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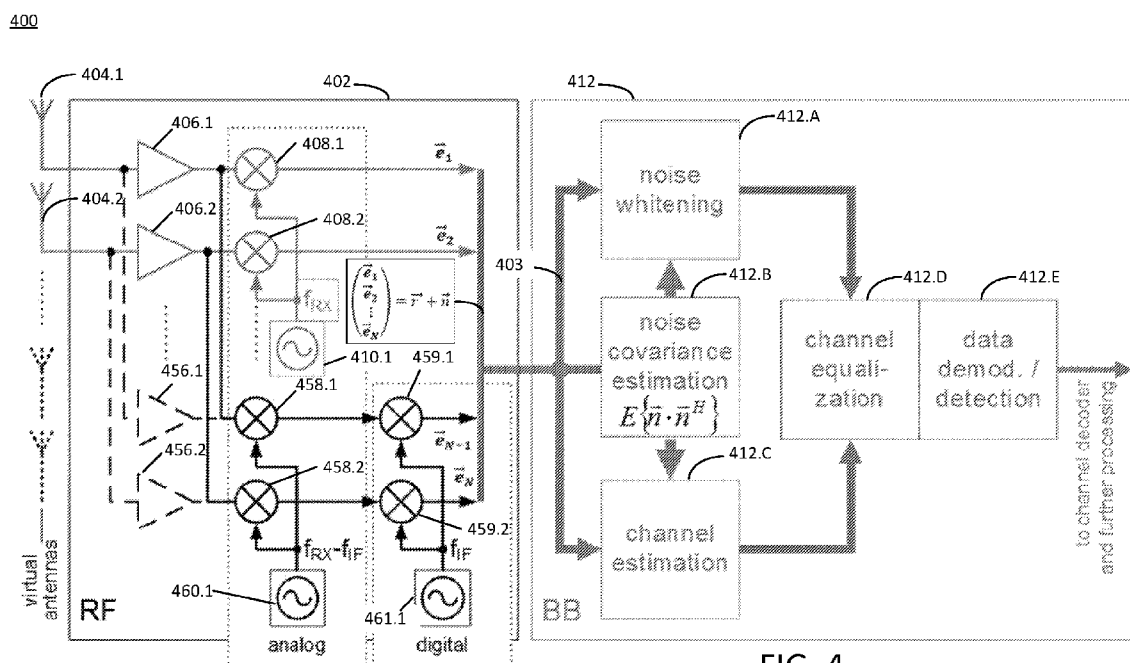


FIG. 4

(57) **Abstract:** A receiver design is provided to address blocker signals not known a priori. The blocker signals may cause a spurious frequency response when downconverted with a particular harmonic of the local oscillator or at unwanted sidebands, and the effect of the blocker signals can thus be shifted out of band by adjusting the LO frequency, which shifts the intermediate frequency (IF) of the downconverted signals. The proposed design implements a diversity receiver architecture in which one or more sets of RF chains are coupled to the main receiver path antennas, but the diversity receiver path signals are downconverted in accordance with different LO frequencies than the main receiver path. The RF chains in the diversity receiver paths may thus be considered being coupled to "virtual" antennas. Algorithms may then be implemented by extending principles of dynamic diversity receiver and best antenna selection used for physical antennas to the virtual antennas.

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DYNAMIC LOW IF MECHANISM FOR BLOCKER AVOIDANCE

TECHNICAL FIELD

[0001] Aspects described herein generally relate to RF receivers and, more particularly, to RF receiver designs implementing low-IF principles to mitigate blocker signals.

BACKGROUND

[0002] Heterodyne topologies are ubiquitous among modern receiver designs. Such designs mix a received radio frequency (RF) signal with a local oscillator (LO) signal to provide a downconverted signal at an intermediate frequency (IF), which is then processed for demodulation. However, a common issue with such designs is an elevated sensitivity to interference at multiples (i.e., harmonics) of the received RF frequency or at unwanted sidebands, particularly for designs that implement a LO that is tuned close to the frequency of the received signal (i.e., a zero-IF or nearly zero-IF system). For instance, in such systems, when a desired signal is received at 700 MHz, the receiver may be prone to additional sensitivity at the frequency region around 2100 MHz due to the third harmonic of the LO signal.

[0003] Moreover, a receiver that is prone to such sensitivities may be exposed to external, unwanted signals during ordinary operation, which are known as “blocker” signals. In some cases, a blocker signal may be associated with a frequency that, when down-converted by the third-harmonic of the LO or at a particular sideband, results in a spurious response (“spur”) frequency that degrades the receiver’s performance. Because the frequency and source of such blocker signals are not known at the time the receiver is designed, current receiver designs do not function to appropriately compensate for their presence.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

- [0004] The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate the aspects of the present disclosure and, together with the description, further serve to explain the principles of the aspects and to enable a person skilled in the pertinent art to make and use the aspects.
- [0005] FIG. 1 illustrates a block diagram of a typical diversity receiver architecture.
- [0006] FIG. 2 illustrates a block diagram of an example diversity receiver architecture in accordance with an aspect of the disclosure.
- [0007] FIG. 3A illustrates the spectral response of a typical receiver architecture in the presence of a blocker signal using downconversion with zero intermediate frequency (IF).
- [0008] FIG. 3B illustrates the spectral response of an example receiver architecture using downconversion with a non-zero intermediate frequency (IF) applied to the diversity receiver path, in accordance with an aspect of the present disclosure.
- [0009] FIG. 4 illustrates a block diagram of an example receiver design, in accordance with an aspect of the disclosure.
- [0010] FIG. 5 illustrates a block diagram of an example power-saving receiver design, in accordance with an aspect of the disclosure.
- [0011] FIG. 6 illustrates a block diagram of an example best IF selection receiver design, in accordance with an aspect of the disclosure.
- [0012] The exemplary aspects of the present disclosure will be described with reference to the accompanying drawings. The drawing in which an element first appears is typically indicated by the leftmost digit(s) in the corresponding reference number.

DETAILED DESCRIPTION

- [0013] In the following description, numerous specific details are set forth in order to provide a thorough understanding of the aspects of the present disclosure. However, it will be apparent to those skilled in the art that the aspects, including structures, systems, and methods, may be practiced without these specific details. The description and representation herein are the common means used by those experienced or skilled in the art to most effectively convey the

substance of their work to others skilled in the art. In other instances, well-known methods, procedures, components, and circuitry have not been described in detail to avoid unnecessarily obscuring aspects of the disclosure.

- [0014] Again, RF blocker signals are associated with external signal sources that may cause receiver degradation when downconverted with a particular harmonic (e.g., the 3rd harmonic) of the receiver's LO or at unwanted sidebands. Typical solutions to address RF blocking is via RF analog mechanisms. For example, blocker isolation may be defined in the level plan for a particular receiver design, and circuit designers may then attempt to achieve the isolation over each potential coupling path. However, during the pre-silicon design phase, this is often strictly limited to 1 or 2 main coupling paths, leading to regular late detections of spurs.
- [0015] Therefore, another standard approach to address blocker signals is to add extra filtering to the RF receive paths, and then optimize the receiver circuit for each harmonic frequency. However, each change typically involves a PCB and/or hardware redesign and, if findings on an issue come late, a resolution with standard design methods yields significant project risk.
- [0016] Further complicating this issue, modern communication protocols (e.g., LTE and the use of carrier aggregation) may utilize a large number of band combinations (e.g., 1000 or more). Moreover, with advanced CMOS technology nodes, the distance between different functional blocks becomes less, and thus the achievable isolation performance is limited. In addition, such isolation is also susceptible to parasitic effects, so it may vary for SoC process fluctuations or any variation of the PCB.
- [0017] When blockers are identified ahead of time from a particular RF design (i.e., blockers known *a priori*) "low-IF" may be implemented in an attempt to mitigate the issue. However, RF blockers are difficult to identify, predict, and/or model for any particular design, as they are associated with external RF signal sources, and therefore these low-IF techniques fail to resolve issues associated with RF blocker signals not known *a priori*.
- [0018] To remedy the aforementioned issues with these typical solutions, the aspects described herein allow a receiver to dynamically adapt and thus mitigate the effects of blocker signals, even when the blocker signals are unknown at the time the receiver is designed. These aspects, which are further discussed below, utilize a main and diversity receiver architecture, with

physical antennas being shared between the two paths. The diversity receiver path thus utilizes the same antennas as the main receiver path, but the diversity receiver path implements a different LO frequency for downconversion of the received RF signals.

[0019] In doing so, the diversity path may provide a series of IF-shifted downconverted signal streams that may be treated in the same way as signals downconverted from different physical antennas for purposes of signal stream processing, but are instead referred to herein as originating from “virtual” antennas. The algorithms described herein may thus extend diversity receiver antenna selection and power handling techniques, which are ordinarily applied to physical antennas, to these virtual antennas. In doing so, established diversity receiver techniques may be implemented to determine the appropriate receive path and/or IF frequency(ies) to ensure that spurs, which would otherwise be present due to the downconversion of blocker signals, are shifted out of band to prevent receiver degradation.

[0020] FIG. 1 illustrates a block diagram of a typical diversity receiver architecture. As shown in FIG. 1, a transmitter 102 transmits an over-the-air wireless RF signal that is received via a main receiver antenna 104A and a diversity antenna 104B. The main receiver path (main RF chain) thus includes the main antenna 104A, which is coupled to an amplifier 106A, a mixer 108A, and a baseband processor 112. Likewise, the diversity receiver path (diversity RF chain) includes the diversity antenna 104B, which is coupled to an amplifier 106B, a mixer 108B, and the baseband processor 112. For clarity, additional components and/or stages associated with the receiver 100 are not shown in FIG. 1 (e.g., additional amplifier stages, analog-to-digital converters, filters, etc.).

[0021] The receiver 100 also includes a LO 110, which generates an LO signal at a frequency equal to f_{RX} that is equivalent to the frequency of the received RF signal. The receiver 100 thus includes a main receiver path and a diversity receiver path that share the same LO 110, and thus downconvert the received RF in accordance with the same LO frequency, producing a downconverted signal having zero IF (or nearly zero IF) in both cases. However, as noted above, the frequency region around $3 \cdot f_{RX}$ is particularly sensitive, as signals at the frequency of $3 \cdot f_{RX}$ will be downconverted with the third harmonic of the LO 110. For some applications (e.g., LTE carrier aggregation) certain carrier channels such as the uplink (UL)

primary component carrier (PCC) and the downlink (DL) secondary component carrier (SCC) may have a similar spectral relationship, which can be expressed in a zero-IF system as:

[0022] $f_{PCC, TX} - 3(f_{SCC, RX}) = 0 \text{ MHz}$

[0023] In other words, the device associated with the receiver 100 may also include one or more transmitters, which are not shown in FIG. 1 for purposes of brevity. During some modes of communications, the device may transmit (via the aforementioned transmitter) a signal associated with the UL PCC. In such a case, the blocker signal may be associated with such a transmitted signal (not shown), which may be cross-coupled back into the receiver along the main and diversity receiver paths. For zero-IF receivers, such as the receiver 100, a spurious response (spur) frequency may be caused by the down-conversion of this blocker signal with the third harmonic of the LO 110. An example of the spectral response of the receiver 100 as a result of the relationship between the blocker signal and the wanted signal is shown in the spectral response graph 300 of FIG. 3A, which indicates the spectral overlap between the blocker signal and the third harmonic of the LO 110. The result of this spectral relationship may be the introduction of a spurious response into the receiver and the degradation of the diversity receiver 100.

[0024] That is, in the case in which spurious response frequencies are known or can be predicted, such as the case described above, such spurs may be circumvented by introducing a non-zero low-IF into the downconverted signal by shifting the LO frequency from f_{RX} . For instance, continuing the previous example and assuming an LTE10 communication system, an IF may be calculated to shift the spur by 20 MHz, and thus out of the communication band, by the following relationship:

[0025] $f_{PCC, TX} - 3(f_{SCC, RX} - IF_{SCC}) - IF_{SCC} = 20 \text{ MHz},$

[0026] which is satisfied when $IF_{SCC} = 10 \text{ MHz}$, and implemented by configuring LO 110 to generate an LO signal at a frequency equal to $f_{SCC, RX} - 10 \text{ MHz}$.

[0027] In other words, the spur frequency caused by the down-conversion of a blocker with the third harmonic of the LO 110 is dependent upon the IF. Thus, when a known blocker at this spurious response frequency is degrading the receiver's performance, the situation can be resolved by

changing the used zero-IF to a different low-IF, thereby moving the spurious response away from the blocker so that the blocker is no longer in band.

[0028] FIG. 2 illustrates a block diagram of an example diversity receiver architecture in accordance with an aspect of the disclosure. Similar to the receiver 100 as shown in FIG. 1, the receiver 200 as shown in FIG. 2 also receives an over-the-air wireless RF signal transmitted by a transmitter 202. The receiver 200 also includes a main receiver antenna 204A and a diversity antenna 204B that function to receive the transmitted RF signal. The main receiver path (main RF chain) includes the main antenna 204A, which is coupled to an amplifier 206A, a mixer 208A, and a baseband processor 212. Likewise, the diversity receiver path (diversity RF chain) includes the diversity antenna 204B, which is coupled to an amplifier 206B, a mixer 208B and the baseband processor 212. For clarity, additional components and/or stages associated with the diversity receiver 200 are not shown in FIG. 2 (e.g., additional amplifier stages, analog-to-digital converters, filters, etc.).

[0029] Unlike the receiver 100 as shown in FIG. 1, however, the receiver 200 includes two LOs 210A-B, each providing an LO signal at a different LO frequency. The receiver 200 thus implements two parallel paths to facilitate reception of RF signals via a second LO on the diversity path to provide a downconverted signal with a different IF than that of the main receiver path. This ensures that each downconverted signal is otherwise identical, and the differences between the two received RF signals arises out of the path differences (different IF, different analog performance, etc.).

[0030] For instance, LO 210A generates a LO signal at a frequency equal to f_{RX} that is equivalent to the frequency of the received RF signal. The main receiver path, therefore, provides a zero-IF downconverted signal. On the other hand, the LO 210B generates a LO signal at a frequency equal to $f_{RX} - IF$. The diversity receiver path, therefore, provides a downconverted signal that is frequency shifted as compared to the downconverted signal on the main receiver path, by some frequency equal to IF, or the difference between the frequencies generated by LO 210A and 210B.

[0031] An example of the spectral response of the diversity receiver 200 is illustrated by examining the differences between FIGs. 3A-3B. In particular, FIG. 3A illustrates the spectral response

of the diversity receiver 200 for the main receiver path, which is equivalent to that of the diversity receiver 100. However, the spectral response graph 350 shown in FIG. 3B illustrates the spectral response of the diversity receiver 200 for the diversity receiver path, which indicates that the blocker signal is now shifted out of band and away from the third harmonic of the LO, thus preventing the spurious frequency response for the diversity path of the receiver 200.

[0032] As a result, the use of a low IF in the diversity receiver path of the diversity receiver prevents a spurious response and the degradation of the diversity receiver for the diversity receiver path. In other words, a low-IF frequency can be calculated to shift spurs at known frequencies (e.g., digital noise or the transceivers own TX signal), thus shifting the interference out of the receiver's operating band. Unfortunately, when the blocker is external to the device, it is typically not known and cannot be modeled or calculated. Therefore, it may not be possible to calculate such an IF shifting frequency to resolve blocker issues not known *a priori*.

[0033] Thus, as further discussed below, the aspects described herein mitigate spurs caused by blocker signal by operating a main receiver path and a diversity receiver path with different IFs in parallel for a period of time and evaluating the difference in the signal quality on both of these paths. In some aspects, this blocker signal may be the result of the downconversion of an external signal with a harmonic (e.g., the third harmonic) of the LO. In other aspects, the blocker signal may be associated with not only multiples of the LO, but at any unwanted sideband. For example, for certain commination systems (e.g., wireless devices on cellular networks) may be associated with a specific spur class, in which another signal is involved to generate a frequency combination. To provide an illustrative example, if such a system (e.g., a mobile device) is clocked with a signal having a frequency of 26 MHz, it is common to have an elevated sensitivity not only at multiples of the LO frequency, but also at frequencies represented as: $LO \pm (n \cdot 26MHz)$, with n being equal to a positive integer. In this example, the frequency region of elevated sensitivity is referred to as a sideband.

[0034] The aspects described herein are therefore not limited to mitigating receiver sensitivities caused by the downconversion of external signals with harmonics of the LO frequency. Additionally or alternatively, the aspects as described herein are also applicable to mitigate

receiver sensitivities for any sideband that can be represented as $[m \cdot (LO \pm n)]$. With m being any number greater than one, and n representing a positive integer value.

[0035] In any event, the aspects described herein facilitate a receiver to identify which downconverted signal stream is free of spurs (or substantially free, meeting a particular threshold of signal quality, etc.) based upon measured signal characteristics, and then selecting one or more IF frequencies to use for subsequently received RF signals to dynamically adapt to the presence of blocker signals not known *a priori*.

[0036] FIG. 4 illustrates a block diagram of an example receiver design, in accordance with an aspect of the disclosure. As discussed herein, when describing the various aspects, the term “receiver” is used by way of example for clarity and not by way of limitation. For example, the receiver architectures described herein may be part of a larger or more complex design, such as a transceiver, one receiver from among several, etc. These additional components (e.g., RF chain components associated with RF transmissions for a transceiver design) are not shown for purposes of clarity and brevity.

[0037] Furthermore, the receiver 400 as shown in FIG. 4 and the additional Figures referenced herein may be considered a portion of a receiver that is implemented as part of any suitable device for which wireless signal transmissions are utilized (e.g., as part of a mobile device). Therefore, the receiver design 400 as shown in FIG. 4 as well as the additional Figures referenced herein may include additional, alternate, or less components to facilitate proper operation in accordance with their respective aspects. Moreover, in accordance with various aspects, the receiver designs as discussed herein may be configured to receive and/or transmit wireless RF signals, and/or process data extracted from these RF signals, using any suitable number and/or type of communication protocols.

[0038] As shown in FIG. 4, the receiver 400 may generally be divided into an RF front end 402 and a baseband processor 412. The baseband processor 412 may be implemented as any suitable number and/or type of computer-based processors configured to perform baseband processing functions and/or to control various functions of the receiver and/or a device in which receiver 400 is implemented. For example, the baseband processor 412 may be configured to receive

and process digitized signal streams associated with each of the RF chains shown in FIG. 4, as further discussed below.

[0039] The RF front end 402 may include any suitable number N of RF chains having any suitable configuration to receive and/or transmit wireless RF signals. Again, the aspects described herein include the RF chains as described with reference to FIG. 4 and the other Figures described herein including additional components not shown for brevity, such as additional amplifier stages, additional mixer stages, additional filter stages, digital-to-analog conversion stages, etc.

[0040] In an aspect, the antennas 404.1-404.2 may be configured to operate together as part of a main receiver path as discussed above with reference to FIGs. 1-2. Thus, one of the RF chains associated with the receiver 400 may include, for example, antenna 404.1, amplifier 406.1, and mixer 408.1, producing a downconverted signal stream including signal samples over time, which is represented as a vector $\vec{e}_1$. Another RF chain may include the antenna 404.2, the amplifier 406.2, and the mixer 408.2, producing a downconverted signal stream represented as a vector $\vec{e}_2$. Thus, the main receiver path associated with the receiver 400 may include both of the aforementioned RF chains (e.g., antennas 404.1, 404.2, amplifiers 406.1, 406.2, mixers 408.1, 408.2, etc.). Alternatively, the term “RF chain” as used herein may include a combination of two or more individual RF chains, such as those discussed above with reference to the overall main receiver path for antennas 404.1, 404.2.

[0041] In any event, various aspects include the RF front end 402 implementing any suitable number of zero-IF RF chains and non-zero IF RF chains. In other words, receiver 400 may include any suitable number N of RF chains that receive the same RF signal via antennas 404.1, 404.2, but downconvert this received RF signal within each receiver path (having one or more RF chains) using a different LO frequency. For instance, as shown in FIG. 4, the two RF chains associated with the main receiver path and the downconverted signal stream vectors $\vec{e}_1$ and $\vec{e}_2$ share the same LO 410.1. These downconverted signal streams $\vec{e}_1$ and $\vec{e}_2$ may thus have a frequency that is the same or substantially the same as the received RF signal (e.g., f_{RX}), thus providing downconverted RF signals having a zero IF after mixing the received RF signal with the signal generated by the LO 410.1 in each respective RF chain.

- [0042]** Furthermore, aspects include the receiver 400 implementing an additional set of RF paths (having one or more RF chains) that downconvert the same signal as that received by the non-zero RF chains at a different LO frequency. For example, a separate receiver path may be considered a diversity receiver path having two non-zero IF RF chains associated with a LO 460.1 and 461.1. One of these RF chains may include an optional amplifier 456.1, an analog mixer 458.1, and a digital mixer 459.1. The other of these RF chains may be associated with the same LO 460.1 and 461.1, and may include an optional amplifier 456.2, an analog mixer 458.2, and a digital mixer 459.2. Again, the term “RF chain” as used herein may also include a combination of both of these aforementioned RF chains (e.g., the entire diversity receiver path).
- [0043]** Of course, the receiver 400 may be configured to receive RF signals over one or more frequency bands, and thus each of the LOs implemented by the receiver 400 may be adjustable or tunable in accordance with the received RF signals at any particular instant in time and/or for any particular frequency or band of frequencies associated with the received RF signals.
- [0044]** Aspects include receiver 400 having any suitable number of main receiver paths and/or diversity receiver paths with any suitable number of RF chains configured in this manner, with each of the non-zero IF RF chains receiving the same RF signal as the zero-IF RF chains associated with the antennas 404.1 and 404.2 (or other suitable antenna configuration of one antenna, more than two antennas, etc.). Thus, aspects include any suitable number of downconverted signal streams being generated by each respective receiver path (which may include one or more RF chains). Again, for purposes of brevity, an analog-to-digital conversion stage is not shown in FIG. 4 or the other Figures references herein, but would ordinarily be present at the output of each RF chain (e.g., the output of mixer 408.1, 408.2, 458.1, 458.2, etc.) and/or as part of the baseband processor 412. Thus, each downconverted signal stream, which is represented as the vector $\vec{e}_1 \dots \vec{e}_N$, may be considered a digitized downconverted signal stream, with each being coupled to the baseband processor 412 via any suitable number of wires, buses, etc., such as bus 403, for example, as shown in FIG. 4.
- [0045]** In this way, each non-zero IF RF chain may be viewed as receiving a separate RF signal via one or more respective “virtual” antennas, as shown in FIG. 4. The details regarding the

baseband processor 412 processing the digitized downconverted signal streams in this way are further discussed below. In other words, each non-zero IF RF chain produces a digitized downconverted signal stream $\vec{e}$ using the same antenna(s) as the zero-IF RF chains, but generate a downconverted signal with a different IF.

[0046] Furthermore, aspects include, for each non-zero IF RF chain, the resulting downconverted signal stream that is subsequently processed via the baseband processor 412 being generated as part of a two-stage process. For example, with reference to the diversity path as shown in FIG. 4, in the first stage, the received RF signal is first mixed with analog LO 460.1 (via analog mixers 458.1, 458.2) to generate the virtual antenna signal. This virtual antenna signal is de-tuned from the received RF signal f_{RX} by any suitable IF frequency (based upon the difference between the LO frequency of LO 410.1 and LO 460.1). The resulting IF-shifted signal output by each RF chain via the analog mixers 458.1, 458.2, is then transformed in subsequent digital processing by a second stage of digital mixers 459.1-459.2 in accordance with a LO frequency that is equal to the same IF frequency used by the analog mixers 458.1, 458.2 to generate “non-zero IF” or “Low IF” digitized downconverted signal streams (e.g., $\vec{e}_{N-1}$, $\vec{e}_N$).

[0047] In this context, the term “non-zero IF” or “Low IF” refers to the analog stage IF-shifting performed by the analog mixers 458.1, 458.2 on a particular receiver path. However, aspects include applying the digital mixing via digital mixers 459.1, 459.2, to shift the resulting downconverted frequency of the virtual antenna signals (e.g., those output by the analog mixers 458.1, 458.2) back to zero IF. To do so, aspects include the use of a digital mixing stage (e.g., via digital mixers 459.1, 459.2) on one or more receiver paths such that identical signal setups (e.g., the same IF and same bandwidth) exist on each path, with the difference being that in one path (e.g., the diversity receiver path associated with analog mixers 458.1, 458.2) LowIF was used for downconversion, whereas in another path (e.g., the main receiver path associated with analog mixers 408.1, 408.2), zero IF is used for downconversion. In this way, aspects enable the use available or known baseband blocks and/or algorithms to facilitate virtual antenna selection, as further discussed herein.

[0048] In an aspect, one or more of these non-zero IF digitized downconverted signal streams may effectively shift the spur out of an operating communications band used in accordance with the

received RF signal. As further discussed below, the baseband processor 412 may evaluate the zero-IF and/or non-zero IF digitized downconverted signal streams to avoid processing signal streams where spurs are present. Upon downconversion by the zero-IF RF chain(s) and the non-zero IF RF chains, the resulting downconverted signal streams, which are represented as vectors $\vec{e}_1, \dots, \vec{e}_N$, include a useful signal part $\vec{r}$ and a noise-plus-interference signal $\vec{n}$. Therefore, aspects include baseband processor 412 performing digital signal processing via noise covariance estimation block 412.B to estimate the noise covariance matrix of the signal $\vec{n}$, which is then utilized to perform subsequent noise whitening (e.g., via noise whitening block 412.A) and channel estimation (e.g., via channel estimation block 412.C). In accordance with such aspects, the baseband processor 412 may then execute channel equalization (e.g., via channel equalization block 412.D) and data demodulation and/or detection (e.g., via data demodulation/detection block 412.E). In various aspects, baseband processor 412 may perform these functions in any suitable manner by executing instructions stored in each of noise whitening block 412.A, noise covariance estimation block 412.B, channel estimation block 412.C, via channel equalization block 412.D, and data demodulation/detection block 412.E. For example, baseband processor may execute these functions in accordance with known techniques, which are adapted to process the IF-shifted signal streams, as further discussed herein.

[0049] In an aspect, the digital signal processing performed via the baseband processor 412 in this manner may be any suitable type of signal processing to appropriately recover data included in the received RF signals. For example, the baseband processor 412 may be configured to execute digital signal processing in accordance with known noise whitening receiver techniques, but extend these techniques to apply to the virtual antenna signals. Such known noise whitening receiver techniques generally consider estimation and compensation of antenna signal correlation. For instance, before equalization of the received signal, such algorithms may include a noise covariance estimation technique that is used in a second step to apply noise whitening to the received RF signal. Such whitening-matched filter pre-processing techniques allow for optimal multiple antenna signal receive performance within diversity receivers.

[0050] However, typical noise-whitening receivers execute digital baseband processing for a number of downconverted signals having the same IF, which are received via separate RF chains, as each RF chain in a typical diversity receiver uses different physical antenna(s) but the same LO for downconversion. Aspects include applying these same noise-whitening techniques via baseband processor 412 in a manner that treats the digitized zero-IF and non-zero-IF downconverted signal streams as originating from separate physical antennas, when each of these signals is, in fact, generated from shared physical antenna(s) but downconverted with different LO frequencies. In this way, such known noise covariance estimation, noise whitening, channel estimation, and channel equalization techniques may be adapted to the properties of the simultaneous received virtual antenna signals originating from the same physical antenna(s). Aspects include the baseband processor 412 executing such noise whitening techniques on each of the digitized zero-IF and non-zero IF downconverted signal streams $\vec{e}_1, \dots, \vec{e}_N$. As a result, even though the same channel estimation may be performed on the digitized zero-IF and non-zero IF downconverted signal streams, any signals distorted by spurs are attenuated as a result of the noise whitening procedure.

[0051] In this way, aspects include the receiver 400 implementing the use of “low-IF” principles for frequency downconversion as a mitigation mechanism, which may be applicable for blockers that are either known or unknown *a priori*. In an aspect, the digitized zero-IF and non-zero IF downconverted signal streams may be simultaneously processed via baseband processor 412 during one time period, and then an RF chain and particular digitized downconverted signal stream (e.g., one of the multiple digitized non-zero-IF downconverted signal streams) may be selected for subsequent reception of RF signals. In doing so, processing of a signal stream that would otherwise include distortions caused by a spur introduced via downconversion of the blocker signal may be avoided.

[0052] For example, the aspects described herein may execute the noise covariance estimation, noise whitening, channel estimation, and channel equalization techniques of simultaneous processing of both zero-IF and non-zero-IF downconverted signal streams. This simultaneous processing may be performed, for example, during a detection phase associated with a particular communication protocol implemented by the receiver 400. In doing so, the

techniques described herein prevent degradation, in contrast to time-interleaved approaches. Continuing this example, the detection phase may be entered before each receiver setup change, prior to a normal reception phase. This technique therefore allows receivers to adapt to non-pre-determined use-cases, such as those implemented via carrier aggregation combinations brought about by future updates, for example, without requiring additional hardware changes.

[0053] As discussed herein, aspects include the receiver 400 mitigating interference created by spurious frequency response caused by downconverted blocker signals by simultaneously processing different “candidate” signals, which may be associated with each of the digitized zero-IF and non-zero IF downconverted signal streams $\vec{e}_1, \dots, \vec{e}_N$, for example. If there is one spur-free candidate (e.g., one of the non-zero IF downconverted signal streams), such candidate processing by the baseband processor 412 yields a demodulation performance equal to spur-free reception using that corresponding candidate. However, the continuous simultaneous processing of multiple digitized downconverted streams in this way may tax power constraints associated with baseband processor 412. Therefore, as further discussed below, additional aspects include modifying the receiver 400 to selectively disable (i.e., switch off) other candidates (i.e., RF chains associated with the downconverted signal streams) for power savings.

[0054] FIG. 5 illustrates a block diagram of an example power-saving receiver design, in accordance with an aspect of the disclosure. The example receiver 500 shown in FIG. 5 includes a similar architecture as the example receiver 400, as shown in FIG. 4. In particular, both receivers 400 and 500 include respective RF front ends 402, 502 and respective baseband processors 412, 512. In aspects, RF front ends 402, 502 and baseband processors 412, 512 operate in a substantially similar manner, and therefore only differences between these components will be further discussed herein. For instance, for receiver 500, RF signals are received and processed in a similar manner as discussed with reference to receiver 400. Moreover, like receiver 400, receiver 500 may utilize an initial phase (e.g., a detection phase) to evaluate the quality of the digitized zero-IF and non-zero IF downconverted signal streams $\vec{e}_1, \dots, \vec{e}_N$. As further discussed below, receiver 500 may then use the results of this analysis to dynamically shut

down specific RF chains based upon this analysis, for instance, during a subsequent phase (e.g., a normal reception phase). Additional common components of receivers 400, 500 are not labeled in FIG. 5 for purposes of brevity.

As compared to receiver 400, receiver 500 includes additional switches 503A-B, 505A-B, 507A-B, and 509A-B, which are configured to selectively deactivate particular RF chains. As a result, when deactivated, that RF chain does not provide a respective digitized downconverted signal to the baseband processor 512. The switches 503A-B, 505A-B, 507A-B, and 509A-B are only some examples of how the deactivation of RF chains may be implemented. In various aspects, receiver 500 may implement any suitable number and/or type of switches to disconnect one or more portions of the RF chains from the physical antennas, thus preventing reception of the RF signal and subsequent signal processing of signals associated with those RF chains. For example, as shown in FIG. 5, switches 503A-B and 507A-B may be coupled in series with an input to one more amplifier stages of each respective RF chain, thus controlling whether the received RF signal is coupled to that particular RF chain. To provide another example, as shown in FIG. 5, switches 505A-B and 509A-B may be coupled in series with an output of one more amplifier stages of each respective RF chain, thus controlling whether a received RF signal is provided to the analog mixer for that particular RF chain. In any event, as further discussed below, the on/off state of each switch, and thus the RF chain associated with each switch, may be controlled by the baseband processor 512 executing instructions associated with dynamic IF block 512.F.

[0055] For example, dynamic IF block 512.F may include logic, executable instructions, and/or code that may utilize preceding channel estimation information and/or operates on the received signals $\vec{e}_1, \dots, \vec{e}_N$ to measure and/or estimate one or more signal characteristics and provide feedback to the RF front end 502 to disable an RF chain and/or baseband processor 512 based upon these signal characteristics. In an aspect, the dynamic IF block 512.F facilitates the baseband processor 512 measuring signal characteristics associated with one or more of the digitized zero-IF downconverted signal streams and/or non-zero IF downconverted signal streams provided by the RF front end 502. These signal characteristics may include any suitable metric to reliably identify whether the RF chain associated with a respective signal

stream should be disabled. For example, baseband processor 512 may measure and/or estimate signal characteristics such as signal power, a received signal strength indicator (RSSI), noise power, a signal-to-noise ratio, interference power, a signal-to-noise plus interference ratio, etc.

[0056] In an aspect, the dynamic IF block 512.F may be an adaptation of one or more known baseband algorithms directed to addressing power savings within a typical diversity receiver, which ordinarily functions to determine which RF chain to switch off based upon the physical antenna coupling to each RF chain. In other words, known baseband algorithms may function to identify signal characteristics associated with multiple received RF signal streams downconverted at the same LO frequency, and thus have the same IF. Such baseband algorithms may facilitate dynamic receiver diversity by using measured signal characteristics to decide which of these RF chains may be switched off for power savings.

[0057] However, in doing so, ordinary baseband algorithms directed to dynamic receiver diversity systems still result in the processed signal potentially containing spurs due to the downconversion of blocker signals in the selected RF chain received via that respective physical antenna. By adapting these algorithms to treat the virtual antenna signals (i.e., the IF-shifted or non-zero IF downconverted signal streams) together with the physical antenna signals (the zero-IF downconverted signal streams), aspects include the baseband processor 512 determining which of the RF chains associated with a respective virtual antenna (or physical antenna) may be switched off for power savings. In an aspect, by evaluating signal characteristics of the zero-IF and/or non-zero IF downconverted signal streams, those having distortions caused by a spur due to a blocker signal may be avoided.

[0058] For example, one or more RF chains may be disabled such that baseband demodulation quality may only need to utilize one (e.g., the best or sufficient) stream from among the zero-IF downconverted signal streams and/or the non-zero IF downconverted signal streams to save power. In an aspect, the baseband processor 512 may execute instructions stored in the dynamic IF block 512.F to periodically re-enable additional (or all) of the RF chains, and thus re-enable processing of additional zero-IF downconverted signal streams and/or non-zero IF downconverted signal streams. This may be triggered, for example, periodically (e.g., during a particular state as defined by a specific communication protocol), when signal quality or

other metric associated with the presently-processed signal stream degrades, when demodulation performance of the presently-processed signal stream falls below a threshold, etc. In this way, receiver 500 may dynamically adapt to the presence of unknown blocker signals while leveraging known diversity power saving schemes that are applied to virtual antenna signals.

[0059] FIG. 6 illustrates a block diagram of an example best IF selection receiver design, in accordance with an aspect of the disclosure. Aspects include receiver 600 further leveraging diversity antenna algorithms to identify the “best” RF chain, for example, via a comparison of any suitable number and/or type of metrics to one another and/or to a particular threshold value. Thus, receiver 600 may facilitate the identification of the “best” IF frequency-shifted signal (i.e., the best of the non-zero IF downconverted signal streams) during a particular time period and/or phase of the receiver’s operation (e.g., a detection phase). Once identified, the best IF may then be selected for subsequent RF signal reception during a different time period and/or phase of the receiver’s operation (e.g., the normal reception phase).

[0060] The example receiver 600 shown in FIG. 6 includes a similar architecture as the example receivers 400, 500, as shown in FIGs. 4-5. In particular, receivers 400, 500, 600 include respective RF front ends 402, 502 and respective baseband processors 412, 512. In aspects, RF front ends 402, 502, 602 and baseband processors 412, 512, 612, operate in a substantially similar manner, and therefore only differences between these components will be further discussed herein. For instance, for receiver 600, RF signals are processed via baseband processor 612 in a similar manner as discussed with reference to receivers 400, 500, although some differences exist between the RF front ends 402, 502, and 602. Additional common components of receivers 400, 500, and 600 are not labeled in FIG. 6 for purposes of brevity.

[0061] The two RF chains shown in FIG. 6 are part of the RF front end 602, with the antennas shown in FIG. 6 representing physical antennas, such as antennas 404.1 and 404.2 depicted in FIG. 4, for example. The two RF chains are shown in FIG. 6 for purposes of brevity, and receiver 600 may include any suitable number of RF chains and antennas in parallel with one another (or a single RF chain and antenna). In any event, the RF chains are each coupled to analog mixers 658.1, 658.2 and a digital mixers 659.1, 659.2, similar to the RF chains as shown in FIG. 4 that

are associated with the non-zero IF RF chains. Furthermore, the analog mixers 658.1, 658.2 are each coupled to an analog LO 660, and the digital mixers 659.1, 659.2 are coupled to a digital LO 661. The analog LO 660 and the digital LO 661 are each configured to generate a LO signal having a selectable LO frequency that is controlled by the baseband processor 612, as further discussed below. Thus, the RF front end 602 may implement one or more parallel RF chains to provide any suitable number of digitized downconverted signal streams to the baseband processor 612.

[0062] In an aspect, the digitized downconverted signal streams may, during a particular time period, have an IF frequency that is shifted from that of the received RF signal f_{RX} based upon the selected IF frequency f_{IF} . In an aspect, baseband processor 612 may execute instructions stored in best IF selection block 612.F to control which IF frequency is selected within the RF chains for the analog and digital downconversion of the received RF signal in an iterative manner. The baseband processor 612 may analyze the resulting digitized downconverted signal streams at each selected IF frequency during each separate time period, and then identify the “best” IF frequency to use for subsequent signal reception to mitigate spurious frequency responses due to the downconversion of a blocker signal.

[0063] To do so, aspects include the difference block 606 generating a signal that is output by the analog LO 660 and input to the analog mixers 658.1, 658.2. This signal has a frequency that is the difference of the received RF signal f_{RX} and the frequency f_{IF} selected by the baseband processor 612 via the switch 604. Moreover, the signal input to the digital LO 661 and input to the digital mixers 659.1, 659.2, is the selected frequency f_{IF} . Of course, the representation of the difference block 606 and the switch 604 is provided for illustrative purposes and ease of explanation, and aspects include receiver 600 implementing any suitable type of selectable and/or controllable system to appropriately adjust the frequencies of the analog LO 660 and the digital LO 661.

[0064] In any event, the baseband processor 612 may control the downconversion frequency such that, during each time period, the digitized downconverted signal streams have different IF frequencies. To provide an illustrative example, if the baseband processor 612 selects $f_{IF} = 0$ via the switch 604, then analog LO 660 would generate an LO signal equal to f_{RX} for analog

mixers 658.1, 658.2, and no digital downconversion would be implemented. In other words, for the selection of an IF frequency $f_{IF} = 0$, the digitized downconverted signal streams would be equivalent to the zero-IF downconverted signals discussed with reference to FIGs. 4 and 5 (e.g., the main receiver path).

[0065] Continuing this example, if a non-zero IF frequency is selected via the switch 604 equal to IF_1 , analog LO 660 would generate an LO signal having a frequency equal to $f_{RX} - IF_1$ for analog mixers 658.1, 658.2, and digital LO 661 would generate a digital LO signal having a frequency equal to IF_1 for digital mixers 659.1, 659.2. In other words, for the selection of a non-zero IF frequency IF_1 , the digitized downconverted signal streams would be equivalent to the non-zero-IF downconverted signal streams associated with the virtual antennas, as discussed with reference to FIGs. 4 and 5 (e.g., a diversity receiver path). Baseband processor 612 may continue the iterative process of selecting any suitable number N of frequencies $IF_1 \dots IF_N$, during different time periods and evaluating the quality of the resulting downconverted signal streams for each selected IF.

[0066] For example, if receiver 600 is configured to provide a zero IF frequency and two additional non-IF frequencies, then the RF chain shown in FIG. 6 would provide different sets of digitized downconverted signal streams represented as vectors $\vec{e}_1$ and $\vec{e}_2$ during three different time periods. During the first time period (for $IF = 0$), the digitized downconverted signal streams $\vec{e}_1$ and $\vec{e}_2$ would represent zero-IF downconverted signal streams. Then during a second, different time period (for $IF = IF_1$), the digitized downconverted signal streams $\vec{e}_1$ and $\vec{e}_2$ would represent non-zero IF downconverted signal streams, with the received RF signal being shifted by the IF frequency IF_1 . During a third, different time period (for $IF = IF_2$), the digitized downconverted signal streams $\vec{e}_1$ and $\vec{e}_2$ would represent non-zero IF downconverted signal streams, with the received RF signal being shifted by the IF frequency IF_2 .

[0067] In various aspects, the IF frequencies selected by the baseband processor 612 may be any suitable IF frequencies having any suitable granularity. Moreover, the baseband processor 612 may select different IF frequencies via any suitable schedule or manner. For example, specific IF frequencies may be selected based upon a particular combination of aggregated carrier frequencies and/or based upon an operating mode of the device in which receiver 600 is

implemented. To provide another example, the IF frequencies may be stepped through in a specific manner randomly, or based upon a particular communication protocol or mode of operation of the device in which receiver 600 is implemented.

[0068] Regardless of the number, type, or manner in which the different IF frequencies are selected, aspects include the baseband processor 612 executing instructions stored in the best IF selection block 612.F to determine an IF frequency for RF signal reception. To do so, the best IF selection block 612.F may implement similar algorithms as known algorithms utilized for best physical antenna selection in diversity receivers. For example, the best IF selection block 612.F may facilitate baseband processor 612 measuring and/or estimating one or more characteristics of the resulting digitized downconverted signal streams during each time period.

[0069] Then, similar to best antenna selection algorithms utilized for the selection of physical antennas, the baseband processor 612 may identify the best virtual antenna is best for reception by measuring similar metrics, for example, as those discussed above with reference to FIG. 5. In this case, the best selected antenna corresponds to the best IF frequency associated with a particular virtual antenna. In other words, by adapting algorithms used to select the best physical antennas used in diversity receiver schemes to virtual antennas discussed herein, the selection of a best IF for RF signal reception (e.g., an IF that leads to a minimum or no spurious frequency responses in the downconverted signal stream), may be determined.

[0070] In some aspects, there may be a fixed or predetermined number of available IF values from which the baseband processor 612 may select. In other aspects, the baseband processor 612 may execute instructions stored in the best IF selection block 612.F to iteratively select arbitrary or random IF values.

[0071] In still other aspects, the receiver 600 may be configured to facilitate a different IF selection per physical antenna. In other words, the two RF chains shown in FIG. 6, as well as any other RF chains that may be implemented in the receiver 600, need not utilize the same analog LO 660 and digital LO 661 for downconversion. Instead, each RF chain may utilize a separate analog and digital LO, with baseband processor 612 controlling the frequency provided by each analog and digital LO separately (e.g., via more than one switch 604 and difference block 606).

- [0072] Although the aspects described herein may be particularly useful for identifying blocker signals not known *a priori*, these aspects may be extended to testing and/or lab use associated with the initial design, configuration, and/or setup of receivers. For example, the aspects described herein may be applied in a lab environment as a built in self-test (BIST) to increase the speed in which blocker tests may be performed at the stage of product testing and design.
- [0073] To provide an illustrative examples, the aspects described herein may be implemented in accordance with a channel frequency sweep simulating the received RF signals to identify critical channel frequencies (or combinations thereof) by applying an external or internal blocker signal at the third harmonic of the channel frequency. Continuing this example, a receiver implementing this test procedure may sequentially apply the zero-IF and low-IF concepts described herein to the RF chains associated with the main and diversity receiver paths, respectively.
- [0074] By measuring certain signal characteristics (e.g., RSSI measurements) on the respective main and diversity paths, the best performing solution and the most critical channels can be found. Such an implementation may be useful, for instance, to increase the speed and efficiency of device characterization (e.g., via software design tools), to decrease the time taken to perform platform and engine development, to identify board-to-board variances, etc. The results of such testing operations may then be stored, for example, in a memory integrated as part of the baseband processor 612 and/or accessible by the baseband processor 612 for re-use during operation of the receiver after design has been completed.

Examples

[0075] The following examples pertain to further aspects.

[0076] Example 1 is a device, comprising: a first radio frequency (RF) chain configured to receive an RF signal and a blocker signal, and to downconvert the received RF signal at a first local oscillator (LO) frequency to provide a first downconverted RF signal at a first intermediate frequency (IF); a second RF chain configured to downconvert the received RF signal at a second LO frequency that is different than the first LO frequency to provide a second downconverted RF signal at a second IF; and one or more processors configured to process data included in the first downconverted RF signal and the second downconverted RF signal to determine which of the first RF chain or the second RF chain to use for subsequent RF signal reception to prevent distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal.

[0077] In Example 2, the subject matter of Example 1, wherein the first IF is substantially equal to zero, and wherein the second IF frequency is based upon the difference between the first LO frequency and the second LO frequency.

[0078] In Example 3, the subject matter of one or more of Examples 1-2, wherein the second RF chain is further configured to digitally mix the second downconverted RF signal with a third LO frequency that is equal to the second IF.

[0079] In Example 4, the subject matter of one or more of Examples 1-3, wherein the second RF chain downconverts the blocker signal at the second LO frequency to shift the spur out of an operating communications band used in accordance with the received RF signal.

[0080] In Example 5, the subject matter of one or more of Examples 1-4, wherein the first RF chain includes a physical antenna that receives the RF signal, and wherein the second RF chain couples the RF signal that is downconverted to the second downconverted RF signal at the second IF via the physical antenna of the first RF chain.

[0081] In Example 6, the subject matter of one or more of Examples 1-5, wherein the one or more processors are configured to attenuate one of the first downconverted RF signal or the second downconverted RF signal that includes distortions caused by the spur, and to process data in

one of the first downconverted RF signal or the second downconverted RF signal that is not attenuated.

[0082] In Example 7, the subject matter of one or more of Examples 1-6, wherein the one or more processors are configured to attenuate the one of the first downconverted RF signal or the second downconverted RF signal by applying a noise whitening process to the first downconverted RF signal and the second downconverted RF signal.

[0083] Example 8 is a device, comprising: a plurality of antennas, each antenna from among the plurality of antennas being coupled to (i) a respective one of a plurality of first radio frequency (RF) chains, and (ii) a respective one of a plurality of second radio frequency (RF) chains, wherein each first RF chain from among the plurality of first RF chains is configured to receive a respective RF signal and a respective blocker signal, and to downconvert each respectively received RF signal at a first local oscillator (LO) frequency to provide a plurality of zero intermediate frequency (IF) signal streams, wherein each second RF chain from among the plurality of second RF chains is configured to receive a respective RF signal and a respective blocker signal, and to downconvert each respectively received RF signal at a second LO frequency that is different than the first LO frequency to provide a plurality of non-zero IF signal streams; and one or more processors configured to selectively process data included in the plurality of zero IF signal streams and the plurality of non-zero IF signal streams to avoid processing data including distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal.

[0084] In Example 9, the subject matter of Example 8, wherein the one or more processors are configured to selectively switch off one or more RF chains from among the plurality of second RF chains based upon which of the plurality of non-zero IF signal streams include distortions caused by the spur.

[0085] In Example 10, the subject matter of one or more of Examples 8-9, wherein the one or more processors are configured to measure signal characteristics associated with the each stream from among the plurality of non-zero IF signal streams, and to switch off one or more RF chains from among the plurality of second RF chains based upon the measured signal characteristics.

- [0086]** In Example 11, the subject matter of one or more of Examples 8-10, wherein each second RF chain from among the plurality of second RF chains is further configured to digitally mix each respectively received RF signal after downconversion at the second LO frequency with a third LO frequency.
- [0087]** In Example 12, the subject matter of one or more of Examples 8-11, wherein the third LO frequency is equal to a difference between the first LO and the second LO.
- [0088]** In Example 13, the subject matter of one or more of Examples 8-12, wherein each second RF chain from among the plurality of second RF chains is configured to downconvert the blocker signal at the second LO frequency to shift the spur out of an operating communications band associated with the received RF signal.
- [0089]** In Example 14, the subject matter of one or more of Examples 8-13, wherein the one or more processors are configured to selectively process data included in the plurality of zero IF signal streams and the plurality of non-zero IF signal streams by attenuating one or more of the plurality of non-zero IF signal streams that include distortions caused by the spur, and to selectively process data in one or more of the plurality of non-zero IF signal streams that are not attenuated.
- [0090]** In Example 15, the subject matter of one or more of Examples 8-14, wherein the one or more processors are configured to attenuate the one or more of the plurality of non-zero IF signal streams that include distortions caused by the spur by applying a noise whitening process to the plurality of non-zero IF signal streams.
- [0091]** Example 16 is a device, comprising: a radio frequency (RF) chain configured to receive an RF signal and a blocker signal, and to downconvert the received RF signal at a local oscillator (LO) frequency to provide a downconverted signal stream; and one or more processors configured to: adjust the LO frequency at different time periods to generate a plurality of downconverted signal streams, each signal stream from among the plurality of downconverted signal streams having a different intermediate frequency (IF) corresponding to the LO frequency used for downconversion of the received RF signal during each of the different time periods, measure one or more signal characteristics associated with each of the plurality of downconverted signal streams, identify, using the measured signal characteristics, which of

the LO frequencies avoid distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal, and downconvert and process data for RF signals received subsequent to the received RF signal in accordance with the identified one or more LO frequencies.

[0092] In Example 17, the subject matter of Example 16, wherein the LO frequency is adjusted based upon a communication protocol used to receive the RF signal.

[0093] In Example 18, the subject matter of one or more of Examples 16-17, wherein the LO frequency is iteratively adjusted in accordance with a predetermined number of LO frequencies.

[0094] In Example 19, the subject matter of one or more of Examples 16-18, wherein one of the plurality of downconverted signal streams has an IF substantially equal to zero.

[0095] In Example 20, the subject matter of one or more of Examples 16-19, wherein the RF chain is further configured to digitally mix each of the plurality of downconverted signal streams during each respective different time period with another LO frequency that is equal to the IF of the respective downconverted signal stream during that time period.

[0096] In Example 21, the subject matter of one or more of Examples 16-20, wherein the identified one or more LO frequencies, when used to downconvert the subsequently received RF signals, cause the resulting respective downconverted signal streams to shift the spur out of an operating communications band that is associated with the subsequently received RF signals.

[0097] Example 22 is a device means, comprising: a first radio frequency (RF) chain means for receiving an RF signal and a blocker signal, and for downconverting the received RF signal at a first local oscillator (LO) frequency to provide a first downconverted RF signal at a first intermediate frequency (IF); a second RF chain means for downconverting the received RF signal at a second LO frequency that is different than the first LO frequency to provide a second downconverted RF signal at a second IF; and one or more processor means for processing data included in the first downconverted RF signal and the second downconverted RF signal to determine which of the first RF chain or the second RF chain to use for subsequent RF signal reception to prevent distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal.

- [0098]** In Example 23, the subject matter of Example 22, wherein the first IF is substantially equal to zero, and wherein the second IF frequency is based upon the difference between the first LO frequency and the second LO frequency.
- [0099]** In Example 24, the subject matter of one or more of Examples 22-23, wherein the second RF chain means digitally mixes the second downconverted RF signal with a third LO frequency that is equal to the second IF.
- [0100]** In Example 25, the subject matter of one or more of Examples 22-24, wherein the second RF chain means downconverts the blocker signal at the second LO frequency to shift the spur out of an operating communications band used in accordance with the received RF signal.
- [0101]** In Example 26, the subject matter of one or more of Examples 22-25, wherein the first RF chain means includes a physical antenna that receives the RF signal, and wherein the second RF chain means couples the RF signal that is downconverted to the second downconverted RF signal at the second IF via the physical antenna of the first RF chain means.
- [0102]** In Example 27, the subject matter of one or more of Examples 22-26, wherein the one or more processor means attenuate one of the first downconverted RF signal or the second downconverted RF signal that includes distortions caused by the spur, and process data in one of the first downconverted RF signal or the second downconverted RF signal that is not attenuated.
- [0103]** In Example 28, the subject matter of one or more of Examples 22-27, wherein the one or more processor means attenuate the one of the first downconverted RF signal or the second downconverted RF signal by applying a noise whitening process to the first downconverted RF signal and the second downconverted RF signal.
- [0104]** Example 29 is a device means, comprising: a plurality of antenna means, each antenna means from among the plurality of antenna means being coupled to (i) a respective one of a plurality of first radio frequency (RF) chain means, and (ii) a respective one of a plurality of second radio frequency (RF) chain means, wherein each first RF chain means from among the plurality of first RF chain means receives a respective RF signal and a respective blocker signal, and downconverts each respectively received RF signal at a first local oscillator (LO) frequency to provide a plurality of zero intermediate frequency (IF) signal streams, wherein each second RF

chain means from among the plurality of second RF chain means receives a respective RF signal and a respective blocker signal, and downconvert each respectively received RF signal at a second LO frequency that is different than the first LO frequency to provide a plurality of non-zero IF signal streams; and one or more processor means for selectively processing data included in the plurality of zero IF signal streams and the plurality of non-zero IF signal streams to avoid processing data including distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal.

[0105] In Example 30, the subject matter of Example 29, wherein the one or more processor means selectively switch off one or more RF chain means from among the plurality of second RF chain means based upon which of the plurality of non-zero IF signal streams include distortions caused by the spur.

[0106] In Example 31, the subject matter of one or more of Examples 29-30, wherein the one or more processor means measure signal characteristics associated with the each stream from among the plurality of non-zero IF signal streams, and to switch off one or more RF chains from among the plurality of second RF chains based upon the measured signal characteristics.

[0107] In Example 32, the subject matter of one or more of Examples 29-31, wherein each second RF chain means from among the plurality of second RF chain means digitally mixes each respectively received RF signal after downconversion at the second LO frequency with a third LO frequency.

[0108] In Example 33, the subject matter of one or more of Examples 29-32, wherein the third LO frequency is equal to a difference between the first LO and the second LO.

[0109] In Example 34, the subject matter of one or more of Examples 29-33, wherein each second RF chain means from among the plurality of second RF chain means downconverts the blocker signal at the second LO frequency to shift the spur out of an operating communications band associated with the received RF signal.

[0110] In Example 35, the subject matter of one or more of Examples 29-34, wherein the one or more processor means selectively process data included in the plurality of zero IF signal streams and the plurality of non-zero IF signal streams by attenuating one or more of the plurality of non-

zero IF signal streams that include distortions caused by the spur, and to selectively process data in one or more of the plurality of non-zero IF signal streams that are not attenuated.

[0111] In Example 36, the subject matter of one or more of Examples 29-35, wherein the one or more processor means attenuate the one or more of the plurality of non-zero IF signal streams that include distortions caused by the spur by applying a noise whitening process to the plurality of non-zero IF signal streams.

[0112] Example 37 is a device means, comprising: a radio frequency (RF) chain means for receiving an RF signal and a blocker signal, and downconvert the received RF signal at a local oscillator (LO) frequency to provide a downconverted signal stream; and one or more processor means for: adjusting the LO frequency at different time periods to generate a plurality of downconverted signal streams, each signal stream from among the plurality of downconverted signal streams having a different intermediate frequency (IF) corresponding to the LO frequency used for downconversion of the received RF signal during each of the different time periods, measuring one or more signal characteristics associated with each of the plurality of downconverted signal streams, identifying, using the measured signal characteristics, which of the LO frequencies avoid distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal, and downconverting and process data for RF signals received subsequent to the received RF signal in accordance with the identified one or more LO frequencies.

[0113] In Example 38, the subject matter of Example 37, wherein the LO frequency is adjusted based upon a communication protocol used to receive the RF signal.

[0114] In Example 39, the subject matter of one or more of Examples 37-38, wherein the LO frequency is iteratively adjusted in accordance with a predetermined number of LO frequencies.

[0115] In Example 40, the subject matter of one or more of Examples 37-39, wherein one of the plurality of downconverted signal streams has an IF substantially equal to zero.

[0116] In Example 41, the subject matter of one or more of Examples 37-40, wherein the RF chain means digitally mixes each of the plurality of downconverted signal streams during each

respective different time period with another LO frequency that is equal to the IF of the respective downconverted signal stream during that time period.

[0117] In Example 42, the subject matter of one or more of Examples 37-41, wherein the identified one or more LO frequencies, when used to downconvert the subsequently received RF signals, cause the resulting respective downconverted signal streams to shift the spur out of an operating communications band that is associated with the subsequently received RF signals.

[0118] An apparatus as shown and described

[0119] A method as shown and described.

Conclusion

- [0120]** The aspects described herein implement IF-shifting techniques to avoid downconversion of blocker signals that lead to spurs. Often these blocker signals are downconverted with the third harmonic of the LO signal, although the aspects described herein are not limited to this particular use case. The aspects described herein may be applicable to mitigating noise and/or blocker signals from any source, and spurs caused by downconversion of blocker signals at any harmonic of the LO.
- [0121]** For example, the aspects described herein may be used to optimize the receive behavior for any IF-dependent RF signal degradation. Furthermore, the aspects described herein may be implemented to mitigate other types of noise or degradation (e.g., flicker noise effects), while evaluating the result of the parallel zero (IF=0) and low-IF path. Such evaluations may be of particular importance, for instance, for low bandwidth scenarios.
- [0122]** The aforementioned description of the specific aspects will so fully reveal the general nature of the disclosure that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific aspects, without undue experimentation, and without departing from the general concept of the present disclosure. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed aspects, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.
- [0123]** References in the specification to “one aspect,” “an aspect,” “an exemplary aspect,” etc., indicate that the aspect described may include a particular feature, structure, or characteristic, but every aspect may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same aspect. Further, when a particular feature, structure, or characteristic is described in connection with an aspect, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other aspects whether or not explicitly described.

- [0124] The exemplary aspects described herein are provided for illustrative purposes, and are not limiting. Other exemplary aspects are possible, and modifications may be made to the exemplary aspects. Therefore, the specification is not meant to limit the disclosure. Rather, the scope of the disclosure is defined only in accordance with the following claims and their equivalents.
- [0125] Aspects may be implemented in hardware (*e.g.*, circuits), firmware, software, or any combination thereof. Aspects may also be implemented as instructions stored on a machine-readable medium, which may be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (*e.g.*, a computing device). For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other forms of propagated signals (*e.g.*, carrier waves, infrared signals, digital signals, etc.), and others. Further, firmware, software, routines, instructions may be described herein as performing certain actions. However, it should be appreciated that such descriptions are merely for convenience and that such actions in fact results from computing devices, processors, controllers, or other devices executing the firmware, software, routines, instructions, etc. Further, any of the implementation variations may be carried out by a general purpose computer.
- [0126] For the purposes of this discussion, the term “processor circuitry” shall be understood to be circuit(s), processor(s), logic, or a combination thereof. For example, a circuit can include an analog circuit, a digital circuit, state machine logic, other structural electronic hardware, or a combination thereof. A processor can include a microprocessor, a digital signal processor (DSP), or other hardware processor. The processor can be “hard-coded” with instructions to perform corresponding function(s) according to aspects described herein. Alternatively, the processor can access an internal and/or external memory to retrieve instructions stored in the memory, which when executed by the processor, perform the corresponding function(s) associated with the processor, and/or one or more functions and/or operations related to the operation of a component having the processor included therein.

[0127] In one or more of the exemplary aspects described herein, processor circuitry can include memory that stores data and/or instructions. The memory can be any well-known volatile and/or non-volatile memory, including, for example, read-only memory (ROM), random access memory (RAM), flash memory, a magnetic storage media, an optical disc, erasable programmable read only memory (EPROM), and programmable read only memory (PROM). The memory can be non-removable, removable, or a combination of both.

[0128] As will be apparent to a person of ordinary skill in the art based on the teachings herein, exemplary aspects are not limited to the 802.11 protocols (*e.g.*, Wi-Fi and WiGig), and can be applied to other wireless protocols, including (but not limited to) Bluetooth, Near-field Communication (NFC) (ISO/IEC 18092), ZigBee (IEEE 802.15.4), Radio-frequency identification (RFID), and/or other wireless protocols as would be understood by one of ordinary skill in the relevant arts. Further, exemplary aspects are not limited to the above wireless protocols and can be used or implemented in one or more wired networks using one or more well-known wired specifications and/or protocols.

WHAT IS CLAIMED IS:

1. A device, comprising:

a first radio frequency (RF) chain configured to receive an RF signal and a blocker signal, and to downconvert the received RF signal at a first local oscillator (LO) frequency to provide a first downconverted RF signal at a first intermediate frequency (IF);

a second RF chain configured to downconvert the received RF signal at a second LO frequency that is different than the first LO frequency to provide a second downconverted RF signal at a second IF; and

one or more processors configured to process data included in the first downconverted RF signal and the second downconverted RF signal to determine which of the first RF chain or the second RF chain to use for subsequent RF signal reception to prevent distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal.

2. The device of claim 1, wherein the first IF is substantially equal to zero, and

wherein the second IF frequency is based upon the difference between the first LO frequency and the second LO frequency.

3. The device of either claim 1 or claim 2, wherein the second RF chain is further configured to digitally mix the second downconverted RF signal with a third LO frequency that is equal to the second IF.

4. The device of either claim 1 or claim 2, wherein the second RF chain downconverts the blocker signal at the second LO frequency to shift the spur out of an operating communications band used in accordance with the received RF signal.

5. The device of either claim 1 or claim 2, wherein the first RF chain includes a physical antenna that receives the RF signal, and

wherein the second RF chain couples the RF signal that is downconverted to the second downconverted RF signal at the second IF via the physical antenna of the first RF chain.

6. The device of either claim 1 or claim 2, wherein the one or more processors are configured to attenuate one of the first downconverted RF signal or the second downconverted RF signal that includes distortions caused by the spur, and to process data in one of the first downconverted RF signal or the second downconverted RF signal that is not attenuated.

7. The device of claim 6, wherein the one or more processors are configured to attenuate the one of the first downconverted RF signal or the second downconverted RF signal by applying a noise whitening process to the first downconverted RF signal and the second downconverted RF signal.

8. A device, comprising:

a plurality of antennas, each antenna from among the plurality of antennas being coupled to (i) a respective one of a plurality of first radio frequency (RF) chains, and (ii) a respective one of a plurality of second radio frequency (RF) chains,

wherein each first RF chain from among the plurality of first RF chains is configured to receive a respective RF signal and a respective blocker signal, and to downconvert each respectively received RF signal at a first local oscillator (LO) frequency to provide a plurality of zero intermediate frequency (IF) signal streams,

wherein each second RF chain from among the plurality of second RF chains is configured to receive a respective RF signal and a respective blocker signal, and to downconvert each respectively received RF signal at a second LO frequency that is different than the first LO frequency to provide a plurality of non-zero IF signal streams; and

one or more processors configured to selectively process data included in the plurality of zero IF signal streams and the plurality of non-zero IF signal streams to avoid processing data including distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal.

9. The device of claim 8, wherein the one or more processors are configured to selectively switch off one or more RF chains from among the plurality of second RF chains based upon which of the plurality of non-zero IF signal streams include distortions caused by the spur.

10. The device of claim 9, wherein the one or more processors are configured to measure signal characteristics associated with the each stream from among the plurality of non-zero IF signal streams, and to switch off one or more RF chains from among the plurality of second RF chains based upon the measured signal characteristics.

11. The device of any one of claims 8-10, wherein each second RF chain from among the plurality of second RF chains is further configured to digitally mix each respectively received RF signal after downconversion at the second LO frequency with a third LO frequency.

12. The device of claim 11, wherein the third LO frequency is equal to a difference between the first LO and the second LO.

13. The device any one of claims 8-10, wherein each second RF chain from among the plurality of second RF chains is configured to downconvert the blocker signal at the second LO frequency to shift the spur out of an operating communications band associated with the received RF signal.

14. The device of any one of claims 8-10, wherein the one or more processors are configured to selectively process data included in the plurality of zero IF signal streams and the plurality of non-zero IF signal streams by attenuating one or more of the plurality of non-zero IF signal streams that include distortions caused by the spur, and to selectively process data in one or more of the plurality of non-zero IF signal streams that are not attenuated.

15. The device of claim 14, wherein the one or more processors are configured to attenuate the one or more of the plurality of non-zero IF signal streams that include distortions caused by the spur by applying a noise whitening process to the plurality of non-zero IF signal streams.

16. A device, comprising:

a radio frequency (RF) chain configured to receive an RF signal and a blocker signal, and to downconvert the received RF signal at a local oscillator (LO) frequency to provide a downconverted signal stream; and

one or more processors configured to:

adjust the LO frequency at different time periods to generate a plurality of downconverted signal streams, each signal stream from among the plurality of downconverted signal streams having a different intermediate frequency (IF) corresponding to the LO frequency used for downconversion of the received RF signal during each of the different time periods,

measure one or more signal characteristics associated with each of the plurality of downconverted signal streams,

identify, using the measured signal characteristics, which of the LO frequencies avoid distortions caused by a spurious response frequency (spur) introduced via downconversion of the blocker signal, and

downconvert and process data for RF signals received subsequent to the received RF signal in accordance with the identified one or more LO frequencies.

17. The device of claim 16, wherein the LO frequency is adjusted based upon a communication protocol used to receive the RF signal.

18. The device of either claim 16 or claim 17, wherein the LO frequency is iteratively adjusted in accordance with a predetermined number of LO frequencies.

19. The device of either claim 16 or claim 17, wherein one of the plurality of downconverted signal streams has an IF substantially equal to zero.

20. The device of either claim 16 or claim 17, wherein the RF chain is further configured to digitally mix each of the plurality of downconverted signal streams during each respective different

time period with another LO frequency that is equal to the IF of the respective downconverted signal stream during that time period.

21. The device of either claim 16 or claim 17, wherein the identified one or more LO frequencies, when used to downconvert the subsequently received RF signals, cause the resulting respective downconverted signal streams to shift the spur out of an operating communications band that is associated with the subsequently received RF signals.

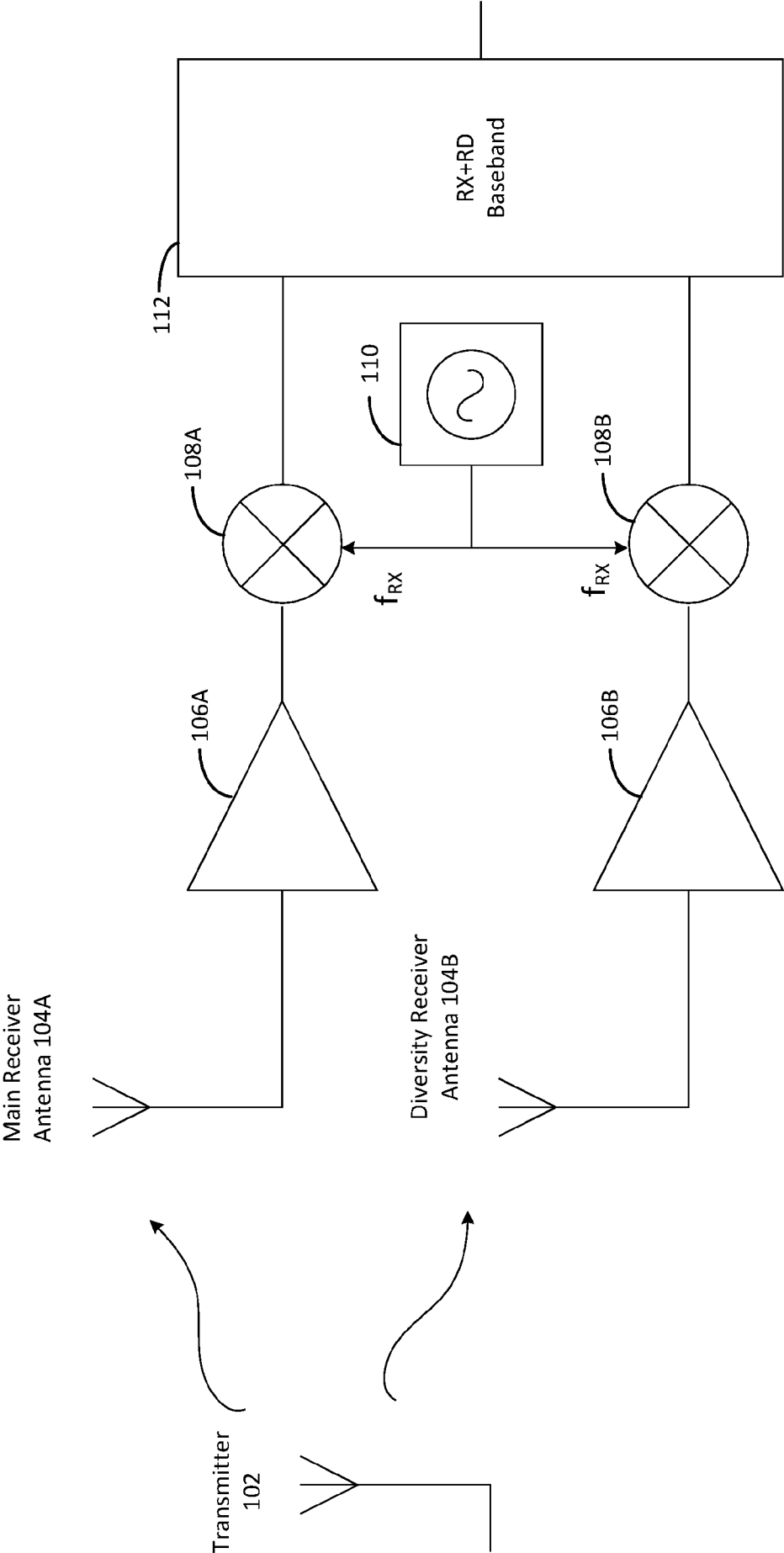


FIG. 1

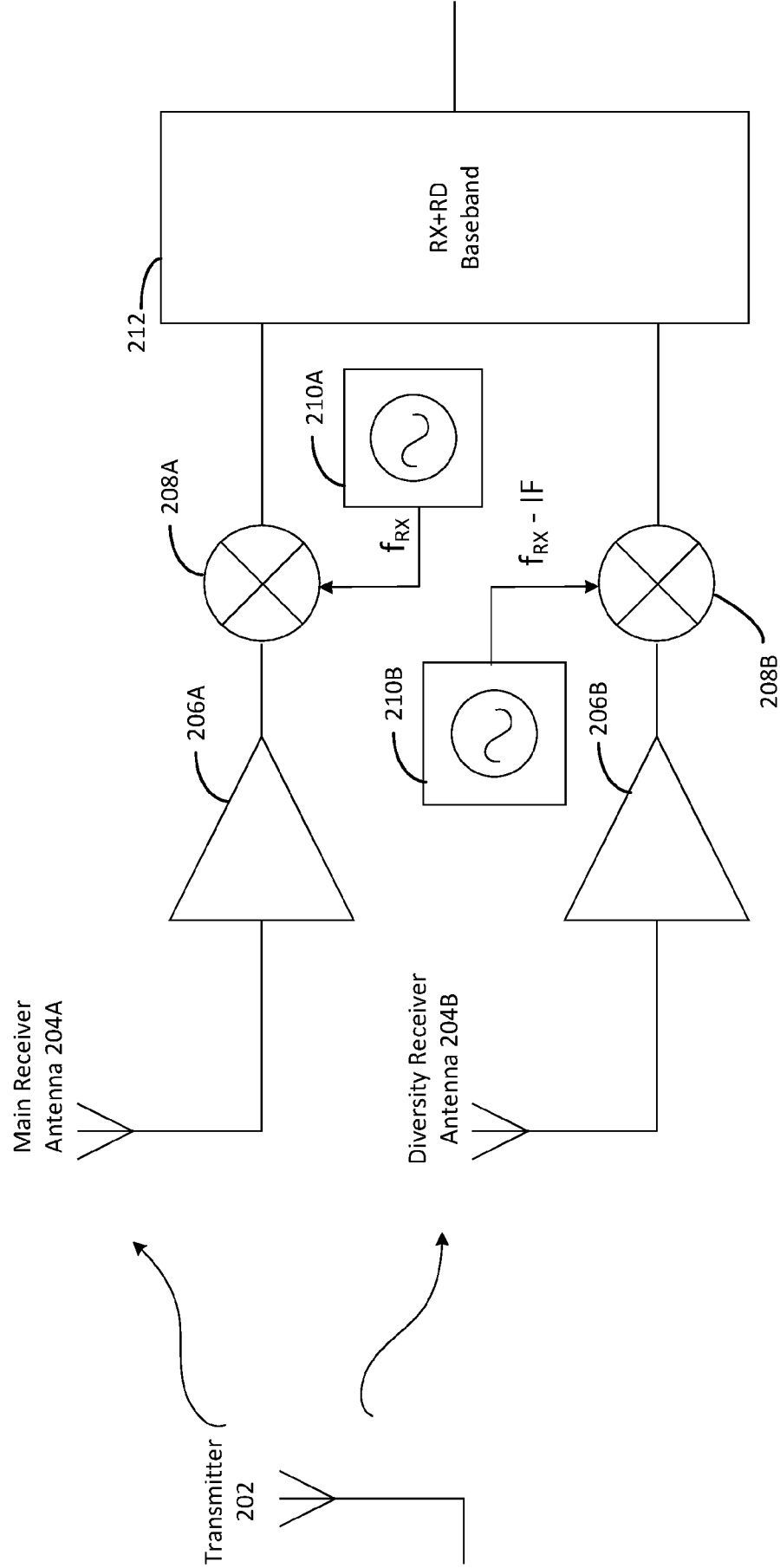
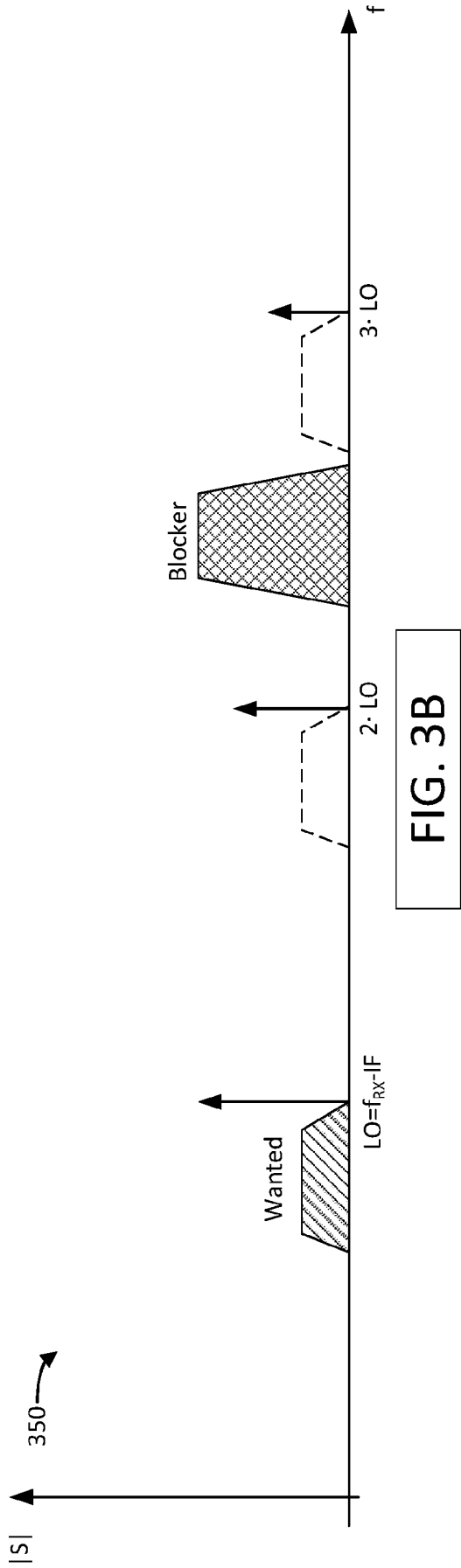
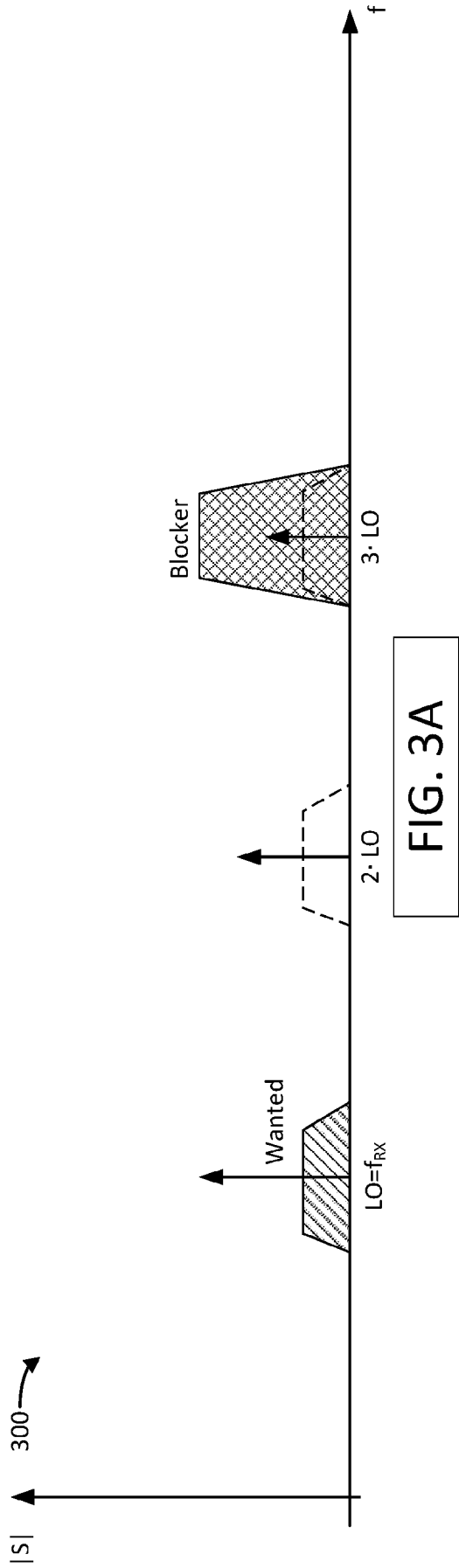


FIG. 2



400

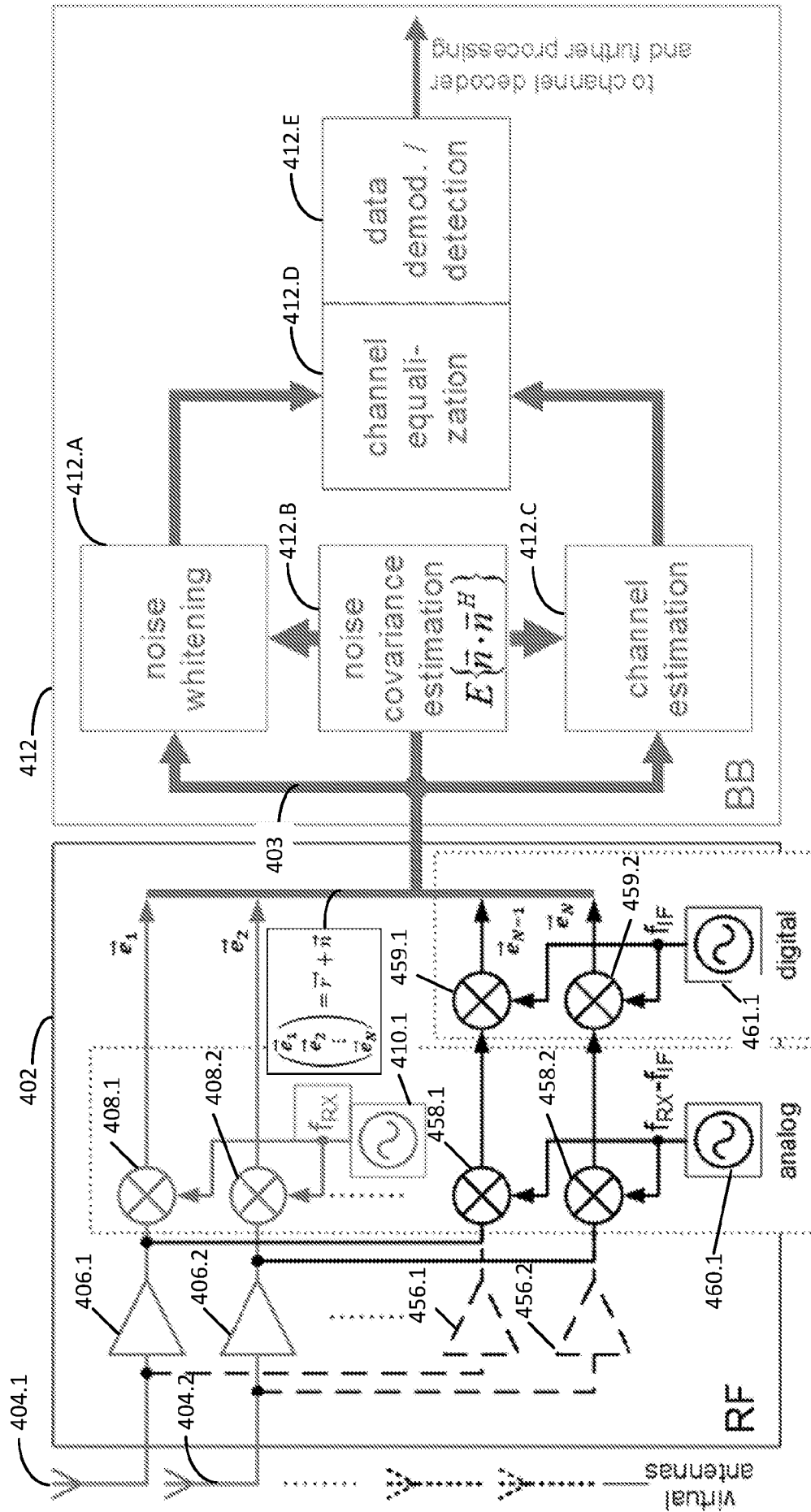


FIG. 4

500

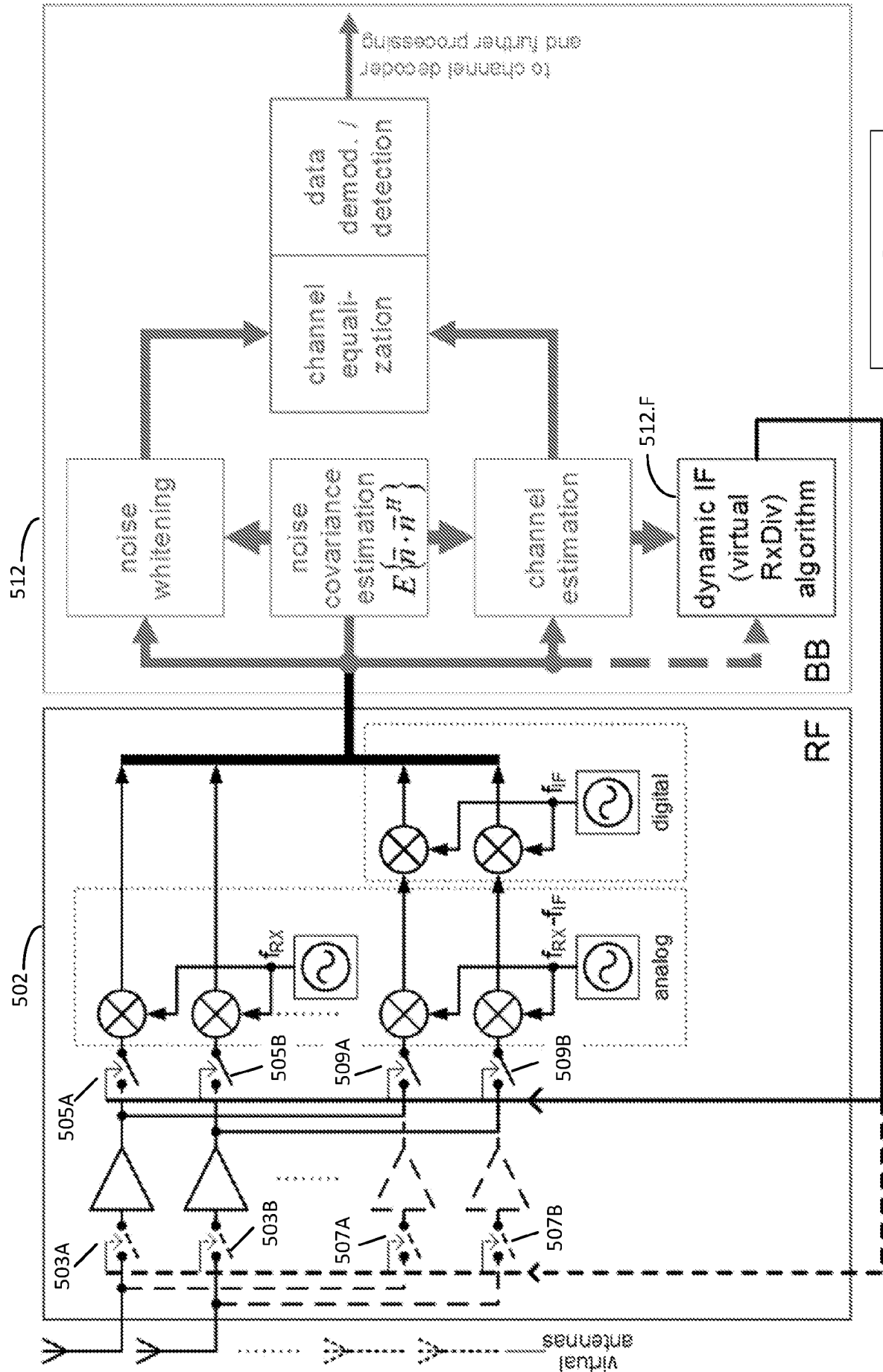
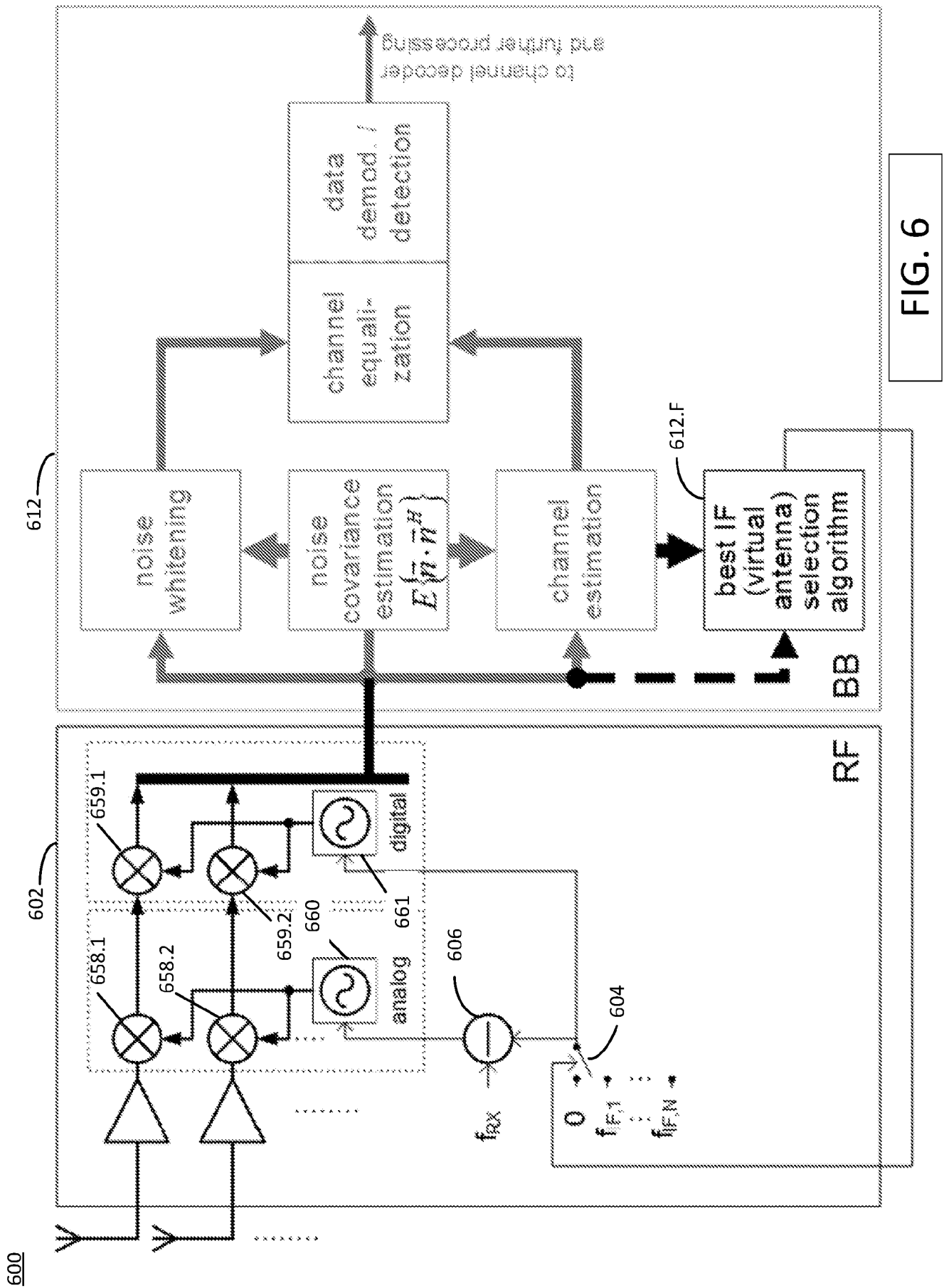


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 18/39711

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H05B 7/08; H04B 1/26; H03D 7/16 (2018.01)
CPC - G06F 12/0815; H03D 7/163; H03D 7/165;

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)

See Search History Document

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

See Search History Document

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

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y --- A	US 2015/0236887 A1 (Broadcom Corporation) 20 August 2015 (20.08.2015); entire document, especially, abstract, FIG. 5-9, 13, para [0007], [0062], [0067], [0070], [0080], [0087]-[0089], [0109], [0110], [0117], [0129]	1, 2, 4, 5, 8, 13/8 ----- 3, 9-12, 13/(9-10) ----- 6, 7, 14-21
Y Y --- A	US 2017/0353929 A1 (ISCO International LLC) 07 December 2017 (07.12.2017); entire document, especially, abstract, FIG. 8, para [0084] US 2015/0110058 A1 (Celeno Communications (Israel) Ltd) 23 April 2015 (23.04.2015); entire document, especially, abstract, FIG. 1, 3, para [0036], [0047], [0060]	3, 11, 12 9, 10, 11/(9-10), 12/11/9, 12/11/10, 13/(9-10) ----- 14/(9-10), 15/14/9, 15/14/10, 16-21
A	US 2012/0076229 A1 (Brobston et al.) 29 March 2012 (29.03.2012); entire document	1-21
A	US 2016/0072656 A1 (Telefonaktiebolaget L M Ericsson) 10 March 2016 (10.03.2016); entire document	1-21
A	US 2015/0334710 A1 (Qualcomm Incorporated) 19 November 2015 (19.11.2015); entire document,	1-21

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

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"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

22 August 2018

Date of mailing of the international search report

18 SEP 2018

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