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(54) Title: TECHNIQUE FOR TESTING LTE-ADVANCED CARRIER AGGREGATION RECEIVER CHARACTERISTICS

Fig. 1C

(57) Abstract: The invention relates to a technique for testing LTE-Advanced Carrier Aggregation CA receiver characteristics. According to a method aspect, for measuring at least a first measured carrier and a second measured carrier of a 3DL, 4DL or 5DL CA operating band set defining at least three downlink carriers, test measurements 170 for the first measured carrier and the second measured carrier are simultaneously performed.

Technique for Testing LTE-Advanced Carrier Aggregation Receiver Characteristics

Technical Field

The invention relates to a method of testing LTE-Advanced Carrier Aggregation receiver characteristics, for example for performing conformance tests such as blocking tests, and further relates to a software implementing corresponding test cases, and a correspondingly configured test system.

Background

LTE-Advanced (LTE Release 10 & beyond) is a 4G (4^{th} Generation) mobile communication system enhancing the basic LTE technology is specified in 3GPP Release 8. Carrier Aggregation (CA) is among the multiple features introduced with LTE-Advanced. In order to increase bandwidth and thereby bitrate, an LTE-Advanced capable UE (User Equipment) can be allocated DL (Downlink) and UL (Uplink) aggregated resources comprising two or more carriers, wherein aggregated carriers are referred to as Component Carriers (CC).

Three different modes of CA are defined within LTE-Advanced:

- intra-band contiguous CA,
- intra-band non-contiguous CA, and
- inter-band CA.

Intra-band CA relates to carrier aggregation wherein the component carriers belong to the same operating frequency band. For contiguous CA, contiguous component carriers are

allocated while for non-contiguous CA carriers are allocated with one or more gaps thereinbetween. In case of inter-band CA, the component carriers belong to different operating frequency bands.

A component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 Megahertz (MHz) and it is envisaged that a maximum of five component carriers can be aggregated, resulting in a maximum aggregated bandwidth of 100 MHz instead of at most 20 MHz without CA. However, according to Release 11 the maximum number of carriers in DL is 2, i.e. 2DL CA and therefore maximum aggregated bandwidth is 40 MHz. As an example, 3GPP TS 36.101 version 11.6.0 Release 11 may be consulted for further details on required UE transmission and reception characteristics.

It is envisaged that more than two, i.e. three downlink carrier aggregation (3DL CA), four downlink carrier aggregation (4DL CA), or five downlink carrier aggregation (5DL CA) will be introduced in the next releases to come. Current implementations are also restricted to one UL carrier, i.e. no CA on UL, while 2UL CA systems can be contemplated for future releases.

UEs can be said to support a specific functionality in case they have tested accordingly to verify proper functioning. 3GPP TS 36.508 version 11.2.0, for example, defines a common test environment for UE conformance testing in Rel. 11 and 3GPP TS 36.521-1 version 11.2.0 Release 11 defines UE conformance specifications for radio transmission and reception for conformance testing including measurement procedures for the conformance tests. Test cases are defined for testing UE capabilities such as reference sensitivity level, maximum input level,

adjacent channel selectivity, blocking characteristics, etc., wherein test cases are defined without taking the CA feature into account, i.e. a single carrier is established only, while other test cases measure the UE capabilities when CA is active, i.e. for 2DL CA in case of Rel. 11.

"Testing LTE Advanced - Application Note" retrievable from http://www.rohde-schwarz.com/en/solutions/wireless-communications/lte/applications/applications_57856.html, also to be found on the Rohde & Schwarz web pages by searching for 'Applications & White Papers for LTE / LTE-Advanced', describes aspects of test environments for testing LTE-Advanced technology components and discusses various testing aspects of such technology components.

A testcase for 2DL CA may comprise picking one of the DL component carriers as the measured carrier and keep the other DL component carrier active; assign an uplink to the band not containing the measured carrier; and then perform the measurements. For example, for selectivity and blocking tests, interferers may be assigned relative to the measured carrier. The test is then to be repeated by swapping the roles of the measured and non-measured carriers/channels.

It can be contemplated that with increasing number of CCs (up to 5) in CA, the number of test cases to be performed multiplies for comprehensive testing, as the tests are to be repeated according to the number of component carriers available.

In order to limit test resources or test efforts in terms of, for example, number of test cases, test time, etc., a routine measure may be to limit sets or suites of test

cases to cover random samples or combinations of tested parameter combinations. However, such approach results in incomplete test coverage and for a given fixed test effort the coverage will decrease rapidly from 2DL CA to 3DL CA and further beyond.

Summary of the invention

There is a need for an approach for testing LTE-Advanced CA receiver characteristics for 3DL CA and beyond, wherein the approach enables limiting test resources such as test time, while at the same time a test coverage is optimized.

The above need is satisfied by a method of testing LTE-Advanced CA receiver characteristics according to claims 1 or 10, a computer-readable medium having corresponding computer-executable instructions according to claim 11, and a corresponding test system according to claim 12.

According to one aspect, a method of testing LTE-Advanced CA receiver characteristics comprises, for measuring at least a first measured carrier and a second measured carrier of a 3DL, 4DL or 5DL CA operating band set defining at least three downlink carriers, establishing one of the non-measured downlink carriers as primary component carrier and establishing the first and second measured carriers as secondary component carriers; and simultaneously performing test measurements for the first measured carrier and the second measured carrier.

The component carriers can be established according to at least one of intra-band contiguous CA, intra-band non-contiguous CA, and inter-band CA.

The tests and/or measurements can be implemented for at least one of conformance tests, in-band blocking tests, out-of-band blocking tests, adjacent channel sensitivity tests, narrow band blocking tests, spurious response tests, reference sensitivity level tests. Other test types can be contemplated including test types to be introduced with future developments of LTE-Advanced and/or the CA feature.

According to various embodiments, the measurements may comprise providing simultaneously a first interfering signal for the first measured carrier and a second interfering signal for the second measured carrier. For particular test cases, for example for intra-band contiguous CA, i.e. neighboring carriers, the first and second interfering signals may be one and the same signal, which can result in further test optimization. For other test cases, the first and second interfering signals may have common properties but may differ in at least one property. According to specific embodiments, the first and second interfering signals may have an offset in frequency, while having the same bandwidth.

A test case for a particular CA configuration may be repeated for various interfering signals differing, e.g., in offset, bandwidth, etc. which may correspond to performing different tests such as in-band and out-of-band blocking test for said particular CA configuration. Additionally or alternatively, for a given set of test cases the interfering signal may sweep over the frequencies (channels, carriers) of a particular operating band, and/or may sweep over multiple operating frequency bands available for CA. The repetitions and/or sweeps may be performed according to a specific pattern. It is

proposed that one and the same such frequency sweep pattern can be followed when providing both the first interfering signal for the first measured carrier and simultaneously the second interfering signal for the second measured carrier. Such approach may minimize efforts for preparing and performing suites of test cases for CA wherein carriers are measured simultaneously.

CA testing may also comprise testing UE capabilities with regard to internal data handling of data received via multiple carriers, which topic may concern a data handling on one or more of a network /IP layer, transport layer, application layer, for example. For testing, impairments such as delay, jitter, loss, corruption, duplication, re-ordering may be provided to one or more of packets, frames, blocks, and/or any other data structure or entity. According to various embodiments, the measurements may comprise providing one or more of such impairments to the first measured carrier and further providing one or more of such impairments to the second measured carrier. A pattern defining a time sequence of specific impairments may be defined same for the measured carriers, or may differ in statistical properties, and/or one and the same pattern may be applied with different time offsets, etc.

According to various embodiments, a set of test cases may be performed for given first and second measured carriers, wherein the set comprises variations in uplink configuration parameters, i.e. various test cases cover uplink configurations in the primary cell (an UL configuration associated to the primary component carrier). Uplink configuration parameters may include properties such as uplink frequencies, uplink resource blocks, uplink power.

A pattern of combinations of varying uplink configuration parameters can be predefined. According to various embodiments, one test case covers measuring two or more carriers. As the number of test cases shrinks compared to measuring each carrier in a separate test case, so does the number of test cases available for testing the uplink. According to some embodiments, a set of test cases may not entirely cover the pattern of uplink configuration parameters, i.e. may exclude one or more parameter combinations. For example, while a coverage may be complete for a full test set including various test cases without CA and with CA CC combinations such as 2DL and 3DL, when considering only a subset of said full test set the uplink coverage may be selected to be not complete. For example, mandatory test cases can be defined to be performed for each CA CC configuration, e.g. including testing parameter combinations based on worst case assumptions, while other test cases can be defined as optional.

A particular test case for a 3DL CA operating band set may be evaluated as including one or more 2DL CA test cases. According to various embodiments, these 2DL CA test cases may then be skipped from a test execution, e.g. may be omitted from a mandatory test execution, as their corresponding measurements are performed in the 3DL CA test case, i.e. the 2DL CA test case may be seen as redundant. Similarly, one or more 1DL test cases may be excluded from execution. For a 4DL CA operating band set, 3DL CA, 2DL CA, and 1DL CA test cases may be skipped. For a 5DL CA operating band set, 4DL CA, 3DL CA, 2DL CA, and 1DL CA test cases may be skipped.

According to another aspect, a method of testing LTE-Advanced CA receiver characteristics is proposed which comprises selecting at least two measured carriers of a CA operating band set defining at least three downlink carriers; establishing at least one non-measured downlink carrier from the CA operating band set; establishing an uplink carrier associated with the non-measured downlink carrier; and simultaneously performing test measurements for the two measured carriers.

According to a further aspect, a computer-readable medium is proposed having computer-executable instructions for performing one or more of the method aspects outlined herein. The instructions may be executed on a computing device of a test system or test environment such as a generic computer adapted for testing purposes or a dedicated computing hardware such as a dedicated test & measurement device. The instructions may specify one or more test cases in a generic programming language, in a language specifically provided for test devices, as a macro or batch file, etc.

The computer-readable (recording) medium may comprise a permanent or re-writeable memory within or associated with a computing device or a removable CD-ROM, DVD or USB-stick, for example. Additionally or alternatively, the computer-executable instructions may be provided for download to a computing device, for example via a data network such as the Internet or a communication line such as a telephone line or wireless link.

According to still another aspect, a test system is proposed which is configured for testing LTE-Advanced CA receiver characteristics. The test system may further be

configured for measuring at least a first measured carrier and a second measured carrier of a 3DL, 4DL or 5DL CA operating band set defining at least three downlink carriers. The system comprises a module adapted to establish one of the non-measured downlink carriers as primary component carrier; a module adapted to establish the first and second measured carriers as secondary component carriers; and a module adapted to simultaneously perform test measurements for the first measured carrier and the second measured carrier.

According to various embodiments, the test system may comprise two independent signal generators which can be configured for providing simultaneously a first interfering signal for the first measured carrier and a second interfering signal for the second measured carrier.

According to various embodiments, the test system may comprise a module such as a Data Application Unit which is adapted for providing one or more impairments to each of the first measured carrier and second measured carrier, the impairments comprising delay, jitter, loss, corruption, duplication and/or re-ordering.

Preparing sets of test cases for providing a comprehensive testing (test coverage) of a feature such as carrier allocation is a complex task which generally comprises preparing test cases for covering a large number of parameters each with its specific variations and ranges. Further, the conformance of the tested device under various conditions such as different types of interfering signals, etc. has to be tested, which conditions by themselves imply further extensive requirements for comprehensive covering.

In view of said complexity, a general approach of preparing test suites may comprise identifying a specific parameter combination and defining said as the subject of a test case (by that action defining the test case), and repeating said action for as many specific parameter combinations as desirable or affordable. Therefore a conventional approach of a test case for 3DL CA may comprise, on the basis of test methodologies known for 2DL CA, selecting one of three carriers as the measured carrier and keeping the other two carriers active; assigning an uplink to one of the carriers or bands being different from or not containing the measured carrier, and then performing the measurements for the measured carrier. For example, for selectivity and blocking tests, interferers would be assigned relative to the measured carrier. The test would then to be repeated by swapping the roles of the measured carrier and the unmeasured carrier without associated uplinks, and the set of these two test cases would have to be repeated two times for permutation of the role of the carrier having the uplink assigned thereto.

In contrast, various embodiments propose to measure multiple component carriers simultaneously when testing LTE-Advanced CA receiver characteristics for 3DL CA and beyond. Simultaneous measurements may be performed for example by joining those tests which comprise measuring one DL carrier, establishing another DL carrier which has an uplink associated therewith, and establishing one (3DL) or more (4DL, 5DL) further DL carriers which are merely kept idle after establishment.

Performing tests and measurements strictly on a carrier-by-carrier basis requires swapping or interchanging measured and idle carriers. Combining those tests into fewer tests with simultaneous DL carrier measurements avoids establishing a DL carrier merely for keeping it idle, although the same carrier is the measured carrier in another test case, and therefore enables saving test time.

Required test efforts increase with increasing numbers of CCs for CA from 2DL to 3DL and beyond. For example, as a required test time correlates with the number of aggregated component carriers, more test time can be saved when applying one or more of the approaches described herein. According to various embodiments, the relationship between the increasing number of CA CCs and the number of test cases is relaxed leading to test efforts scaling more advantageously with increasing carrier numbers.

A reduced number of test cases to be performed as compared to measuring on a carrier-by-carrier basis leads to a corresponding reduction in test overhead and test complexity regarding various issues such as management of test cases, test initiation, setup of initial conditions per test case, etc.

Although the number of test cases can be reduced, a degree of coverage can be kept high. For example, according to various embodiments full coverage of given CA configurations can be achieved.

When testing configurations with a given number of measured carriers, tests with corresponding configuration with lower number of carriers can be identified and may be skipped or declared optional. Such approach can further

contribute to minimize the number of test cases while a desired degree of coverage can be kept high.

While focusing on receiver characteristics herein, it can be contemplated that the approaches discussed can likewise be applied for testing transmitter characteristics. For example, according to one aspect, a method of testing LTE-Advanced CA transmitter characteristics may comprise, for measuring at least a first measured carrier and a second measured carrier of a 3UL, 4UL or 5UL CA operating band set defining at least three uplink carriers, establishing one of the non-measured uplink carriers as primary component carrier and establishing the first and second measured carriers as secondary component carriers; and simultaneously performing test measurements for the first measured carrier and the second measured carrier.

Brief Description of the Drawings

In the following, the invention will further be described with reference to exemplary embodiments illustrated in the figures, by way of example only. In the drawings:

Fig. 1A schematically illustrates a test environment proper for performing embodiments of the invention;

Fig. 1B schematically illustrates various 1DL, 2DL and 3DL CA configurations for testing purposes;

Fig. 1C schematically illustrates a further 3DL CA configuration for testing purposes;

Fig. 2 is a block diagram schematically illustrating functional modules of an embodiment of a test system according to the invention;

Fig. 3 is a flow diagram illustrating an operation of the test system of Figs. 1 and 2;

Fig. 4A is a block diagram schematically illustrating functional modules of a further embodiment of a test system according to the invention;

Fig. 4B is a block diagram schematically illustrating functional modules of a still further embodiment of a test system according to the invention;

Fig. 5A is a flow diagram illustrating an operation of the test system of Fig. 4A;

Fig. 5B is a flow diagram illustrating an operation of the test system of Fig. 4B;

Fig. 6 schematically illustrates a combined frequency sweep of two interfering signals according to an embodiment of the invention;

Fig. 7A illustrates a sequence of testcases for a 3DL operating band subset;

Fig. 7B illustrates a sequence of testcases for various 2DL operating band subsets corresponding to the 3DL testcases of Fig. 7A; and

Fig. 8 is a flow diagram illustrating an operation of a further embodiment of the invention.

Detailed Description of Embodiments

Fig. 1A schematically illustrates an embodiment of a test environment (testbed) 100 including a test system 102 for test & measurement of a device under test (DUT) 104. The test system 102 comprises as a test & measurement device a Radio Communication Tester (RCT) 106 and a signal generator or source measurement unit (SMU) 108. Further, a Data Application Unit (DAU) 110 is controlled by the RCT 106. A repository 112 is provided for storing test cases (TC) to be executed.

The DUT 104 may be any device capable of communicating via a radio interface 114 such as a correspondingly enabled chip, chipset, network card, stick, etc. Other exemplary implementations of the DUT 104 may comprise a consumer device such as any kind of a mobile device, smartphone, tablet or other general-purpose computer with integrated communicating facility, a field device for industrial purposes, etc. The radio interface 114 may be specified by an LTE-Advanced standard such as Release 11, 12 or later. The radio interface 114 may be implemented via cable between test system 102 and DUT 104, as known to the skilled practitioner.

The DUT 104 and operation thereof may be measured by the RCT 106 as discussed in more detail below, and/or a measurement module 116 may be provided, which may be adapted for monitoring one or more of internal status of DUT 104, an ability of DUT 104 of receiving data, error

rates of receptions, internal data handling, etc. Measurement results may be stored in a storage unit 118, which may comprise storing test protocols on which post processing, analysis, etc. can be performed.

Test environment 100 may comprise further equipment such as shielding arrangements, etc. as known to the skilled practitioner. While RCT 106 and measurement module 116 are illustrated as separate devices in Fig. 1, according to other embodiments both may be implemented as a single test & measurement device.

For executing a test run which may generally comprise executing a plurality of test cases, corresponding batch files and/or macro files may be retrieved by RCT 106 from repository 112, its execution be controlled by RCT 106, and test protocols being provided as a result of test execution be provided in, for example, a storage unit such as storage 118.

Fig. 1B illustrates principles of performing CA tests. DL carriers or channels are illustrated as open-top squares, an uplink associated to a particular DL carrier as a cross filling a corresponding square. A measured carrier is indicated by an arrow. According to a test case 152, a single downlink (1DL) is associated with a single uplink, i.e. no CA.

Case 154 illustrates a 2DL CA configuration wherein one of two downlinks is associated with an uplink, and the other DL CC not being associated with the downlink is the measured carrier. Generally, test cases defined for CA may comprise that one of the aggregated carriers may have associated an uplink therewith, while another carrier is

focused on as the measured carrier, i.e. blocking tests, sensitivity tests, etc. are performed with regard to the measured carrier while the carrier having the UL associated thereto may be designated as a non-measured carrier (which does not exclude testing UL configurations). For complete test coverage of the 2DL subset to which the test case 154 belongs, a further test is required wherein the measured / non-measured roles of the carriers are swapped.

Test case 156 illustrates a 3DL configuration wherein one of three DL CCs has the uplink associated thereto and one of two remaining carriers is the measured carrier. The third carrier 158 is not measured and after establishment merely has to be kept active (idle) during testing the measured carrier. Said 3DL configuration requires the further test case 160 wherein the role of the measured carrier and the non-measured, idle carrier are swapped

In a test preparation phase, for example for a particular LTE-Advanced Release, the test cases 156 and 160 can be generated, e.g., automatically, by using the 2DL test cases such as illustrated by case 154 as a template or basis.

According to various embodiments, it is proposed to deviate from such test case generation mechanism, and to provide for a test organization such that the test cases 156 and 160 are performed simultaneously (in parallel, at the same time), i.e. the two measured carriers 158 and 162 may be measured in parallel or simultaneously, as indicated in Fig. 1C by test case 170, which illustrates the combination of cases 156 and 160 in a way similar to what has been discussed for the test cases of Fig. 1B.

When combining the test cases 156 and 160 into one, it is a matter of perspective whether to talk of one test case 170 or two test cases 156, 160. For example, with regard to test organization and test execution, one might prefer talking of one test case 170, as setting up the initial conditions in the test system 102 and DUT 104 need to be performed only once, while with regard to the test results, there are two data sets, namely for the first, and for the second measured carrier, i.e. one might refer to two cases 156, 160. For these and other reasons, there is no sharp distinction made herein between (one) 'test case' and (multiple) 'test cases'; for example, any test case may be considered as comprising multiple sub-test cases also with respect to various other parameters to be tested.

Fig. 2 is a block diagram illustrating functional modules of the RCT 106. A Carrier Aggregation control (CA ctrl) module 202 accepts information on one or more test cases to be performed from repository 112. The CA ctrl module 202 controls accordingly a Primary Component (PC) control module 204 and a Secondary Component (SC) control module 206. The PC module 204 is adapted to initiate establishment of a primary CC or primary cell channel arrangement over radio interface 114 for DUT 104. The SC module 206 is adapted to initiate establishment of a secondary CC or secondary cell channel arrangement over radio interface 114 for DUT 104.

Radio communication between RCT 106 and DUT 104 is accomplished by transceiving (transmission and reception, Tx/Rx) equipment 210 which comprises antenna equipment for performing radio transmissions and receptions via radio

interface 114. The RCT 106 including control equipment such as CA ctrl 202 and transceiving equipment 210 may operate as an eNodeB emulator when performing test cases, wherein the skilled practitioner is familiar with details of such emulation.

For test measurement purposes, in addition or alternatively to the measurement device 116 (Fig. 1), a measurement module 212 may be provided which may be adapted, for example, for monitoring and analyzing data received from DUT 104 via UL 220 of radio interface 114.

An operation of the test system 102 of Figs. 1A and 2 for the purpose of testing DUT 104 will be described with reference to the flow diagram in Fig. 3. Generally, the operation 300 relates to testing an LTE-Advanced CA receiver characteristics of DUT 104. Corresponding test cases may be retrieved by CA ctrl module 202 from repository 112 and PC 204 / SC 206 components be triggered accordingly for establishing a desired CA configuration. The exemplary test case is assumed to comprise setup of a 3DL CA connection via radio interface 114 with DUT 104, and may further comprise sending data with predefined properties such as data rate, etc. to the DUT 104 via the DL carriers.

Further for reasons of exemplary illustration, a test subject is assumed to relate to reception capabilities of DUT 104 with regard to a 3DL operating band set 213 illustrated schematically in Fig. 2 as comprising three DL carriers 214, 216, 218 over radio interface 114 and one UL carrier 220. Specifically, the test subject may concern measuring reception capabilities of DUT 104 with regard to a reception via DL CC 214, i.e. carrier 214 is intended as

a measured channel or carrier. At the same time, a further test subject concerns measuring reception capabilities of DUT 104 with regard to a reception via DL CC 216, i.e. carrier 216 is also intended as a measured channel or carrier. In other words, two test cases are intended to be performed in parallel, namely a first test of testing DUT 114 with regard to CC 214, and a second test of testing DUT 114 with regard to CC 216. CC 218 is intended non-measured.

The test case to be performed may comprise testing one or more of intra-band CA and inter-band CA, and/or may comprise testing one or more of contiguous CA and non-contiguous CA. For example, channels/carriers 214 and 216, respectively, can be allocated in one and the same operating band, or can be allocated in different operating bands, the latter case exemplarily be indicated by long-dashed line 222 in Fig. 1. Further purely for reasons of illustration it may be assumed that channels/carriers 216 and 218 are located in one band, which would include the options of both being allocated on neighboring frequencies, i.e. in a contiguous way, or can be allocated with a frequency gap in between, i.e. in a non-contiguous way, the latter case exemplarily being indicated by short-dashed line 224.

In step 302, PC module 204 operates to provide DL ctrl 226 for establishing the non-measured DL CC 218 as primary component carrier, which includes or is accompanied by UL ctrl 228 of establishing UL 220 in association to DL 218. The skilled practitioner is familiar with the corresponding LTE-Advanced CA procedures. Normally, both DL carrier 218 and UL carrier 220 will belong to one and the same operating band.

In step 304, SC module 204 operates to provide DL ctrl 230 and DL ctrl 232 for establishing the carriers 214 and 216, respectively, intended as measured carriers or secondary component carriers.

In step 306, the RCT 106 operates to control the carriers/channels 214 - 220 according to the details of the test case to be performed. For example, data may simultaneously be sent via transceiving equipment 210 and each of the DL CCs 214 and 216 to the DUT 204 with predefined data rates. In this respect, a control module such as the CA ctrl 202 or SC ctrl 206 needs to trigger test conditions as required with regard to simultaneously measuring both carriers 214 and 216. The measurement device 116 (Fig. 1) and/or module 212 of RCT 106 may then operate to simultaneously perform test measurements for each of the measured carrier 214 and the measured carrier 216.

As an example, module 212 may operate to check acknowledgement messages (or frames, blocks) or non-acknowledgement messages (frames, blocks) received via UL 220 from DUT, wherein said ACK or NACK messages indicate successful reception or not of data sent via the measured DL CCs. Specifically, the module 212 need to be adapted to check ACKs and NACKs for un/successful reception via DL 214, and for un/successful reception via DL 216.

In step 308, measurement device 116 and/or measurement module 212 in RCT 106 provide a test protocol to, e.g., storage 118. For example, a single test protocol regarding the simultaneous measurement of DUT 104 with regard to channels 214 and 216 may be written, and/or two separate

protocols may be written for each of the measured CC 214, and the measured CC 216. A post-processing on the test protocol/s may be performed by other components of the test system 102, and/or may be performed remote of testbed 100.

The test environment generally introduced with respect to the previous figures may be employed, for example, for performing simultaneous tests on 3DL, 4DL or 5DL configurations. For example, tests & measurements may be performed for conformance tests such as sensitivity tests or blocking tests, wherein blocking tests may comprise in-band blocking tests, out-of-band blocking tests, narrow band blocking tests, spurious response tests, etc., and sensitivity tests may comprise adjacent channel sensitivity tests, reference sensitivity level tests, etc.

Fig. 4A shows functional details of an exemplary embodiment of SMU 108 of Fig. 1, which comprises two signal generators (SG) 402 and 404 and transceiving equipment 406. The latter may comprise features and functionalities similar to what has been described above for transceiving equipment 210 of RCT 106. The generators 402 and 404 may be operated independent of each other, and each of generators 402 and 404 may generate signals such as may be provided by an eNodeB, wherein the signals may however be adapted for test purposes.

The generated signals may be provided to DUT 104 via radio interface 114 which may be implemented as discussed above. For example, when there is a cable-based coupling between RCT 106 and DUT 104, the SMU 108 may also be coupled via cable and appropriate connector.

It is noted that while RCT 106 and SMU 108 are illustrated as separate components in Fig. 1, according to other embodiments both functionalities may be provided as an integrated component using, e.g., one and the same transceiving equipment such as equipment 210.

Fig. 5A illustrates an operation of the test system 102 of Fig. 1 with specific exemplary regard to SMU 108 of Fig. 4A. In step 502, the SMU 108 is controlled to provide an interfering signal 408 with respect to measured carrier 214 in Fig. 2, and to simultaneously provide another interfering signal 410 with respect to measured carrier 216. For example, signal 408 may be provided from signal generator 402 and signal 410 may be provided from signal generator 404. Step 502 may be performed within the course of step 306 of Fig. 3, as illustrated in Fig. 5A, i.e. during the course of measurement of DL carriers 214 and 216.

Properties of signals 408 / 410 depend on the details of the test case/s to be performed. For example, for out-of-band blocking tests, a bandwidth of interferer signal 408 may be near to or overlapping with the band or carrier (channel) 214, and a bandwidth of interferer signal 410 may be near to or overlapping with the band or carrier (channel) 216.

For truly simultaneous measurements in time of two carriers, two separate and independent signal generators are required.
SMU 108 may therefore be adapted to operate both generators 402 and 404 in parallel, i.e. each of the generators 404 and 406 may simultaneously generate signals and provide these to radio interface 114 / DUT 104, for

example if controlled accordingly by a test control equipment such as RCT 106 of Fig. 1.

According to other embodiments, the tests on the measured carriers may be performed quasi-parallel. This may concern that a single test case is performed with regard to a setup of test equipment 102 and/or DUT 104, wherein both measured carriers / channels 214 and 216 are established and kept in an active state, but the measurements are then performed sequentially, i.e. only one of the carriers is measured at a time. Such test execution saves test time for example as compared to performing separate test cases each including its own test setup phase with setting the test system and the DUT to defined initial conditions. In contrast to truly simultaneous measurements, less test equipment may be required, e.g., only a single signal generator may be required.

Assuming a truly simultaneous test execution in the example discussed with respect to Figs. 4A and 5A, both interfering signals 408 and 410 are generated and provided at the same time, and also test execution in DUT 104 will be truly simultaneous, for example in that receiving and processing facilities for carriers 214 and 216, respectively, may work in parallel. Measurements to be performed for both measured carriers 214 and 216 in parallel may require quasi-parallel operation only, for example the measurement module 212 may listen to UL channel 220 and has to check for responses concerning both DL channels 214 and 216 (and may ignore or discard responses for channel 218).

During a test case sequence, an interfering signal such as signal 408 or 410 may be applied according to a predefined

pattern. For example, a frequency sweep pattern may be defined according to which the signal sweeps over frequencies of interest. This may concern, for example, performing different types of test for one and the same CA allocation configuration, wherein, e.g., sequentially a spurious response test, a narrow band blocking test, an in-band blocking test, and an out-of-band blocking test are performed. When employing a pair of two parallel interferer signals such as the pair of signals 408 and 410 (i.e. when performing simultaneous measurements of parallel DL CCs), the interfering signals of the pair may both follow one and the same frequency sweep pattern, in order that, for example, for both measured carriers the same sequence of tests can be performed.

Additionally or alternatively, with regard to a sequence of tests of a specific test type, an interfering signal may also be applied according to a defined frequency sweep. For example, the interfering signal may sweep according to a predetermined pattern over the carriers or channels of a particular operating band, and/or over a sequence of operating bands. Also in this case the interfering signals of a pair of independently controlled interferers may follow one and the same frequency sweep pattern.

Fig. 6 exemplarily and schematically illustrates a first operating frequency band B1 and a second operating frequency band B2. Each band comprises multiple carriers or channels designated with f11, f12, f13, ... for B1 and f21, f22, f23, ... for B2. Exemplarily, a set of out-of-band blocking tests may be applied sequentially to each of the carriers of B1. An interferer i1 would be applied in any specific test case with a bandwidth overlapping (for

example) the correspondingly tested channel. With regard to the set of test cases, i1 may sweep 602 on a test-by-test basis over the frequency range of B1, wherein i1 may exemplarily be formed same for all test cases except for an offset which would be specific for each test case. Therefore an interfering signal i11 being a specific representation of i1 may be applied for testing measured carrier f11, for the next test case a specific interfering signal i12 may be formed similar to i11 except that i12 is shifted in frequency to be applied for testing measured carrier f12, etc.

When testing simultaneously bands B1 and B2, the further interfering signal i2 may follow a similar sweep pattern 602 as does i1, wherein i2 may be generated similar to i1 except for some, e.g., constant, offset. For example, a sequence of test cases may be generated wherein when the interferer i11 is applied to measured carrier f11, simultaneously the interferer i21 being a specific representation of i2 may be applied for testing measured carrier f21. When the interferer i12 is applied to measured carrier f12, simultaneously the interferer i22 may be applied for testing measured carrier f22, etc.

When generating test cases for simultaneous measurement of CA carriers in bands B1 and B2, the frequency sweep pattern of i2 may be generated from the pattern of i1, for example by applying an offset measuring the offset between bands B1 and B2. Such approach may simplify test generation.

Fig. 4B shows functional details of an exemplary embodiment of DAU 110 of Fig. 1. DAU 110 comprises two packet generators (PG) 432 and 434. Each PG may operate to

provide a stream of packets (or frames, messages) 436 and 438, respectively, wherein a stream may comprise, for example, a stream of IP (Internet Protocol) packets. One or more impairments can be imprinted onto the data streams 436 and/or 438. For example, one or more packets may exhibit a specific delay, a predefined jitter may be imprinted on the data stream, some packet loss and/or re-ordering may be simulated on a packet sequence such as, for example, a TCP stream, one or more packets may be corrupted and/or duplicated, etc. Such impairments may enable, for example, testing an internal data handling of DUT 104.

While DAU module 110 is illustrated as a separate device in Figs. 1 and 5B, according to other embodiments the functionality thereof may also be provided embedded into the RCT 106.

Fig. 5B illustrates an operation of the test system 102 of Fig. 1 with specific regard to DAU 110. In step 532, one or more impairments are provided to each of the measured carriers 214 and 216 in Fig. 2. The DAU 110 may be adapted to simultaneously generate and provide the two data streams 436 and 438 to be transported via measured carrier 214 and carrier 216, respectively, downlink to DUT 104. The data streams 436 and 438 may be generated independently, i.e. the packet generators 432 and 434 work truly independently. According to another embodiment, only a single packet generator may be provided and one stream is copied and may be optionally buffered for some time (offset) for achieving a transmission with a delayed pattern of impairments. Generally, a pattern of impairments imprinted on each of the data streams may be the same, or may be different.

Step 532 may be performed within the course of step 306 of Fig. 3, as illustrated in Fig. 5B, i.e. during the course of measurement of DL carriers 214 and 216. Providing functionality such as discussed with regard to DAU 110, in particular regarding a capability of simultaneously providing two or more data streams with targeted impairments, enables adding further to an efficiency of testing 3DL CA and beyond as test cases for two or more measured and/or loaded carriers can be performed simultaneously in parallel.

Fig. 7A schematically illustrates an exemplary sequence of test cases for performing 3DL CA tests on an arbitrarily picked subset of operating frequency bands B4, B5, and B30. Complete test coverage requires measuring each of the channels of the subset covering all possible permutations. The table illustrated in Fig. 7A may result from a scheme for preparing test cases as required for testing 3DL CA configurations. For example, for measuring channel or band B4, a test case 702 has to be performed wherein the uplink is associated to B5, and a test case 704 has to be performed wherein the uplink is associated to B30. Similar test cases have to be prepared and performed for measured channels / bands B5, and B30.

Assuming the set illustrated in Fig. 7A would reflect a sequence of tests execution, the set may be reordered to group together various test cases which may be performed in parallel. For example, test cases 702 and 712 both require an active uplink in B5 which means that carriers B4 and B30 may be measured in parallel for this configuration, similar to combining test cases 156 and 160 of Fig. 1B into one test case 170 of Fig. 1C. Similarly,

test cases 704 and 708 both require the uplink associated with band/channel B30, and accordingly carriers B4 and B5 may be measured in parallel for said configuration. Test cases 706 and 710 both require the uplink to be associated with band/channel B4 and accordingly carriers B5 and B30 may be measured in parallel for said configuration.

While the exemplary test set in Fig. 7A refers to bands, the considerations likewise can be applied to each of intra-band and inter-band 3DL CA allocations and combinations thereof.

Fig. 7B illustrates exemplary subsets of test cases for performing 2DL CA tests, wherein the depicted subset is intended to relate to the same LTE-Advanced test set or test framework as the 3DL subset of Fig. 7A. In particular, Fig. 7B indicates those 2DL subsets which can be seen as being related to the 3DL subset of Fig. 7A due to referring also to the operating frequency bands B4, B5, and B30.

For subset B4_B5 in Fig. 7B, when an uplink is associated to a channel in band B5, the channel to be measured is in band B4 (case 732). For complete testing of the combination, all permutations have to be covered, i.e. the roles of the channels have to be swapped. Therefore, when an uplink is associated to a channel in band B4, the channel to be measured is in band B5 (case 734). Similar combinations are to be generated and executed for the 2DL subsets B4_B30, B5_B30.

From a comparison of the tables in Figs. 7A and 7B it turns out that each 2DL test case corresponds to a 3DL test case. For example, 2DL test case 732 comprises an UL

active in B5, while measuring the CC of B4, which configuration is also tested in 3DL test case 702. 2DL test case 734 comprises an UL active in B4, while measuring the CC of B5, which configuration is also tested in 3DL test case 706, etc. The difference between test cases corresponding in this way is that the 3DL test cases have one more CC allocated or activated than the 2DL test cases. Under the assumption that the receiver performance would remain same irrespective of whether or not a 3rd DL CC is allocated, the verification of the 2DL subsets depicted in Fig. 7B can be regarded as being redundant in view of the 3DL test configurations of Fig. 7A. Then, the test cases depicted in Fig. 7B could be skipped (omitted), i.e. excluded from the set of test cases.

Applying the discussion to the sets of Figs. 1B and 1C, for example the 2DL test case 154 could be skipped in view of the 3DL test case 170.

Omitting in this way a CA test case with lower number of CCs in view of a corresponding CA test case with higher number of CCs allows to even further optimize test time. With regard to the examples depicted in Figs. 7A and 7B, according to one aspect a single 3DL CA test case including simultaneous measuring of two DL carriers can be performed and said test case replaces two 3DL CA test cases measuring each a single DL carrier only; additionally or alternatively two 2DL CA test cases can be excluded from the test suite in view of one corresponding 3DL CA test case.

The assumption of receiver performance being independent of allocated number of DL carriers may be tested by providing a corresponding (small) number of test cases.

Additionally or alternatively, one, some or more of the skipped 2DL CA tests may conditionally be performed in case a corresponding 3DL CA test case has failed.

The example of Figs. 7A and 7B has been discussed from the perspective of excluding 2DL CA tests in view of corresponding 3DL CA tests. In practical circumstances, one might prepare a test suite by first listing all required 2DL CA tests and 3DL CA tests and then scanning the list of 2DL CA tests and excluding those 2DL tests found to correspond to a listed 3DL CA test.

Another assumption which may be considered additionally or alternatively may comprise that the receiver performance would remain the same irrespective of whether or not a downlink carrier has an uplink associated thereto or not. Under that assumption a verification of various 1DL test cases can be regarded as being redundant in view of the 3DL (and/or 2DL) test cases of Fig. 7A (Fig. 7B). Then, 1DL test cases can be excluded, but can be provided for optional execution in case of failure of corresponding 3DL (and/or 2DL) test cases. Further savings in test time and test efforts can result, while keeping the test coverage at high level.

It is noted that the examples discussed here with reference to performing 3DL CA test cases and skipping 2DL and/or 1DL test cases can be generalized to performing 4DL and/or 5DL CA test cases. For example, 4DL CA test cases measuring simultaneously two or three CCs without associated UL would allow skipping one or more of corresponding 3DL, 2DL and/or 1DL test cases.

From the perspective of the primary cell or primary CC (i.e. the CC having the UL associated therewith), the above approaches may lead to a considerably reduced number of test cases available for testing different UL configurations for given DL configurations, i.e. test coverage may be less than complete in this respect. It is however noted that transmitter characteristics of a DUT is generally intended to be tested by a separate test suite. However, in order for an optimized test coverage also taking account of UL performance for given receiver characteristics, a pattern of uplink configuration parameters may be defined and may be implemented by distributing the pattern over the remaining test cases. Varying UL configurations can be implemented taking account of extreme parameter values, worst case assumptions, etc. for achieving optimized coverage without the entire available UL configuration being implemented.

Fig. 8 is a flow diagram depicting an alternative or additional embodiment of an operation of a test system. The operation 800 relates to testing an LTE-Advanced CA receiver characteristics. In step 802, at least two measured carriers of a CA operating band set defining at least three downlink carriers are selected. In step 804, at least one non-measured downlink carrier from the CA operating band set is established. In step 806, an uplink carrier associated with the non-measured downlink carrier is established. In step 808, test measurements for the two measured carriers are performed simultaneously. It is noted that steps 804 and 806 may be executed in any order, including parallel execution. In step 810, a test protocol is provided representing results of the performed test.

According to various embodiments discussed herein, testing of carrier allocation from 3DL CA and higher can be optimized. Test cases regarding measurement of carriers not associated with an uplink can be performed simultaneously, which may include measuring the carriers within one test case (quasi-parallel), or which may include truly simultaneously applying test conditions such as interferer signals to the two or more measured carriers.

For example, simultaneous measurements of some or all of those DL carriers not associated to an UL carrier allows optimizations in test times due to various aspects of test case set up need to be performed only once, e.g., establishing initial conditions, establishing the various DL and UL carriers, etc. Moreover, in case of truly parallel measurements, the time for test execution is correspondingly reduced.

Various optimization options are discussed which take into account, amongst others, the available or desired test environment; for example truly simultaneous test execution may require presence of two (or more) independent signal generators. While some optimization options may involve a trade-off in test case / test effort optimization vs. test coverage, the latter can eventually be kept at high level by, for example, declaring tests involving lower CC numbers optional which may mean that such cases need only performed in case higher CC number CA test cases have failed. In this way, the various embodiments discussed herein allow developing test suites implementing an optimum of desired test time and test coverage.

While the invention has been described in relation to its preferred embodiments, it is to be understood that this description is intended non-limiting and for illustrative purposes only. In particular, various combinations of features wherein the features have been described separately hereinbefore are apparent as advantageous or appropriate to the skilled artisan. Accordingly, it is intended that the invention be limited only by the scope of the claims appended hereto.

Claims

1. A method of testing LTE-Advanced Carrier Aggregation CA receiver characteristics, comprising:

for measuring at least a first measured carrier and at least a second measured carrier of a 3DL, 4DL or 5DL CA operating band set defining at least three downlink carriers;

establishing one of the non-measured downlink carriers as primary component carrier;

establishing the first and second measured carriers as secondary component carriers; and

simultaneously performing test measurements for the first measured carrier and the second measured carrier.

2. The method according to claim 1,
wherein the component carriers are established according to one of intra-band contiguous CA intra-band non-contiguous CA, and inter-band CA.

3. The method according to claim 1 or 2,
wherein the measurements are implemented for at least one of conformance tests, in-band blocking tests, out-of-band blocking tests, adjacent channel sensitivity tests, narrow band blocking tests, spurious response tests, reference sensitivity level tests.

4. The method according to claim 3,
wherein the measurements comprise simultaneously providing a first interfering signal for the first measured carrier and a second interfering signal for the second measured carrier.

5. The method according to claim 4, wherein the first and second interfering signal are simultaneously provided according to one and the same frequency sweep pattern.

6. The method according to claim 3 or 4, wherein the measurements comprise providing one or more impairments to each of the first measured carrier and second measured carrier, the impairments comprising delay, jitter, loss, corruption, duplication and/or re-ordering.

7. The method according to any of claims 1 to 6, wherein a set of test cases is performed for given first and second measured carriers and the set excludes at least one specific combination of uplink configuration parameters from a predefined pattern of uplink configuration parameters for the primary component carrier.

8. The method according to any of claims 1 to 7, wherein a set of test cases is performed excluding at least one test case for at least one 2DL CA operating band set as being redundant in view of at least one test case for at least one 3DL, 4DL or 5DL CA operating band set.

9. The method according to any of claims claim 1 to 8, wherein a set of test cases is performed excluding at least one test case for at least one 1DL operating band as being redundant in view of at least one test case for at least one 3DL, 4DL or 5DL CA operating band set.

10. A method of testing LTE-Advanced Carrier Aggregation CA receiver characteristics, comprising:

selecting at least two measured carriers of a CA operating band set defining at least three downlink carriers;

establishing at least one non-measured downlink carrier from the CA operating band set;

establishing an uplink carrier associated with the non-measured downlink carrier; and

simultaneously performing test measurements for the two measured carriers.

11. A computer-readable medium having computer-executable instructions for performing the method according to any of claims 1 to 10.

12. A test system configured for testing LTE-Advanced Carrier Aggregation CA receiver characteristics, and further configured for measuring at least a first measured carrier and at least a second measured carrier of a 3DL, 4DL or 5DL CA operating band set defining at least three downlink carriers, the system comprising:

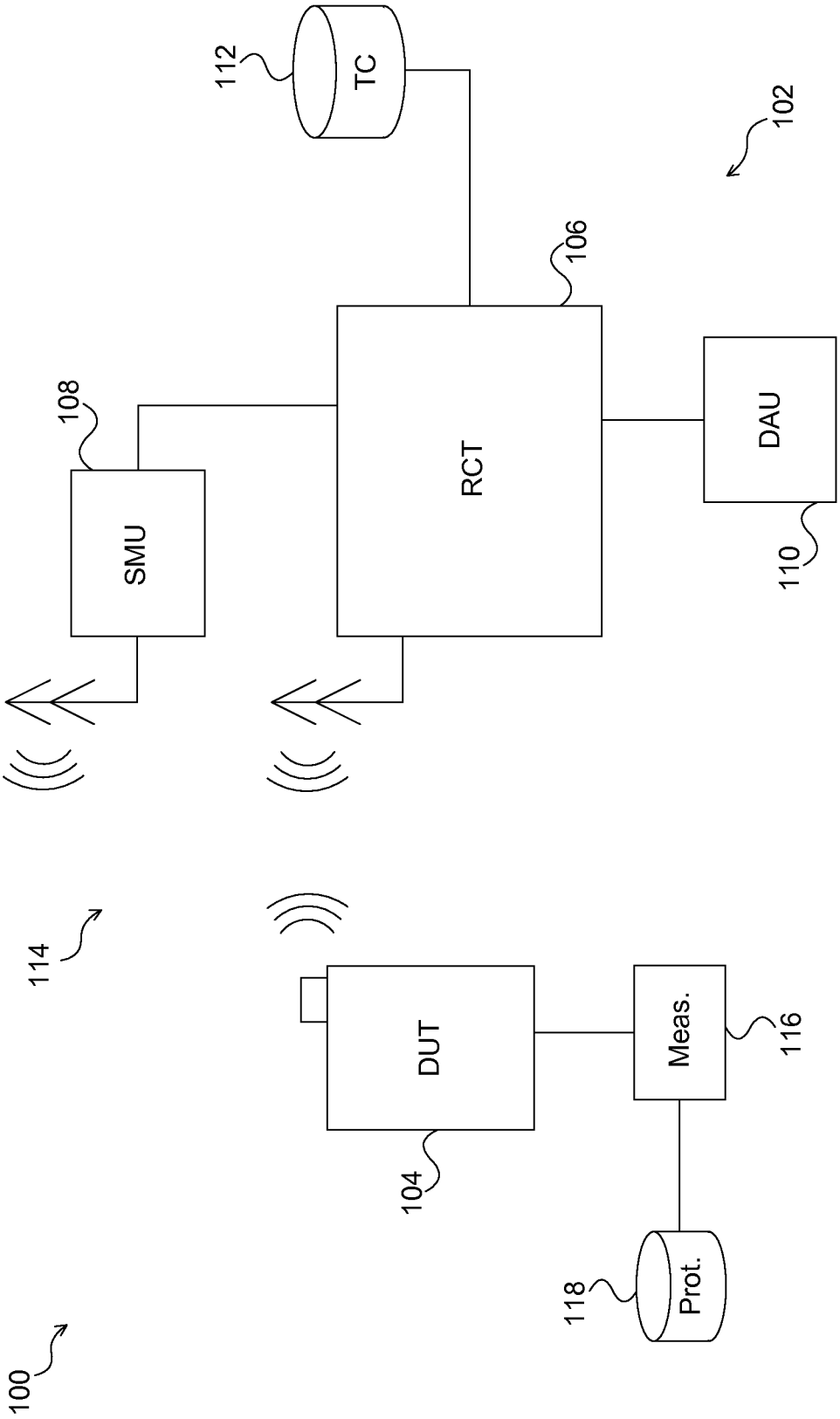
a module adapted to establish one of the non-measured downlink carriers as primary component carrier;

a module adapted to establish the first and second measured carriers as secondary component carriers; and

a module adapted to simultaneously perform test measurements for the first measured carrier and the second measured carrier.

13. The test system according to claim 12, comprising two independent signal generators configured for providing simultaneously a first interfering signal for the first measured carrier and a second interfering signal for the second measured carrier.

14. The test system according to claim 12 or 13, comprising a module adapted for providing one or more impairments to each of the first measured carrier and second measured carrier, the impairments comprising delay, jitter, loss, corruption, duplication and/or re-ordering.


100
102
104
106
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116
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TC
RCT
SMU
DAU
DUT
Meas.
Prot.

Fig. 1A

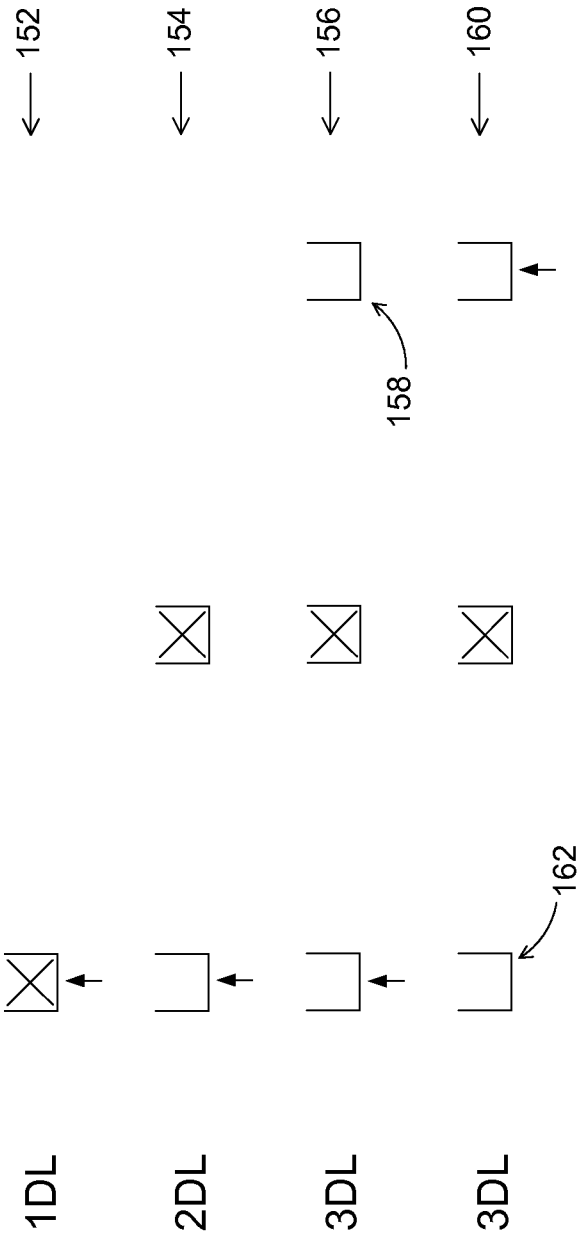


Fig. 1B

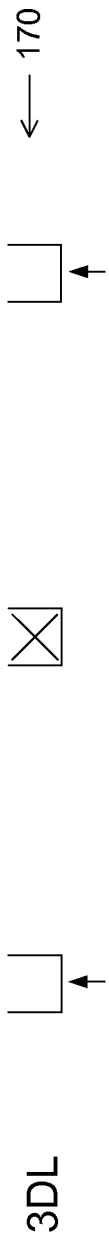
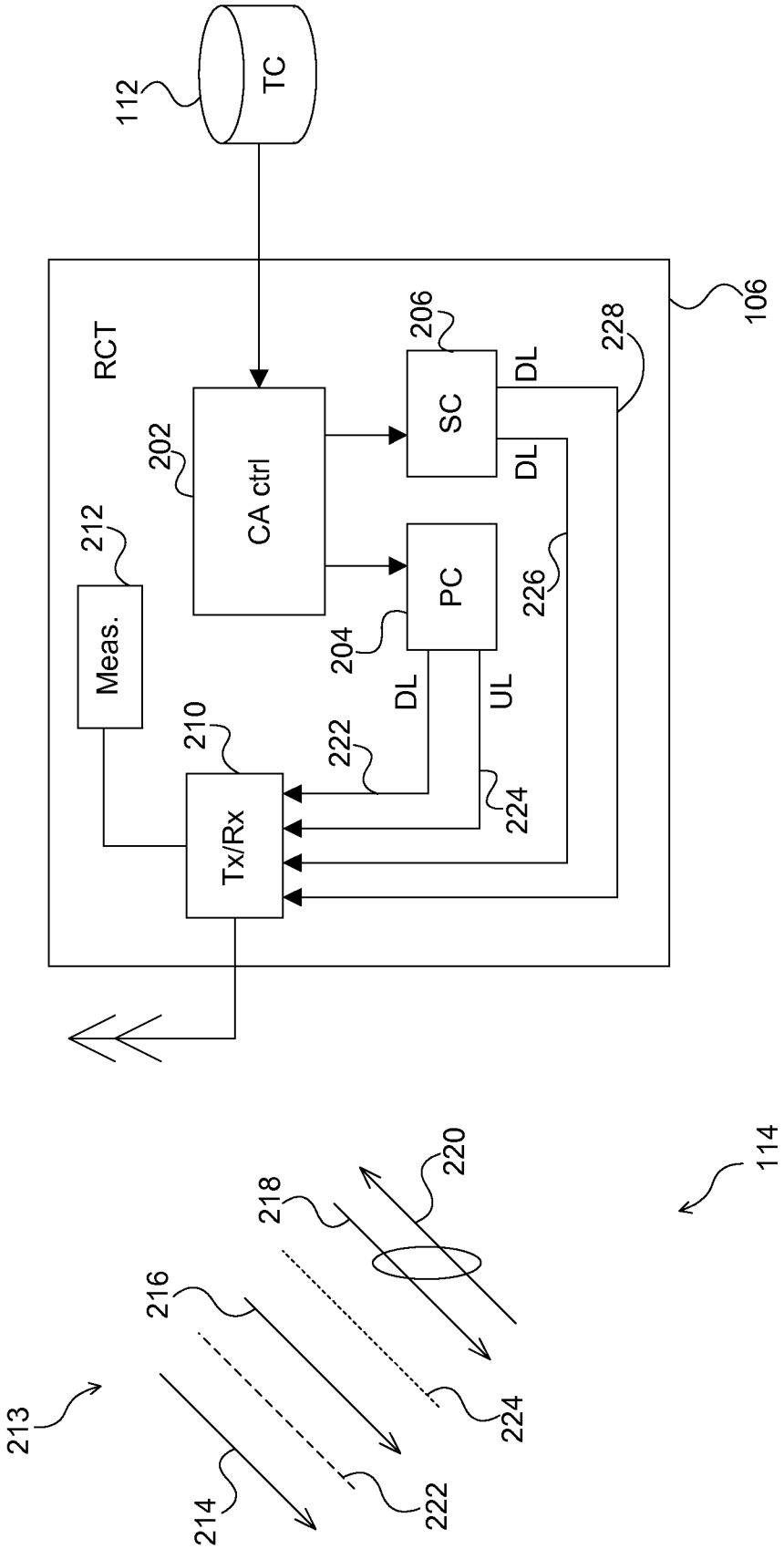


Fig. 1C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TC
106
RCT
206
SC
DL
228
202
CA ctrl
DL
212
Meas.
PC
226
204
DL
UL
210
222
224
Tx/Rx
114
220
218
216
213
224
214
222

Fig. 2

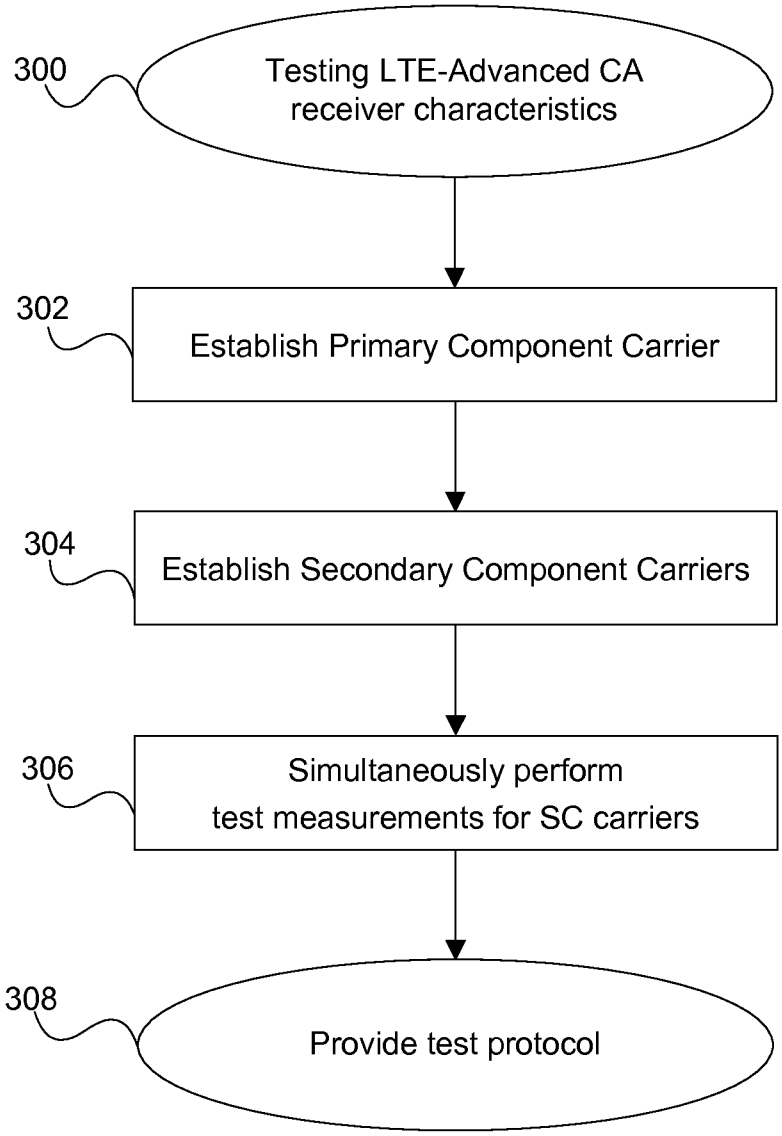

300
Testing LTE-Advanced CA receiver characteristics
302
Establish Primary Component Carrier
304
Establish Secondary Component Carriers
306
Simultaneously perform test measurements for SC carriers
308
Provide test protocol

Fig. 3

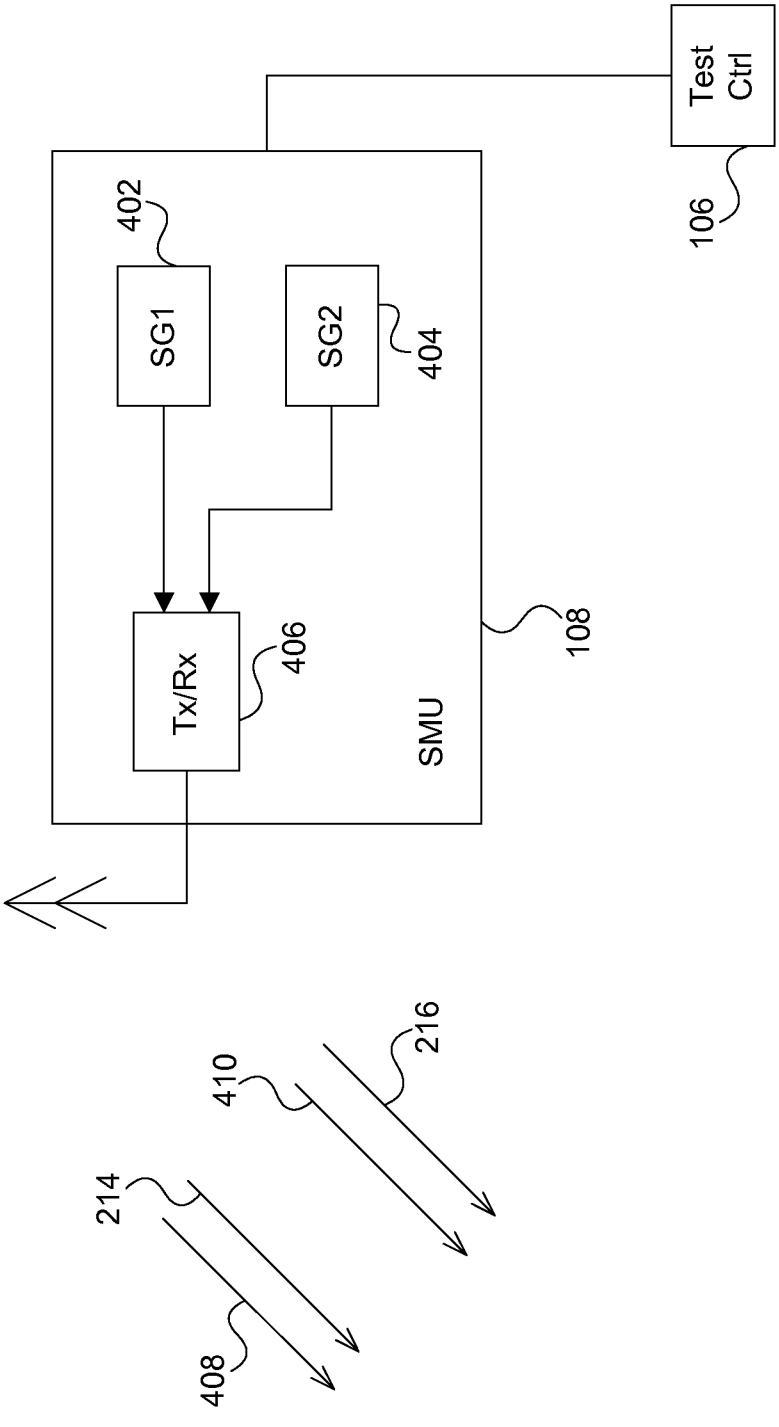
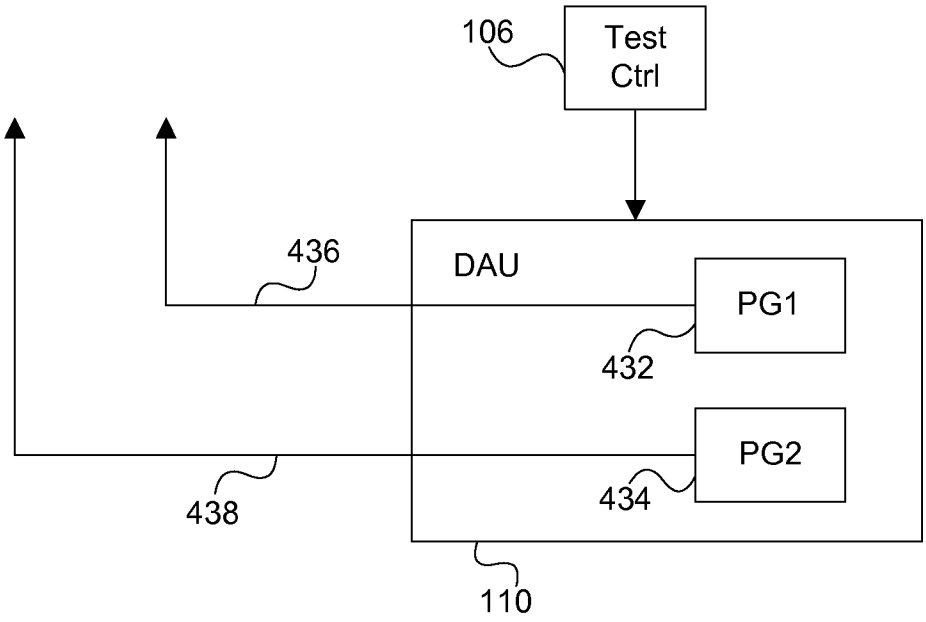


Fig. 4A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Test Ctrl
436
DAU
PG1
432
PG2
434
438
110

Fig. 4B

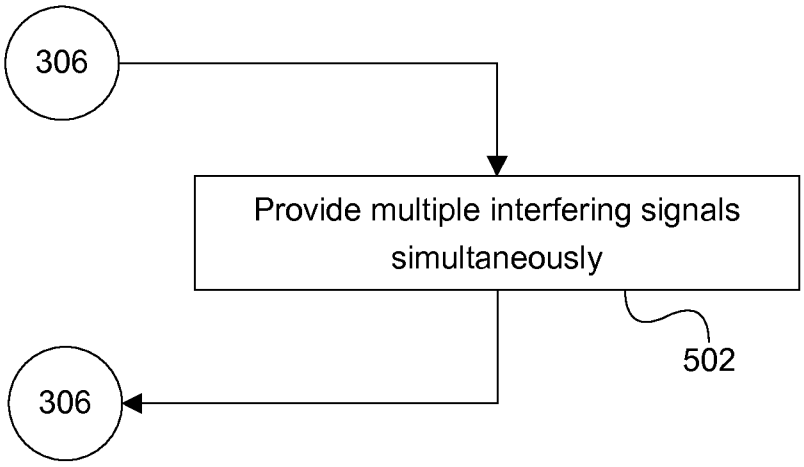
306
Provide multiple interfering signals simultaneously
502
306

Fig. 5A

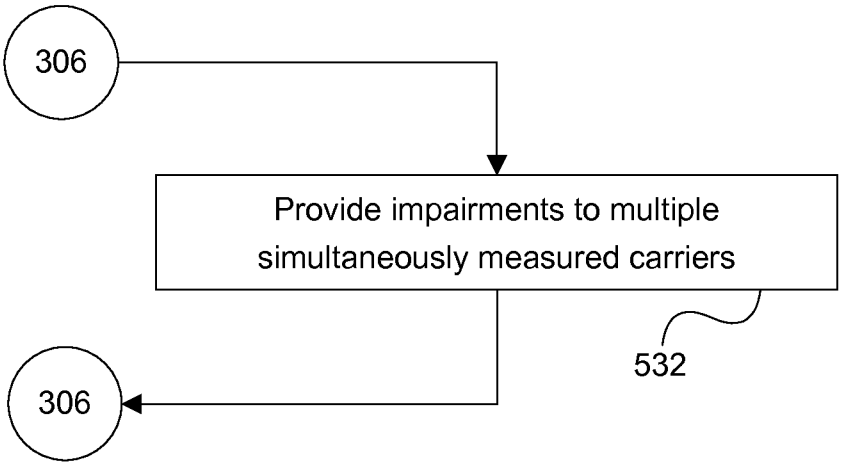
306
Provide impairments to multiple simultaneously measured carriers
532
306

Fig. 5B

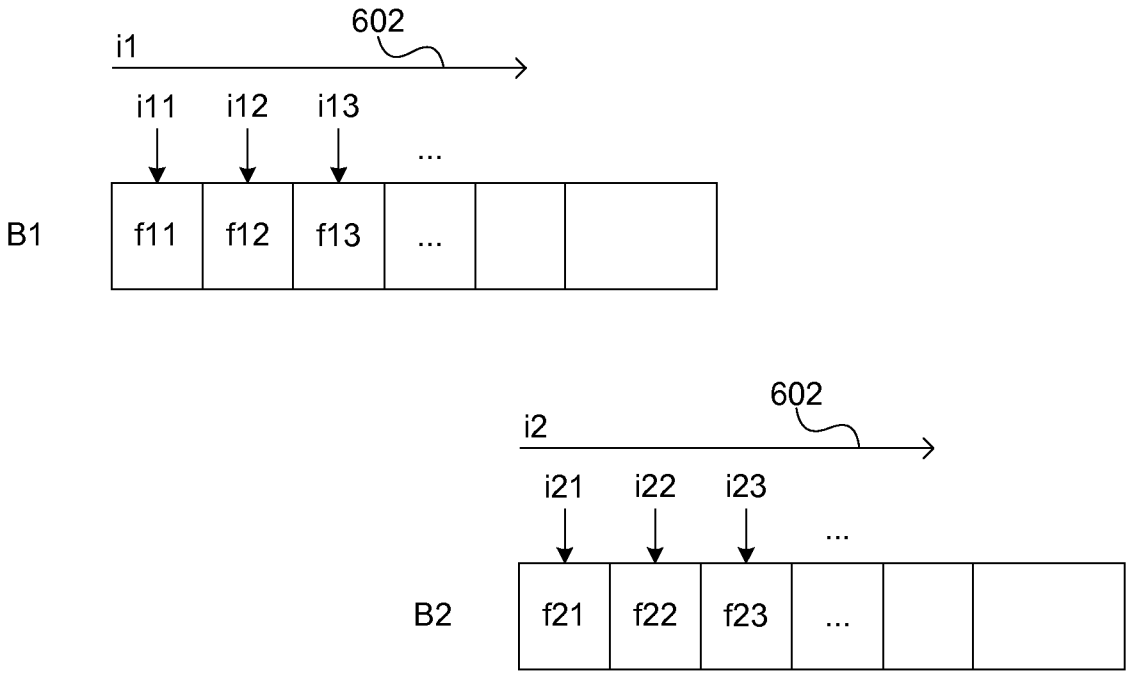
602
i1
i11
i12
i13
...
B1
f11
f12
f13
...
602
i2
i21
i22
i23
...
B2
f21
f22
f23
...

Fig. 6

3DL Subset	Measured	DL Active	UL Active	
B4_B5_B30	B4	B4, B5, B30	B5	← 702
	B4	B4, B5, B30	B30	← 704
	B5	B4, B5, B30	B4	← 706
	B5	B4, B5, B30	B30	← 708
	B30	B4, B5, B30	B4	← 710
	B30	B4, B5, B30	B5	← 712

Fig. 7A

2DL Subset	Measured	DL Active	UL Active	
B4_B5	B4	B4, B5	B5	← 732
	B4	B4, B30	B4	← 734
B4_B30	B4	B4, B30	B30	← 736
	B30	B4, B30	B4	← 738
B5_B30	B5	B5, B30	B30	← 740
	B30	B5, B30	B5	← 742

Fig. 7B

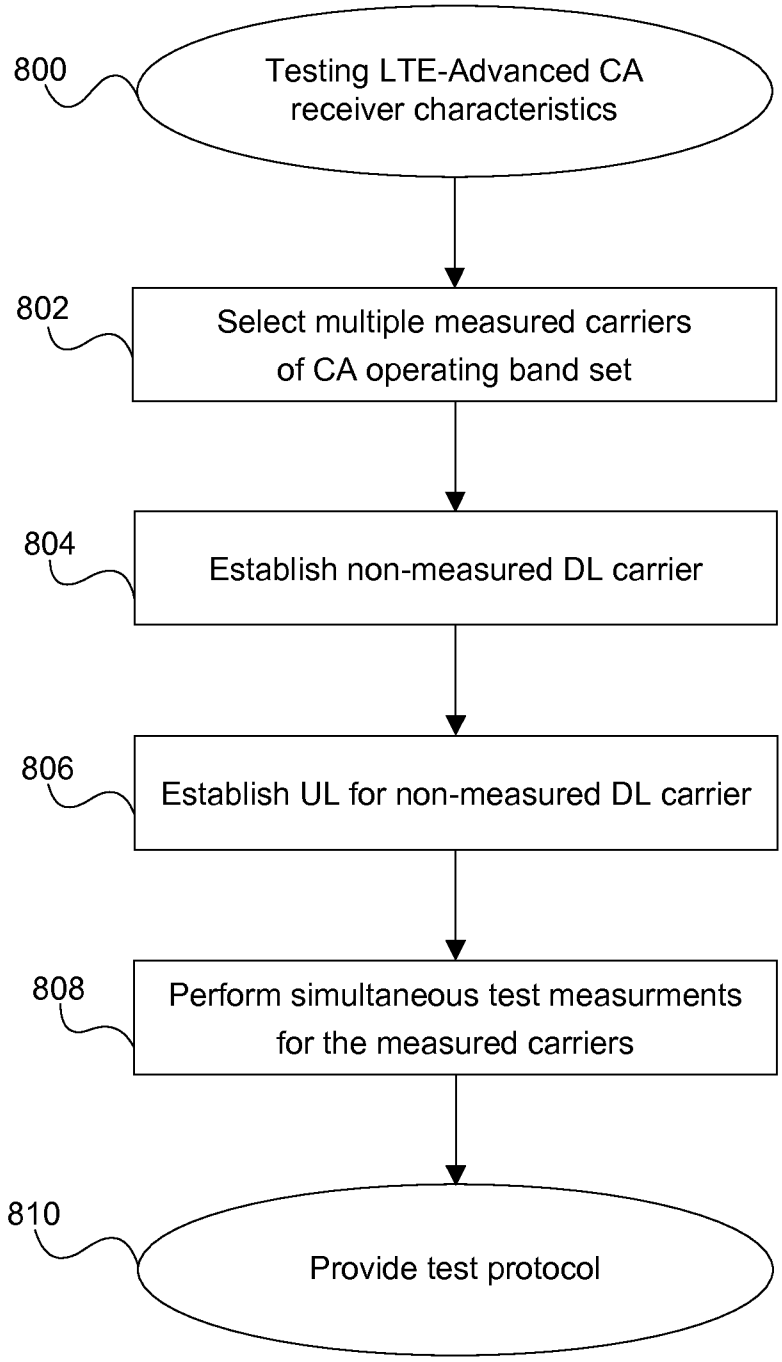
800
Testing LTE-Advanced CA receiver characteristics
802
Select multiple measured carriers of CA operating band set
804
Establish non-measured DL carrier
806
Establish UL for non-measured DL carrier
808
Perform simultaneous test measurments for the measured carriers
810
Provide test protocol

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/054489

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L1/24 H04L5/00 H04W24/08
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)
H04L H04W

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

Electronic data base consulted during the international search (name of data base and, where 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	Anders Hedlund ET AL: "An Introduction to Carrier Aggregation Testing An Ascom Network Testing White Paper Contents", , 15 February 2014 (2014-02-15), XP055190930, Retrieved from the Internet: URL:http://www.2test.ru/upload/news/Ascom_TEMS_Inv_17/WP_carrier_aggregation_testing.pdf [retrieved on 2015-05-21] page 9 - page 18; figures 8,9,11 -----	1-14
A	GB 2 504 293 A (ANRITSU CORP [JP]) 29 January 2014 (2014-01-29) page 3 - page 9; figures 1,2 ----- -/--	1-14

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

[X] See patent family annex.

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 May 2015	08/06/2015

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

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Tomi Johansson ET AL: "3GPP LTE Release 9 and 10 requirement analysis to physical layer UE testing", , 4 September 2013 (2013-09-04), XP055190963, Retrieved from the Internet: URL:https://helda.helsinki.fi/bitstream/handle/10138/42301/thesis_Tomi_Johansson.pdf?sequence=3 [retrieved on 2015-05-21] page 20 - page 60 -----	1-14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/054489

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		JP 5688435 B2	25-03-2015
		JP 2014027656 A	06-02-2014
		US 2014029440 A1	30-01-2014