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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 December 2014 (24.12.2014)

(10) International Publication Number
WO 2014/202112 A1

(51) International Patent Classification:
H03F 1/30 (2006.01) *H03F 1/02* (2006.01)
H03F 3/189 (2006.01) *H03F 1/32* (2006.01)
H03F 3/24 (2006.01)

(21) International Application Number: PCT/EP2013/062505

(22) International Filing Date: 17 June 2013 (17.06.2013)

(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).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: A RADIO TRANSMITTER WITH AMPLIFIER PATHS HAVING OUT-PHASED RADIO FREQUENCY SIGNALS

(57) **Abstract**: There is provided receiving two out-phased radio frequency signals from corresponding amplifier paths of a radio transmitter, and determining a filter for at least one of the amplifier paths, wherein the filter is arranged to minimize a minimum square error of the difference of the combined radio frequency signals.

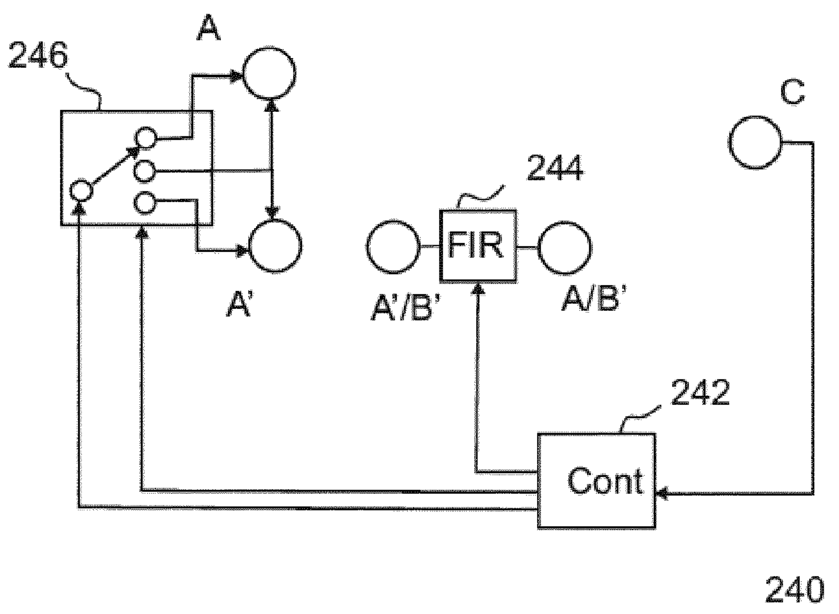

Fig. 2d

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A RADIO TRANSMITTER WITH AMPLIFIER PATHS HAVING OUT-PHASED RADIO FREQUENCY SIGNALS

FIELD

The present invention relates to a radio transmitter and more particularly to amplifier paths having out-phased radio frequency signals.

BACKGROUND

The following description of background art may include insights, discoveries, understandings or disclosures, or associations together with disclosures not known to the relevant art prior to the present invention but provided by the invention. Some such contributions of the invention may be specifically pointed out below, whereas other such contributions of the invention will be apparent from their context.

In a modern Base Station (BS), a Radio Frequency (RF) Power Amplifier (PA) is the biggest heat generating part. Development of the wireless communications networks introduces smaller cell sizes that are increasingly deployed indoor scenarios. In indoor scenarios sufficient cooling for the BSs has to be provided to facilitate maintaining operational temperatures of the BSs within acceptable limits. On the other hand, heat generated by the BSs increases the indoor temperature. The heat radiation from the BSs may cause the indoor temperature of a building to exceed its limits set e.g. according to structural requirements or health requirements.

Out-phased power amplifiers have been known as a concept for a long time as an approach for the simultaneous realization of high-efficiency and high-linearity in amplification of radio frequency transmissions. The concept has been revived recently for wireless communication applications under the rubric of LInear amplification with Nonlinear Components (LINC).

The LINC concept takes an envelope modulated band pass waveform and resolves it into two out-phased constant envelope signals, which are applied to highly efficient—and highly nonlinear—power amplifiers, whose outputs are summed.

One of the major disadvantages of this technique is the extremely tight tolerance on the matching of the two amplifier paths to achieve acceptably small out-of-band rejection. The out-of-band spectrum, created by the incomplete cancellation of the quadrature signal, strongly depends upon the modulation schemes.

SUMMARY

The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to a more detailed description that is presented later.

Various embodiments comprise method(s), apparatus(es), a computer program product and a system as defined in the independent claims. Further embodiments are disclosed in the dependent claims.

According to an aspect of the invention there is provided a method comprising receiving two out-phased radio frequency signals from corresponding amplifier paths of a radio transmitter, and determining a filter for at least one of the amplifier paths, wherein the filter is arranged to minimize a minimum square error of the difference of the combined radio frequency signals.

According to an aspect there is provided an apparatus comprising means configured to perform a method according to an aspect.

According to an aspect there is provided an apparatus comprising a receiver circuitry to receive two out-phased radio frequency signals from corresponding amplifier paths of a radio transmitter, and a controller to determine a filter for at least one of the amplifier paths, wherein the filter is arranged to minimize a minimum square error of the difference of the combined radio frequency signals.

According to an aspect there is provided a computer program product comprising executable code that when executed, cause execution of functions of a method according to an aspect.

According to an aspect there is provided a communications system comprising one or more apparatuses according to an aspect.

According to another aspect of the invention there is provided an arrangement comprising at least one processor, and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to perform a method according to an aspect.

Although the various aspects, embodiments and features of the invention are recited independently, it should be appreciated that all combinations of the various aspects, embodiments and features of the invention are possible and within the scope of the present invention as claimed.

Some embodiments may provide improvements comprising aligning outputs of non-linear power amplifiers.

Further advantages will become apparent from the accompanying description.

BRIEF DESCRIPTION OF THE FIGURES

In the following the invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings, in which

Figure 1 illustrates an arrangement for wireless communications according to an embodiment;

Figure 2a illustrates a block diagram of an apparatus having two amplifier paths including non-linear amplifiers according to an embodiment;

Figures 2b, 2c and 2d illustrate block diagrams of apparatuses for aligning the outputs of amplifier paths according to an embodiment;

Figure 3 illustrates a process of aligning amplifier paths including non-linear amplifiers; and

Figure 4 illustrates a process of defining a filter for an amplifier path of two amplifier paths including non-linear amplifiers, according to an embodiment.

DETAILED DESCRIPTION OF SOME EMBODIMENTS

In the following, out-phased radio frequency signals are used to refer to radio frequency signals that have constant envelopes. The out-phased radio frequency signals have different phases. The out-phased radio frequency signals may be generated from a received radio frequency signal. The amplitude of the received radio frequency signal is used to modulate phases of the out-phased radio frequency signals. In one example two out-phased radio frequency signals may be defined by $S_1(t)=V_m\exp[j\{\theta(t) + \psi(t)\}]$ and $S_2(t)=V_m\exp[-j\{\theta(t) + \psi(t)\}]$, where the $\theta(t)$ denotes phase of the received radio frequency signal, V_m the constant amplitude and $\psi(t)$ the phase modulation. The phase modulation is applied to the out-phased signals with a different sign, whereby the $S_1(t)$ and $S_2(t)$ are out-phased.

In the following embodiments, amplifier paths may comprise non-linear power amplifiers, e.g. in the LINC concept. Typically the power amplifiers are of the same type and have the same operational characteristics, for example the same frequency response.

In the following embodiments outputs of amplifier paths are aligned. The aligning is performed using a filter that processes a radio frequency signal an amplifier path.

Figure 1 illustrates an arrangement 100 for wireless communications according to an embodiment. In the illustration, the arrangement comprises a device 102 including a communications unit 104 for communicating over a wireless medium. The communications may include wireless transmissions from the device to another device, for example between a User Equipment (UE) a base station and/or between two UE. Accordingly, the device is arranged to operate as a transmitter on the wireless medium. For this purpose the device may implement a transmitter unit that communicates data, messages and/or signalling to the wireless medium. The wireless medium may comprise a radio frequency band, where transmissions are communicated between the transmitter and the receiver by using radio frequency signals. The transmitter unit operations may be implemented by hardware or software or a combination of hardware and software. The device may further comprise a receiver unit, as is conventional in many communications devices that are examples of the arrangement, including UE, a base station and a mobile phone.

The functionality of the device may be achieved by the communicating devices implementing one or more entities of a common communications protocol. The common communications protocol may be implemented by structural parts, for example the transmitter having radio frequency parts that are operative on the frequency band used for the communications. Examples of the radio frequency parts include antennas, and modulation and demodulation circuits.

A common communications protocol between the devices may be implemented at the devices by instructions, for example a computer program code, that are executable by a processor so that data, messages and/or signalling can be encoded according to a communications protocol at the transmitter and decoded according to the communications protocol at the receiver. The instructions may be stored in a memory. The communications device may include a processing unit that may execute the instructions.

Figures 2a, 2b, 2c and 2d illustrate block diagrams of apparatuses, for example the apparatus of Figure 1, where only those parts of the apparatus are illustrated that are necessary for understanding the embodiments.

Figure 2a illustrates a block diagram of an apparatus 200 having two amplifier paths including non-linear amplifiers according to an embodiment. The apparatus may conform to the LINC concept, for example. The apparatus comprises a signal separation unit 202 and two amplifier paths 204, 206 between the signal separation unit and a combiner 208. The signal separation receives a signal $S_{in}(t)$ to be transmitted. The signal may comprise a baseband signal, whereby the signal separation unit modulates the received signal into a frequency band used for transmissions. The received signal may also comprise a radio frequency signal on a transmission frequency band of the apparatus. The signal separation unit outputs out-phased radio frequency signals $S_1(t)$, $S_2(t)$ on the two amplifiers paths. The amplifier paths include non-linear power amplifiers 210, 212 that amplify the out-phased radio frequency signals received from the signal separation unit. The amplifiers output amplified radio frequency signals that are combined in the combiner, for example by summing the radio frequency signals. The combiner outputs a combination $S_{out}(t)$ of the amplified out-phased signals for transmission on the transmission frequency band.

Figures 2b, 2c and 2d illustrate block diagrams of apparatuses 220, 230, 240 for aligning the outputs of amplifier paths according to an embodiment. The apparatuses may be connected to an apparatus having two amplifier paths including non-linear amplifiers, for example the apparatus in Figure 2a. Connection points for connecting the apparatuses of Figures 2b, 2c and 2d to the apparatus of Figure 2a are shown by corresponding reference points A, A', B, B', and C in the Figures.

The apparatuses described in Figures Figure 2b, 2c and 2d comprise a controller 222, 232, 242, a filter 224, 234, 244 and a switch 226, 236, 246. The apparatuses connect to the amplifier paths at the reference points indicated in the Figures. The switch is connected to the reference points A and A' in the amplifier paths.

In Figure 2b, the apparatus connects the filter 224 at the reference point A', that is before the power amplifier in the amplifier path. The controller is connected to the amplifier paths at reference points B and B', i.e. after the power amplifiers and before the combiner.

In Figure 2c, the apparatus connects the filter 234 at the reference point B', that is after the power amplifier in the amplifier path and before the combiner. The controller is connected to the amplifier paths at reference points B and B' after the power amplifiers and before the combiner.

In Figure 2d, the apparatus connects the filter according to the amplifier paths as described in Figures 2b or 2d. The controller is connected to the reference point C that is after the combiner.

Accordingly, in Figures 2b, 2c and 2d the he controller receives an output of the filter connected to the amplifier path and a non-filtered signal from the amplifier paths that is not filtered by the filter. The received signals from the two amplifier paths comprise two amplified out-phased radio frequency signals from corresponding amplifier paths of a radio transmitter as in Figures 2b and 2c or a combination of the amplified out-phased radio frequency signals from the combiner output C as in Figure 2d. The filtering may be performed before or after the amplification. When the filtering is performed before amplification the filter may be defined so that the amplification performed on the filtered signal provides an amplified signal that is aligned with the amplified signal on the amplifier path that does not have a filter. Accordingly, by filtering before the amplification the filtered signal may be adapted to the characteristics of the amplifier. When the filtering is performed after the amplification, the filtering corrects the amplified signal towards the amplified signal on the amplifier path that does not have a filter on the amplifier path. In this way the filter adapts the amplified signal to the signal of the other amplifier path. The controller connects to the filter to control characteristics of the filter, for example coefficients of the filter, which define the impulse response of the filter. The controlling of the filter may comprise calculating a minimum square error of the difference of the combined radio frequency signals.

Typically the Power Amplifiers (PAs) are analogue devices having non-linear operational characteristics. Accordingly, the input and output to a power amplifier may be analogue signals. For this purpose the controller 222, 232, 242 may include an Analogue to Digital (A/D) conversion circuitry that converts the analogue radio frequency signals received from the connection points to digital form to be processed and a Digital to Analogue Conversion (D/A) circuitry that converts digital signals to analogue form to be fed to the amplifier paths via the switch 226.The A/D and/or D/A conversion circuitry operate using a sampling rate that is preferably sufficient to include the signal inside the frequency band of transmission, where the PAs operate.

The filter may comprise for example a digital Finite Impulse Response (FIR) filter. Then the filter connected by the connection points before or after the PA in an amplifier path may be equipped with an A/D circuitry at its input and a D/A circuitry at its output.

The controller connects to the switch by a control signal and by a test signal. The control signal switches the test signal to connect to one amplifier path at a time or to both amplifier paths at a time. In this way the test signal may be fed to the amplifier paths simultaneously or one test signal at a time.

It should be appreciated that the blocks of the apparatuses in Figures 1, 2a, 2b, 2c and 2d illustrate logical blocks and the actual physical implementation may be different. The logical blocks may be implemented by hardware, software and/or a combination of hardware and software entities.

It should be appreciated that the apparatuses illustrated in Figures 2b, 2c and 2d may be connected with a communications device, for example a mobile phone and a base station. The apparatus may be included for example within such a communications device and connected to a communications circuitry therein.

Figure 3 illustrates a process of aligning amplifier paths including non-linear amplifiers. The process may be executed by the apparatuses of Figures 2b, 2c or 2d, when the apparatus is connected to amplifier paths of a radio transmitter, for example a radio transmitter illustrated in Figure 2a. The process starts 302, when the radio transmitter is switched on and generates out-phased frequency signals to be amplified by the PAs.

In 304 amplifier paths of the radio transmitter are calibrated with each other. In the calibration a Minimum Mean Square Error (MMSE) of the difference of the combined radio frequency signals is minimized. A filter is connected to one of the amplifier paths. The filter may comprise, for example a digital FIR filter, that is adjusted by the calibration. The calibration may be performed preceding the actual transmission of data on a radio frequency.

In 306, the calibrated radio frequency signals are output for transmission by the radio transmitter. the radio frequency signals may now include the actual data communicated on the transmission radio frequency.

In 308, the amplifier paths are aligned and the process ends. It should be appreciated that the above process may be repeated, so that the amplifier paths may be kept aligned. The alignment may be changed for example due to changes in operational temperature of the amplifiers.

In an embodiment, the calibration step 304 is repeated on the basis of the minimum square error of the difference of the combined radio frequency signals exceeding a threshold. Accordingly, the MMSE may be calculated during use of the radio transmitter after the calibration process has adjusted the FIR filter using test signals specific for the calibration. Then, when the MMSE exceeds a threshold, the calibration process in step 304 may be performed again to adjust the filter. In this way, the outputs of the amplifier paths may be kept aligned after an initial calibration. In the calibration process performed after the initial calibration, the actual transmitted data may be used for the calibration. After initial calibration, the filter coefficients can be updated on the basis of the observed outputs from reference points B and B' or C. Thereby, tests signals are not needed after the initial calibration. In this way the initial calibration may be maintained during the actual operation of communications between the devices.

It should be appreciated that the test signals used in the initial calibration may not necessarily be transmitted on the radio frequency. In this way interference generated by the apparatus may be reduced. Accordingly, a further switch may be arranged to the block diagrams of Figures 2b to 2d, to disconnect the outputs of the amplifier paths from the radio frequency band used for transmissions for the duration of the initial calibration. This switch may be arranged after the reference points used for the calibration and preceding an antenna of the apparatus that acts between the amplifier paths and the radio frequency band for transmission. After the initial calibration the outputs of the amplifier paths may be connected for transmission on the radio frequency, i.e. to the antenna.

Figure 4 illustrates a process of defining a filter for an amplifier path of two amplifier paths including non-linear amplifiers, according to an embodiment. The process may be used for calibrating amplifier paths in step 304 of the Figure 3. The process starts 402, when the radio transmitter is switched on and generates out-phased frequency signals to be amplified by PAs on the amplifier paths.

In 404, the out-phased radio frequency signals are received from both of the amplifier paths. The signals may be received after the amplification and before combining of the amplifier paths, e.g. in points B and B' in Figure 2a or after combining in point C in Figure 2a. When the signals are received for processing in a digital domain, analogue received signals may be converted into digital signals by A/D converters. The received signals may comprise test signals fed to the amplifier paths.

In an embodiment, one test signal is fed to the amplifier paths at a time. In this way the effect of each amplifier path to the test signal may be measured at a time. When the test signal is fed through the filter connected to the amplifier path, a suitable time for feeding the test signal to the second amplifier path may be determined on the basis of the length of the impulse response of the filter. The length of the impulse response of the filter may be determined on the basis of the memory length of the filter, when a digital FIR filter is used. In one example the filter length may be two or higher in units of a sampling rate used in the digital filter.

In an embodiment the test signals may comprise wideband radio frequency signals. The bandwidth of the test signal may be at least equal to the frequency band of transmission, where the PAs operate to amplify input signals.

In an embodiment the test signals may be orthogonal with respect to each other. Orthogonal test signals may be fed to the amplifier paths simultaneously. Thereby, determining the filter may be faster than if test signals would be fed to the amplifier paths one at a time.

In 406 a filter is determined for at least one of the amplifier paths. The determining of the filter may comprise determining an impulse response of the filter. The filter may be characterized by coefficients used to multiply the received signal. The filter may include memory for storing a copy of the received signal at a given time instant. The output of the filter may be formed of the received signal multiplied by a coefficient. More than one copy of the received signals may be used to form the output of the filter. Each of the copies of the received signals may be associated with its own coefficient. The copies of the received signals may be stored in the filter for different time lengths. The longest duration of storing a copy of the received signal is referred to as a memory length of the filter. Memory length of digital filters may be determined on the basis of a maximum number of sampling periods the filter stores a sample received at the filter. A more detailed description of filters may be referred to in “Digital Signal Processing, A Computer-Based Approach; Sanjit K. Mitra, ISBN 0-07-115793-X”, where examples of basic FIR digital filter structures are described in Section 6.4, for example.

In an embodiment coefficients of the filter may be defined by measuring the received 404 signals from the amplifier paths, e.g. in points C or B and B’ in Figure 2a. The received signals may comprise amplified test signals fed to the amplifier paths.

Filter coefficients may be determined from received test signals from both amplifier paths on the basis of a MMSE, wherein the MMSE may be defined by:

$$E = |\mathbf{z} - \mathbf{Y}^*\mathbf{b}|^2 \qquad (1),$$

where **Y** denotes an amplified test signal received from an amplifier path including the filter, and z denotes an amplified test signal received from an amplifier path not including the filter, and b denotes the impulse response of the filter, and E is the value of the MMSE. Accordingly, in the Equation (1) **Y*b** describes the filtering of **y** with a filter having an impulse response **b**.

The filter may be determined by coefficients according to:

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b = inv(Y'*Y)*Y'*z,
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where **Y’** denotes a transpose of the **Y**.

The process ends 408 after the filter has been determined and radio frequency signals amplified by the amplifier paths are now aligned.

The steps/points, and related functions described above in Figures 3 and 4 are in no absolute chronological order, and some of the steps/points may be performed simultaneously or in an order differing from the given one. Other functions can also be executed between the steps/points or within the steps/points and other signaling messages sent between the illustrated messages. Some of the steps/points or part of the steps/points can also be left out or replaced by a corresponding step/point or part of the step/point.

The present invention is applicable to a transmitter, a mobile phone, a base station and/or to any communications device that communicates on a wireless medium. All words and expressions should be interpreted broadly and they are intended to illustrate, not to restrict, the described embodiments.

Apparatuses, such as a transmitter, a mobile phone, a base station and/or to any communications device, or apparatuses implementing the functionality of a corresponding apparatus described with an embodiment may be implemented as an electronic digital computer, which may comprise a working memory (RAM), a central processing unit (CPU), and a system clock. The CPU may comprise a set of registers, an arithmetic logic unit, and a control unit. The control unit is controlled by a sequence of program instructions transferred to the CPU from the RAM. The control unit may contain a number of microinstructions for basic operations. The implementation of microinstructions may vary, depending on the CPU design. The program instructions may be coded by a programming language, which may be a high-level programming language, such as C, Java, etc., or a low-level programming language, such as a machine language, or an assembler. The electronic digital computer may also have an operating system, which may provide system services to a computer program written with the program instructions. The memory may be a volatile or a non-volatile memory, for example EEPROM, ROM, PROM, RAM, DRAM, SRAM, firmware, programmable logic, etc.

An embodiment provides a computer program embodied on a distribution medium, comprising program instructions which, when loaded into an electronic apparatus, constitute the functionality according to an embodiment.

The computer program may be in source code form, object code form, or in some intermediate form, and it may be stored in some sort of carrier, which may be any entity or device capable of carrying the program. Such carriers include a record medium, computer memory, read-only memory, electrical carrier signal, telecommunications signal, and software distribution package, for example. Depending on the processing power needed, the computer program may be executed in a single electronic digital computer or it may be distributed amongst a number of computers.

An apparatus according to an embodiment may also be implemented as one or more integrated circuits, such as application-specific integrated circuits ASIC. Other hardware embodiments are also feasible, such as a circuit built of separate logic components. A hybrid of these different implementations is also feasible.

Apparatuses, such as a transmitter, a mobile phone, a base station and/or to any communications device, or apparatuses implementing the functionality of a corresponding apparatus described with an embodiment comprise not only prior art means, but also means for receiving two out-phased radio frequency signals from corresponding amplifier paths of a radio transmitter, and determining a filter for at least one of the amplifier paths, wherein the filter is arranged to minimize a minimum square error of the difference of the combined radio frequency signals.

More precisely, the various means comprise means for implementing functionality of a corresponding apparatus described with an embodiment and it may comprise separate means for each separate function, or means may be configured to perform two or more functions. Present apparatuses comprise processors and memory that can be utilized in an embodiment. Programs, also called program products, including software routines, applets and macros, can be stored in any apparatus-readable data storage medium and they include program instructions to perform particular tasks. All modifications and configurations required for implementing functionality of an embodiment may be performed as routines, which may be implemented as added or updated software routines, application circuits (ASIC) and/or programmable circuits. Further, software routines may be downloaded into an apparatus.

For example, an apparatus according to an embodiment may be implemented in hardware (one or more apparatuses), firmware (one or more apparatuses), software (one or more modules), or combinations thereof. For a firmware or software, implementation can be through modules (e.g., procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in any suitable, processor/computer-readable data storage medium(s) or memory unit(s) or article(s) of manufacture and executed by one or more processors/computers. The data storage medium or the memory unit may be implemented within the processor/computer or external to the processor/computer, in which case it can be communicatively coupled to the processor/computer via various means as is known in the art.

It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

CLAIMS

1. Method comprising:

receiving two out-phased radio frequency signals from corresponding amplifier paths of a radio transmitter; and

determining a filter for at least one of the amplifier paths, wherein the filter is arranged to minimize a minimum square error of the difference of the combined radio frequency signals.

2. A method according to claim 1, comprising:

connecting the filter to the at least one of the amplifier paths;

amplifying the out-phased radio frequency signals; and

combining the amplified radio frequency signals.

3. A method according to claims 1 or 2, wherein the filter is connected to the amplifier path before the amplifier.

4. A method according to any one of the preceding claims, wherein the filter is connected to the amplifier path after the amplifier.

5. A method according to any one of the preceding claims, comprising:

connecting the filter to the at least one of the amplifier paths;

feeding a test signal to each of the amplifier paths;

receiving the amplified test signals; and

determining the filter by filter coefficients on the basis of the amplified test signals.

6. A method according to claim 5, wherein a test signal comprises a wideband radio frequency signal having a bandwidth of at least the bandwidth of amplification of the amplifier paths.

7. A method according to claims 5 or 6 wherein the test signal is fed through each of the amplifier paths at a time, preferably separated by a time period at least the length of the memory of the filter.

8. A method according to claims 5, 6 or 7, wherein the test signals comprise orthogonal test signals.

9. A method according to claims 5, 6, 7, or 8, wherein the amplifier paths comprise non-linear power amplifiers and at least one of the amplifier paths include a filter, and the outputs of the amplifier paths are initially calibrated by determining the filter by a test signal fed to both of the amplifier paths and after the initial calibration, updating the filter on the basis of outputs of the amplifier paths for transmission on a radio frequency.

10. A method according to any one of the preceding claims, wherein the filter comprises a digital Finite Impulse Response filter for example of length 2 or more.

11. A method according to any one of the preceding claims, wherein the amplifier paths perform non-linear amplification and the amplifier paths are combined for transmission after amplification of the radio frequency signals.

12. An apparatus comprising means configured to perform a method according to any one of claims 1 to 11.

13. An apparatus according to claim 12, wherein the means comprise:

a receiver circuitry to receive two out-phased radio frequency signals from corresponding amplifier paths of a radio transmitter; and

a controller to determine a filter for at least one of the amplifier paths, wherein the filter is arranged to minimize a minimum square error of the difference of the combined radio frequency signals.

14. An apparatus according to claims 12 or 13, wherein the apparatus comprises a radio transmission unit of a wireless transmitter for example a mobile phone or a base station.

15. A computer program product comprising executable code that when executed, cause execution of functions of a method according to any one of claims 1 to 11.

16. A communications system comprising an apparatus according to any one of claims 12 to 14.

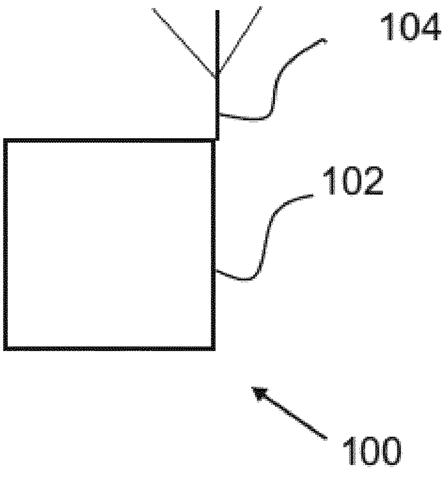

Fig. 1

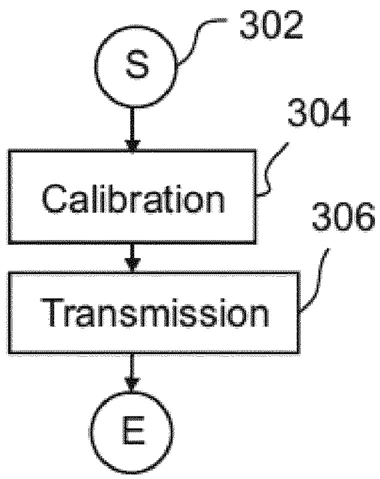

Fig. 3

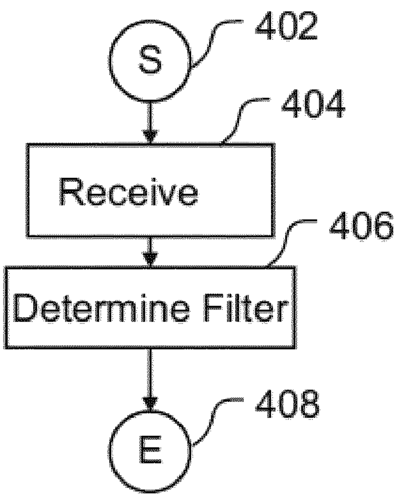

Fig. 4

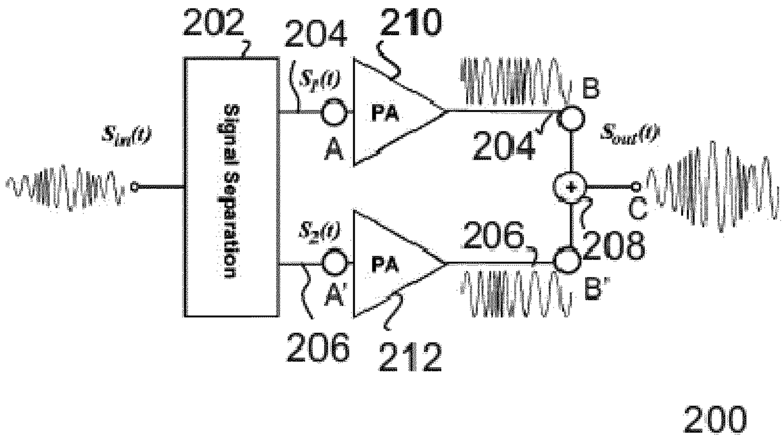
202
204
210
Signal Separation
PA
PA
A
A'
B
B'
C
204
206
208
206
212
200

Fig. 2a

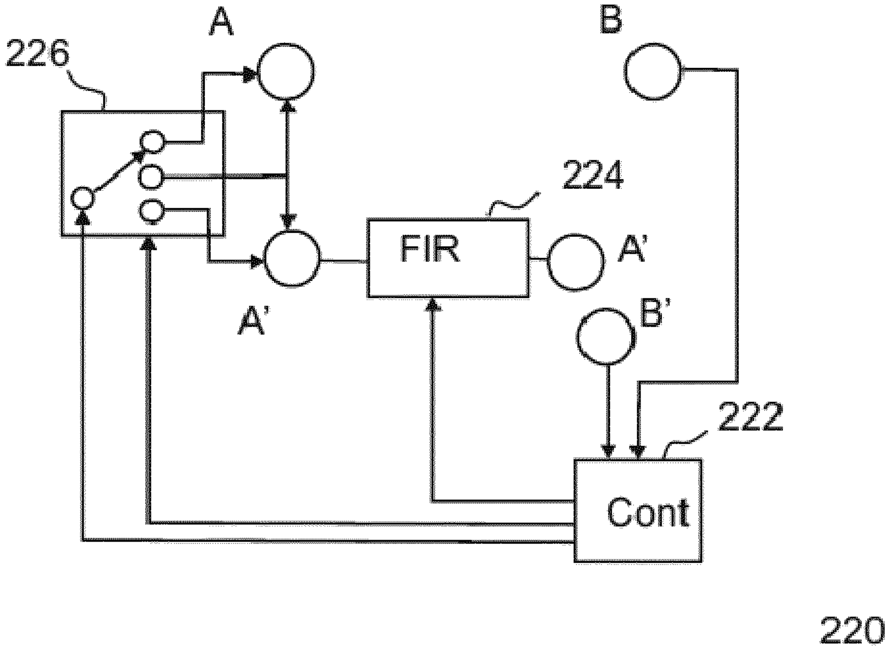
226
A
B
224
FIR
A'
A'
B'
222
Cont
220

Fig. 2b

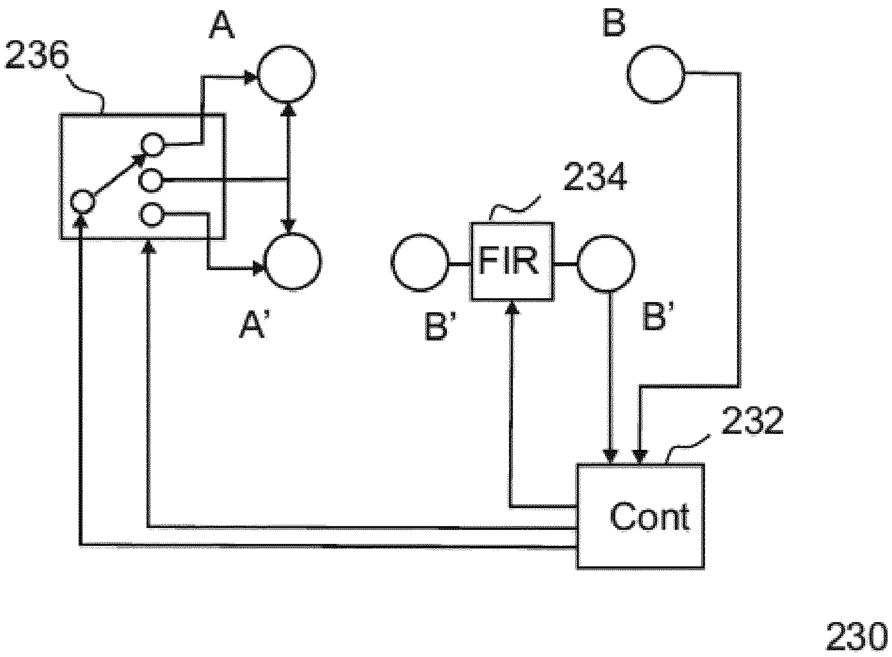
236
A
B
234
FIR
A'
B'
B'
232
Cont
230

Fig. 2c

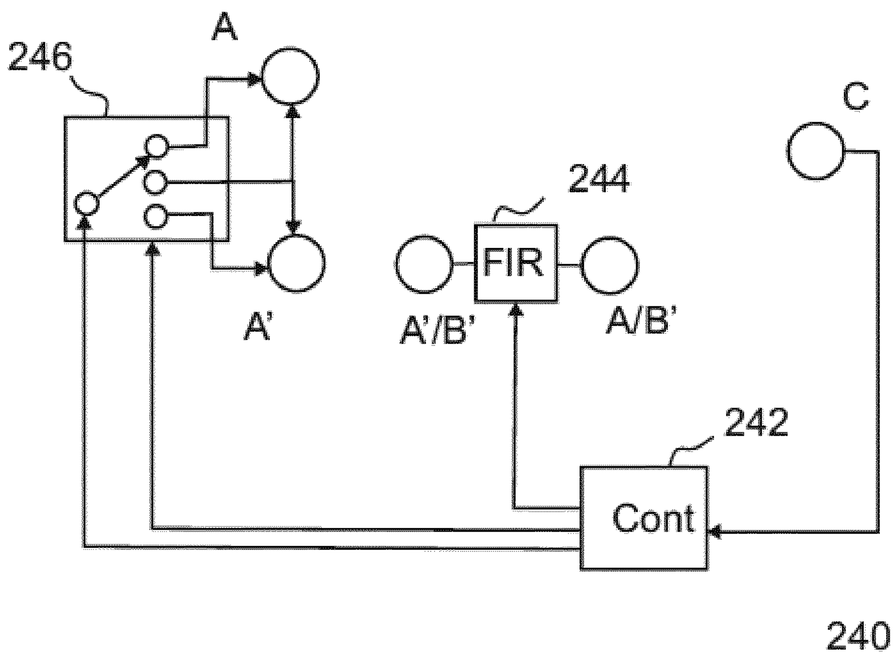
246
A
C
244
FIR
A'
A'/B'
A/B'
242
Cont
240

Fig. 2d

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/062505

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03F1/30 H03F3/189 H03F3/24 H03F1/02 H03F1/32
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)
H03F

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 2010/321107 A1 (HONCHARENKO WALTER [US]) 23 December 2010 (2010-12-23) paragraphs [0009], [0022] - [0045], [0054]; figures 3,5 -----	1-16
X	US 2002/047745 A1 (KOLANEK JAMES C [US]) 25 April 2002 (2002-04-25) paragraphs [0002], [0017], [0039] - [0113]; figures 3,4,7 -----	1-16
X	EP 1 667 331 A1 (MATSUSHITA ELECTRIC IND CO LTD [JP] PANASONIC CORP [JP]) 7 June 2006 (2006-06-07) paragraphs [0011], [0016] - [0108]; figures 4,7,10 -----	1-16
	-/--	

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

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 October 2013	18/10/2013

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	Goethals, Filip

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/062505

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/075194 A1 (RAVI ASHOKE [US] ET AL) 27 March 2008 (2008-03-27) paragraphs [0001], [0056] - [0066]; figures 9,10,12 -----	1-16

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2013/062505

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010321107 A1	23-12-2010	CN 102460956 A	16-05-2012
		EP 2443739 A1	25-04-2012
		JP 2012531095 A	06-12-2012
		KR 20120026549 A	19-03-2012
		US 2010321107 A1	23-12-2010
		WO 2010147754 A1	23-12-2010
US 2002047745 A1	25-04-2002	AU 7362701 A	02-01-2002
		AU 2001273627 A8	04-09-2008
		US 2002047745 A1	25-04-2002
		WO 0199271 A2	27-12-2001
EP 1667331 A1	07-06-2006	CN 1853351 A	25-10-2006
		EP 1667331 A1	07-06-2006
		JP 3910167 B2	25-04-2007
		JP 2005101940 A	14-04-2005
		US 2007076814 A1	05-04-2007
		WO 2005031993 A1	07-04-2005
US 2008075194 A1	27-03-2008	NONE	