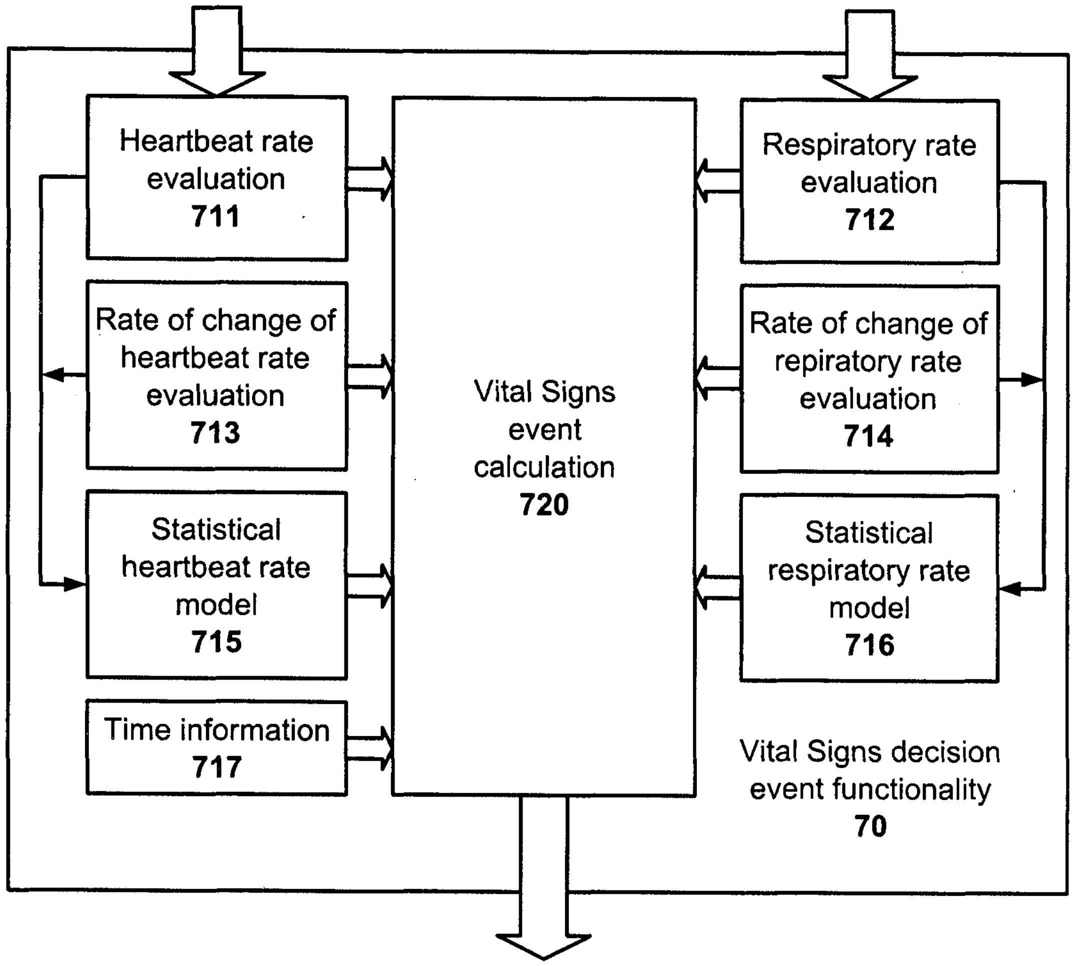
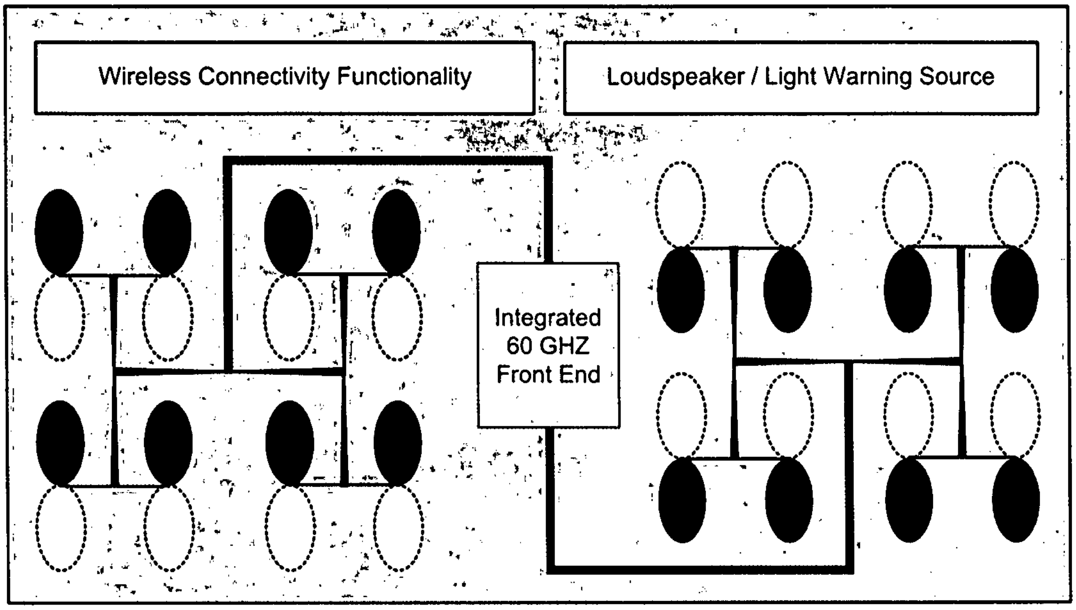
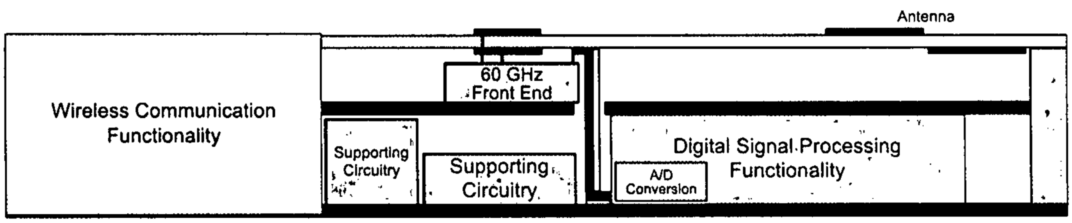

Heartbeat rate evaluation
711
Rate of change of heartbeat rate evaluation
713
Statistical heartbeat rate model
715
Time information
717
Vital Signs event calculation
720
Respiratory rate evaluation
712
Rate of change of repiratory rate evaluation
714
Statistical respiratory rate model
716
Vital Signs decision event functionality
70

Fig. 7



Possible Sensor Module Front Functional Topology



Possible Sensor Module Lateral Functional Topology

Fig. 8

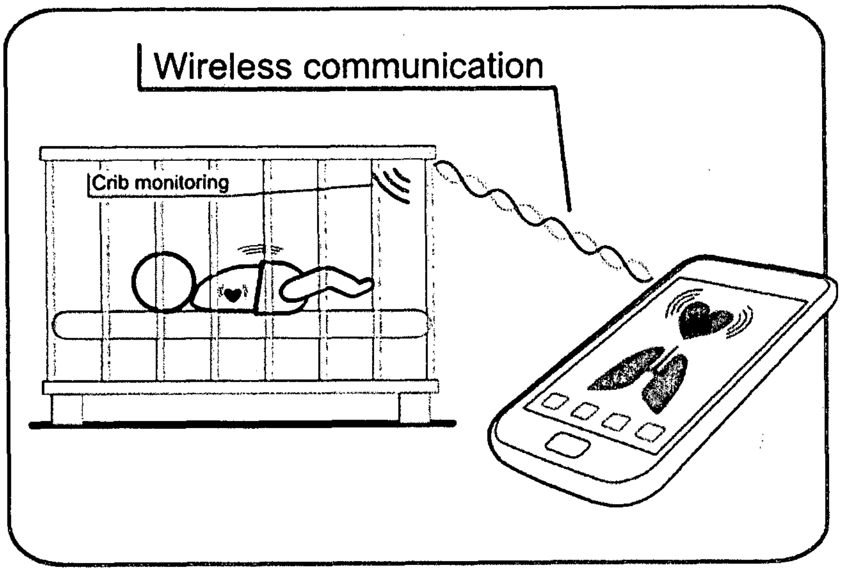


Fig. 9

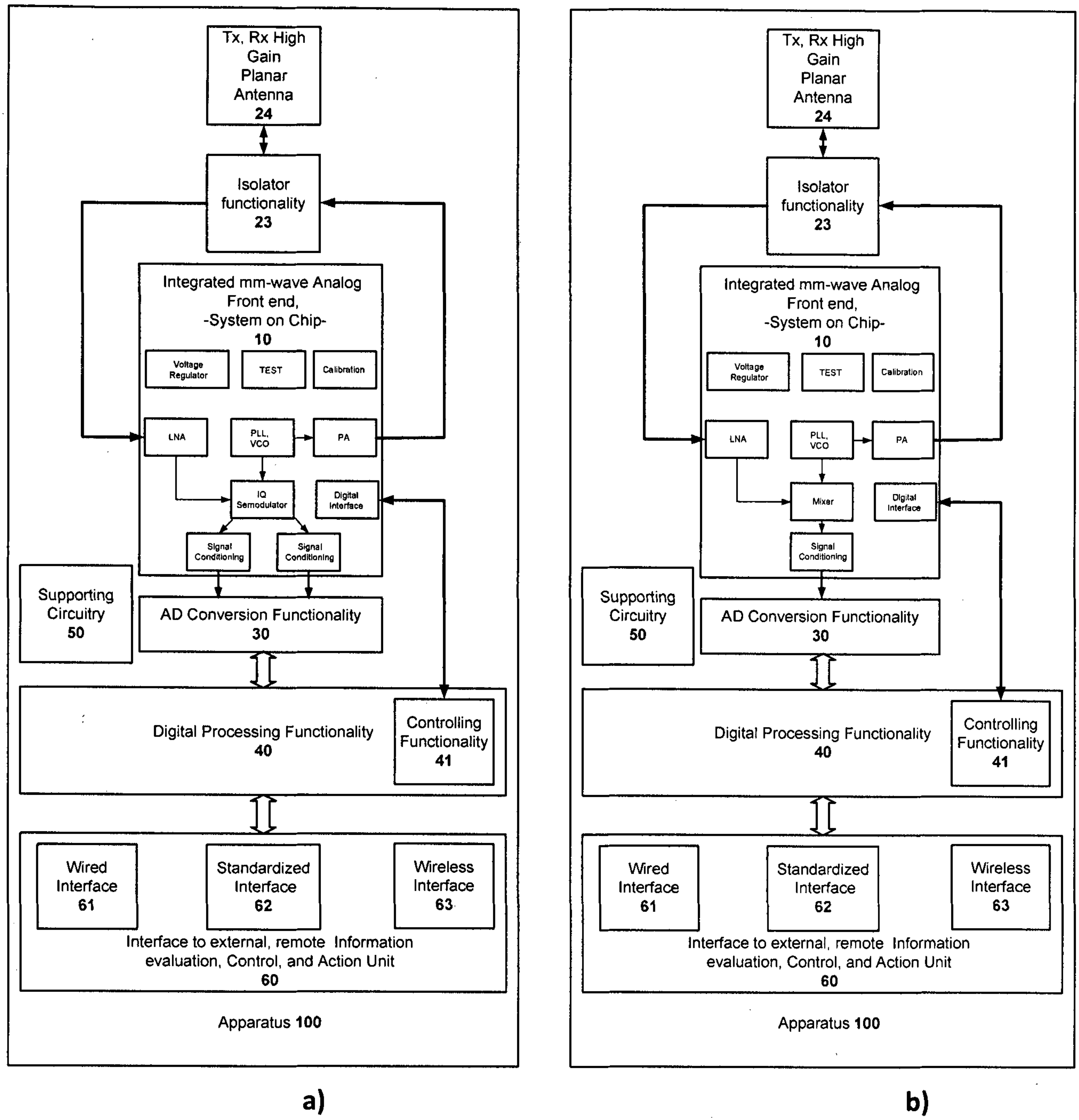

Tx, Rx High Gain Planar Antenna 24
Isolator functionality 23
Integrated mm-wave Analog Front end, -System on Chip- 10
Voltage Regulator
TEST
Calibration
LNA
PLL, VCO
PA
IQ Semodulator
Digital Interface
Signal Conditioning
Signal Conditioning
Supporting Circuitry 50
AD Conversion Functionality 30
Digital Processing Functionality 40
Controlling Functionality 41
Wired Interface 61
Standardized Interface 62
Wireless Interface 63
Interface to external, remote Information evaluation, Control, and Action Unit 60
Apparatus 100
a)
Tx, Rx High Gain Planar Antenna 24
Isolator functionality 23
Integrated mm-wave Analog Front end, -System on Chip- 10
Voltage Regulator
TEST
Calibration
LNA
PLL, VCO
PA
Mixer
Digital Interface
Signal Conditioning
Supporting Circuitry 50
AD Conversion Functionality 30
Digital Processing Functionality 40
Controlling Functionality 41
Wired Interface 61
Standardized Interface 62
Wireless Interface 63
Interface to external, remote Information evaluation, Control, and Action Unit 60
Apparatus 100
b)

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/RS2015/000011

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S7/00 G01S7/03 G01S7/35 G01S7/41 G01S13/58
G01S13/88
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)
G01S

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/146796 A1 (MARGON KENNETH [MY] ET AL) 14 June 2012 (2012-06-14) figures 1,2,20,21 abstract paragraphs [0003], [0009], [0047], [0055], [0074] - [0076] -----	1-17
X	US 2010/152600 A1 (DROITCOUR AMY [US] ET AL) 17 June 2010 (2010-06-17) figures 1A,2,4,6C,25A,28-30 abstract paragraphs [0215], [0247] ----- -/--	1-17

[X] Further documents are listed in the continuation of Box C.

[X] 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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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	Date of mailing of the international search report
2 September 2015	10/09/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Alberga, Vito

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/101343 A1 (WIRELESS 2000 RF & UWB TECHNOL [CA]; FOO SENGLEE [CA]) 13 September 2007 (2007-09-13) figures 1,5 abstract paragraphs [0017] - [0019] -----	1-17
X	US 3 796 208 A (BLOICE J) 12 March 1974 (1974-03-12) cited in the application figures 1-4 abstract column 3, line 43 - line 48 column 8, line 48 - line 50 -----	1-17

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/RS2015/000011

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012146796 A1	14-06-2012	NONE	
US 2010152600 A1	17-06-2010	US 2010152600 A1	17-06-2010
		US 2010240999 A1	23-09-2010
		US 2010249630 A1	30-09-2010
		US 2010249633 A1	30-09-2010
		US 2010292568 A1	18-11-2010
		WO 2010132850 A1	18-11-2010
WO 2007101343 A1	13-09-2007	CN 101437442 A	20-05-2009
		CN 102512148 A	27-06-2012
		EP 1996068 A1	03-12-2008
		HK 1130417 A1	14-09-2012
		JP 5312053 B2	09-10-2013
		JP 2009528859 A	13-08-2009
		KR 20080106465 A	05-12-2008
		US 2009227882 A1	10-09-2009
		US 2014070958 A1	13-03-2014
		US 2015141794 A1	21-05-2015
		WO 2007101343 A1	13-09-2007
US 3796208 A	12-03-1974	DE 2205411 A1	15-03-1973
		FR 2141047 A5	19-01-1973
		GB 1378754 A	27-12-1974
		US 3796208 A	12-03-1974