

(43) International Publication Date  
7 November 2013 (07.11.2013)

- (51) **International Patent Classification:**  
*H04B 1/04* (2006.01) *H04L 27/36* (2006.01)
- (21) **International Application Number:**  
PCT/SE2012/050464
- (22) **International Filing Date:**  
3 May 2012 (03.05.2012)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (71) **Applicant (for all designated States except US):** TELEFONAKTIEBOLAGET L M ERICSSON (PUBL) [SE/SE]; S-164 83 Stockholm (SE).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** JOHANSSON, Bernt [SE/SE]; Grills udde 7, S-139 40 Värmdö (SE). BERGLUND, Bo [SE/SE]; Ångkvarnsgatan 10 ; 1401, S-753 08 Uppsala (SE).
- (74) **Agent:** AYOUB, Nabil; Ericsson AB, Patent Unit Kista RAN 2, S-164 80 Stockholm (SE).
- (81) **Designated States (unless otherwise indicated, for every kind of national protection available):** AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ,

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

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

**Declarations under Rule 4.17:**

— of inventorship (Rule 4.17(iv))

**Published:**

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

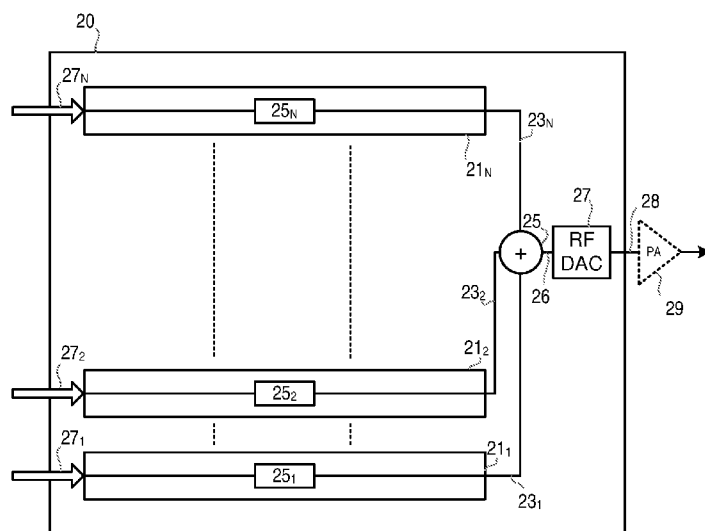
(54) **Title:** RADIO COMMUNICATION TRANSMITTER APPARATUS AND METHOD

Figure 2a

(57) **Abstract:** A radio communication transmitter apparatus 20 is operable to transmit multiple radio frequency bands in a telecommunication system. The apparatus comprises a plurality of digital transmitter chains 21<sub>1</sub> to 21<sub>N</sub>, wherein each digital transmitter chain is coupled to receive a digital representation 27<sub>1</sub> to 27<sub>N</sub> of a respective base band signal for processing by a respective digital transmitter chain. Each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub> comprises a digital transmitter 25<sub>1</sub> to 25<sub>N</sub> that is adapted to convert a respective digital base band signal directly into a digital representation of a radio frequency signal 23<sub>1</sub> to 23<sub>N</sub>. A digital combining unit 25 is coupled to receive the output of each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub>, and adapted to combine the digital representation of a radio frequency signal 23<sub>1</sub> to 23<sub>N</sub> received from each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub> into a digital representation of a radio frequency signal 26 comprising multiple radio frequency bands. A digital to analogue converter 27 is coupled to receive the digital representation of a radio frequency signal 26 comprising multiple radio frequency bands, and adapted to convert

the digital representation of a radio frequency signal 26 into an analogue radio frequency signal 28 comprising multiple radio frequency bands.

## Radio Communication Transmitter Apparatus and Method

### Technical Field

5

The present invention relates to a radio communication transmitter apparatus operable to transmit multiple radio frequency bands in a telecommunication system, and to a method performed in such an apparatus.

### 10 Background

For many years the deployment of telecommunication systems, for different standards and many frequency bands, has been realized to a large extent by placing radio base stations (RBS) in cellular networks covering large areas. An  
15 important link in a traditional radio base station architecture is between the active parts of the system (that is the digital and analog components of the system) to the passive parts (such as the filters and antennas). This high-power analog radio-frequency (RF) link is critical in the sense that it sometimes requires long cables of high quality and large dimensions, in order keep the  
20 unavoidable signal quality losses and power losses to a minimum. Such links suffer from the disadvantage of having high costs.

There has been a recent change to integrate the power amplifier and other RF blocks more closely with the physical antenna in order to avoid this critical link,  
25 and has resulted in what is termed an integrated antenna unit (IAU). The introduction of an IAU implies a change from RF feeders into a high-speed digital interface between a digital processing unit (DPU) and the IAU.

In order to implement a base station today with two or more frequency bands,  
30 several complete transmitters are combined on the analogue side after a transmission filter.

Thus, when implementing transmitters for multiple frequency bands, two or

more transmitters are implemented in the analogue domain, one transmitter for each frequency band.

Figure 1 shows a known dual band transmitter having two digital transmitters  
5 110<sub>1</sub>, 110<sub>2</sub> for handling first and second frequency bands, the digital transmitters feeding first and second digital pre-distortion units (DPDs) 111<sub>1</sub>, 111<sub>2</sub>. The output of each DPD 111<sub>1</sub>, 111<sub>2</sub> is converted into an analogue signal by a respective one of first and second digital to analogue converters 112<sub>1</sub>, 112<sub>2</sub>. A separate analogue up-converter 113<sub>1</sub>, 113<sub>2</sub> is provided for converting  
10 each analogue baseband signal into a respective analogue RF signal. Each analogue up-converter 113<sub>1</sub>, 113<sub>2</sub> is controlled by a respective tuneable local oscillator 114<sub>1</sub>, 114<sub>2</sub>. The outputs from the first and second analogue up-converters 113<sub>1</sub>, 113<sub>2</sub> are combined in an analogue combiner 115, before being  
15 fed to a power amplifier 116 (which feeds an antenna or antenna array, not shown). It will be appreciated that the transmitter shown in Figure 1 is bulky, since it comprises multiple DPDs 111<sub>1</sub>, 111<sub>2</sub>, multiple DACs 112<sub>1</sub>, 112<sub>2</sub> and multiple analogue up-converters 113<sub>1</sub>, 113<sub>2</sub>.

Furthermore, since tuneable local oscillators 114<sub>1</sub>, 114<sub>2</sub> are required per  
20 transmitter chain, these have the disadvantage in that each requires tuning control, additional space and increased power consumption.

Figure 1 also shows a feedback path for feeding a dual-band DPD processing unit 117. The feedback path comprises an analogue splitter 118, which feeds  
25 first and second analogue down-converters 119<sub>1</sub>, 119<sub>2</sub>, which in turn feed first and second transmitter observation receivers (TORs) 120<sub>1</sub>, 120<sub>2</sub>. The outputs from the first and second TORs 120<sub>1</sub>, 120<sub>2</sub> are used for controlling the DPDs 111<sub>1</sub>, 111<sub>2</sub>. The transmitter shown in Figure 1 is therefore bulky because it also requires multiple analogue down-converters 119<sub>1</sub>, 119<sub>2</sub> and multiple TORs  
30 120<sub>1</sub>, 120<sub>2</sub>. Further, the multiple analogue down-converters 119<sub>1</sub>, 119<sub>2</sub> in the TOR chain also require separate tuneable local oscillators.

It can be seen from the above that the conventional technology has a

disadvantage in that the multi band transmitters become bulky, particularly as more and more frequency bands are introduced, and have low energy efficiency and increased manufacturing cost due to the fact that several complete RF transmitters or several transmitter components in the analogue domain are  
5 used to implement the multi band transmitters.

### Summary

It is an aim of the present invention to provide a method and apparatus which obviate or reduce at least one or more of the disadvantages mentioned above.  
10

According to a first aspect of the invention, there is provided a radio communication transmitter apparatus that is operable to transmit multiple radio frequency bands in a telecommunication system. The apparatus comprises a plurality of digital transmitter chains, wherein each digital transmitter chain is  
15 coupled to receive a digital representation of a base band signal, and wherein each digital transmitter chain comprises a digital transmitter that is configured to convert a respective digital base band signal directly into a digital representation of a radio frequency signal. A digital combining unit is coupled to receive the output of each digital transmitter chain, and adapted to combine the digital  
20 representation of a radio frequency signal received from each digital transmitter chain into a digital representation of a radio frequency signal comprising multiple radio frequency bands. A digital to analogue converter is coupled to receive the digital representation of a radio frequency signal comprising multiple radio frequency bands, and adapted to convert the digital representation of a  
25 radio frequency signal into an analogue radio frequency signal comprising multiple radio frequency bands.

This has the advantage of enabling a less bulky transmitter apparatus to be provided for handling multiple frequency bands. For example, the use of the  
30 digital transmitter chains, as defined above, enable common components to be shared.

According to another aspect of the present invention, there is provided a method in a radio communication transmitter apparatus that is operable to transmit multiple radio frequency bands in a telecommunication system. The method comprises the steps receiving in each of a plurality of digital transmitter chains a digital representation of a respective base band signal for processing by a respective digital transmitter chain, and converting at each digital transmitter chain a respective digital radio base band signal directly into a digital representation of a radio frequency signal. The digital representation of a radio frequency signal of each digital transmitter chain is combined into a digital representation of a radio frequency signal comprising multiple radio frequency bands. The digital representation of a radio frequency signal comprising multiple radio frequency bands is converted into an analogue radio frequency signal comprising multiple radio frequency bands.

15 Brief description of the drawings

For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the following drawings in which:

20

Figure 1 shows a radio communication transmitter apparatus according to the prior art;

Figure 2a shows a radio communication transmitter apparatus according to an embodiment of the present invention;

25

Figure 2b shows the steps performed in a radio communication transmitter apparatus according to an embodiment of the present invention;

Figure 3 shows a radio communication transmitter apparatus according to another embodiment of the present invention;

30

Figure 4 shows a radio communication transmitter apparatus according to another embodiment of the present invention;

Figure 5 shows a radio communication transmitter apparatus according to  
5 another embodiment of the present invention;

Figure 6 shows a radio communication transmitter apparatus according to another embodiment of the present invention;

10 Figure 7 shows a radio communication transmitter apparatus according to another embodiment of the present invention; and

Figure 8 shows a radio communication transmitter apparatus according to another embodiment of the present invention.

15

#### Detailed description

The embodiments of the invention provide implementations of a multi band radio frequency (RF) transmitter apparatus that enable common components to  
20 be shared. The embodiments of the invention will be described in relation to using Direct Radio Frequency Technology (DRF) in the digital domain. It is noted, however, that other implementations of digital transmitter apparatus may be used, which provide the same functions as discussed below.

25 Figure 2a shows a radio communication transmitter apparatus 20 according to an embodiment of the present invention. The radio communication transmitter apparatus 20 is operable to transmit multiple radio frequency bands in a telecommunication system. The radio communication transmitter apparatus 20 comprises a plurality of digital transmitter chains 21<sub>1</sub> to 21<sub>N</sub>. Each digital  
30 transmitter chain is coupled to receive a digital representation 27<sub>1</sub> to 27<sub>N</sub> of a respective base band signal. Each digital transmitter train 21<sub>1</sub> to 21<sub>N</sub> comprises a digital transmitter 25<sub>1</sub> to 25<sub>N</sub> that is configured to convert (up-convert) a digital baseband signal directly into a digital representation of a radio frequency signal

23<sub>1</sub> to 23<sub>N</sub>. A digital transmitter 25<sub>1</sub> to 25<sub>N</sub> of Figure 2a (and the other  
embodiments described below) may comprise, for example, a digital transmitter  
that is configured to up-convert a digital base band signal directly to a digital  
representation of a radio frequency signal using Direct Radio Frequency  
5 Technology, DRF.

A digital combining unit 25, for example a digital summing unit, is coupled to  
receive the output of each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub>, and adapted to  
combine the digital representation of a radio frequency signal 23<sub>1</sub> to 23<sub>N</sub>  
10 received from each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub> into a digital  
representation of a radio frequency signal 26 comprising multiple radio  
frequency bands. The digital combining unit 25 may be realised as a field  
programmable gate array (FPGA), for example, or some other form of digital  
processing device for processing the digital RF signals. The digital combining  
15 unit 25 preferably has processing capabilities, including but not limited to high  
processing speed and/or a high clock rate, to handle the wide bandwidths  
associated with the multiple band signals.

A digital to analogue converter 27 is coupled to receive the digital  
20 representation of a radio frequency signal 26 comprising multiple radio  
frequency bands, and adapted to convert the digital representation of a radio  
frequency signal 26 into an analogue radio frequency signal 28 comprising  
multiple radio frequency bands. As will be described later in the application, this  
output 28 of the digital to analogue converter 27 may be processed downstream  
25 prior to being coupled to a power amplifier or a transmit antenna.

The digital to analogue converter 27 is preferably a high speed digital to  
analogue converter, such that it is capable of processing the multiple frequency  
band signals. The digital to analogue converter 27 is preferably configured to  
30 support a high sample rate at RF frequency, with the sample frequency  
preferably being at least the same as half the highest frequency of operation  
f<sub>max</sub> for operation in the 1st Nyquist zone, the same as f<sub>max</sub> when operating  
in the 2nd Nyquist zone and 2/3 f<sub>max</sub> for operation in the 3rd Nyquist zone.

The digital to analogue converter 27 may be configured to work in a so called mixed mode that supports operation in at least the 1st and 2nd Nyquist zone, but possibly also the 3rd Nyquist zone. The digital to analogue converter 27 is  
5 driven with a fixed clock frequency, without any tuning or frequency shifting. The digital to analogue converter preferably has a high dynamic range, i.e. high SFDR (Spurious free dynamic range) and low noise.

It can therefore be seen from Figure 2a that the separate signals corresponding  
10 to each frequency band are up converted by the digital transmitter units and combined digitally by the digital combining unit, prior to being converted from digital to analogue format. This has the advantage of removing the need for multiple analogue up-converters to be provided. This also has the advantage of enabling other components to be shared, as will be described in the  
15 embodiments below.

It is noted that the signals received by the digital transmitters  $25_1$  to  $25_N$  and/or output from the digital transmitters  $25_1$  to  $25_N$  may be subject to various processing techniques, as will be described further in relation to the other  
20 embodiments of the invention.

The embodiment of Figure 2a has the advantage of providing a frequency agnostic transmitter, and can be easily adapted or programmed to handle any range or combination of multiple radio frequency bands. The frequency range  
25 and combinations of multiple radio frequency bands can be set within the limits imposed by the highest sample rate  $f_{\text{max}}$  in combination with the performance of other components, such as an anti aliasing filter performance used with the embodiments of Figures 6, 7 and 8 below. The apparatus therefore enables a multi band, multi carrier and multi antenna transmitter to be realized.

30

This has the advantage of enabling a less bulky transmitter apparatus to be provided for handling multiple frequency bands. For example, the use of the

digital transmitter chains as defined above enable common components to be shared.

According to an alternative embodiment, each digital transmitter chain may be coupled to receive multiple base band signals in digital form, including a digital base band signal for processing by the respective digital transmitter chain. In such an embodiment each digital transmitter 25<sub>1</sub> to 25<sub>N</sub> may be programmable to select a particular base band signal from the digital representation of multiple base band signals 27<sub>1</sub> to 27<sub>N</sub>, and adapted to convert the selected digital base band signal into a digital representation of a radio frequency signal 23<sub>1</sub> to 23<sub>N</sub>, for example using a DRF transmitter.

Figure 2b shows the steps performed by a radio communication transmitter apparatus according to an embodiment of the present invention, which is operable to transmit multiple radio frequency bands. In step 201 the method comprises the step of receiving in a plurality of digital transmitter chains 21<sub>1</sub> to 21<sub>N</sub> a digital representation 27<sub>1</sub> to 27<sub>N</sub> of a respective base band signal. Each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub> converts a respective digital base band signal into a digital representation of a radio frequency signal 23<sub>1</sub> to 23<sub>N</sub>, step 203. For example, each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub> may comprise a digital transmitter 25<sub>1</sub> to 25<sub>N</sub> that is configured to up-convert a digital baseband signal directly to a digital representation of a radio frequency signal 23<sub>1</sub> to 23<sub>N</sub>, for example using a DRF transmitter. The digital representation of a radio frequency signal 23<sub>1</sub> to 23<sub>N</sub> of each digital transmitter chain 21<sub>1</sub> to 21<sub>N</sub> is combined, step 205, into a digital representation of a radio frequency signal comprising multiple radio frequency bands. The digital representation of a radio frequency signal comprising multiple radio frequency bands is then converted into an analogue radio frequency signal comprising multiple radio frequency bands, step 207.

30

Figure 3 shows a radio communication receiver apparatus 20 according to another embodiment of the present invention. As with Figure 2a, the radio communication transmitter apparatus 20 is operable to transmit multiple radio

frequency bands in a telecommunication system. The radio communication transmitter apparatus 20 comprises a plurality of digital transmitter chains  $21_1$  to  $21_N$ . Each digital transmitter chain is coupled to receive a digital representation  $27_1$  to  $27_N$  of a respective base band signal. Each digital transmitter train  $21_1$  to  $21_N$  comprises a digital transmitter  $25_1$  to  $25_N$  that is configured to up-convert a digital baseband signal directly to a digital representation of a radio frequency signal  $23_1$  to  $23_N$ . For example, a digital transmitter  $25_1$  to  $25_N$  of Figure 2a (and the other embodiments described below) may comprise a digital transmitter that is configured to up-convert a digital base band signal directly to a radio frequency signal using Direct Radio Frequency Technology, DRF.

A digital combining unit 25, for example a digital summing unit, is coupled to receive the output of each digital transmitter chain  $21_1$  to  $21_N$ , and adapted to combine the digital representation of a radio frequency signal  $23_1$  to  $23_N$  received from each digital transmitter chain  $21_1$  to  $21_N$  into a digital representation of a radio frequency signal 26 comprising multiple radio frequency bands.

A digital to analogue converter 27 is coupled to receive the digital representation of a radio frequency signal 26 comprising multiple radio frequency bands, and adapted to convert the digital representation of a radio frequency signal 26 into an analogue radio frequency signal 28 comprising multiple radio frequency bands.

The radio communication transmitter apparatus 20 of Figure 3 further comprises a common processing unit 30. The common processing unit 30 is coupled to receive multiple base band carrier signals  $31_1$  to  $31_N$ , and is adapted to digitally process the multiple base band carrier signals to produce the digital representation  $27_1$  to  $27_N$  of each base band signal for each of the digital receiver chains.

It can therefore be seen that the multi band transmitter is fed by base band carrier signals, for different carriers and frequency bands, to the common processing block 30. The common processing block may be configured to perform processing tasks such as crest factor reduction (CFR, CFAR) or digital pre-distortion (DPD). It is noted that the embodiments described herein relate to just one example of a DPD implementation, and that other implementations are possible, for example DPD on base band signals for multi frequency band transmitters, without departing from the scope of the invention as defined in the appended claims. The processed (or corrected) base band signal for each frequency band is then fed to a respective DRF digital transmitter that digitally converts the base band signal to digital RF in the right frequency band. The digital RF signals from different frequency bands are combined in the digital combining unit 25 into one digital signal 26 that is fed to the high speed DAC 27.

Figure 4 shows a radio communication transmitter apparatus 20 as described above in relation to Figures 2a and 3, but further comprising a digital pre-distortion unit 33 (DPD) coupled between the digital combining unit 25 and the digital to analogue converter 27. The digital pre-distortion unit 33 is configured to modify the digital representation of a radio frequency signal 26 comprising multiple radio frequency bands prior to conversion by the digital to analogue converter 27. In order to handle the multiple bands, the digital pre-distortion unit 33 may be configured to deal with characteristics of the multiple bands, such as one or more of the spacing between bands, the width of each band, the frequency range of each band, and so forth.

A look-up table 35 (LUT) is provided for controlling the operating parameters of the digital pre-distortion unit 33, wherein the look-up table is controlled by the common processing unit 30 using a control signal 36. The control signal 36 may be based on a feedback signal received by the common processing unit 30, for example as described below in Figure 5.

Each of the embodiments described above and below can feed a wide band power amplifier 29 for amplifying the analogue radio frequency signal 28 comprising multiple radio frequency bands.

5 Figure 5 shows a further embodiment of a radio communication transmitter apparatus 20, similar to the embodiments of Figures 2a, 3 and 4. The radio communication transmitter apparatus 20 of Figure 5 further comprises a feedback unit 41 coupled to monitor an output signal of the transmitter, for example by taking the output of a power amplifier 29, and adapted to provide a  
10 feedback signal 40 to the common processing unit 30. Alternatively, the feedback unit 41 can derive its input signal by coupling to a transmit antenna (not shown) that is fed by a power amplifier (29). The feedback unit 41 comprises a digital receiver 37 (for example a DRF receiver) coupled to the output of the power amplifier 29 (or antenna) via a high speed radio frequency  
15 ADC 39. The feedback unit 41 also comprises a transmitter observation receiver 38, TOR, coupled to receive an output of the digital receiver 37. As such, a measurement signal, decoupled at the power amplifier (or antenna after the power amplifier) is fed to a digital TOR for RF signal characterization. The characterized RF signal is fed as a feedback signal 40 into the common  
20 processing unit 30 for DPD processing. The function of the digital TOR 38 will be familiar to a person skilled in the art, for example as described in a paper entitled "Linearizing Power Amplifiers Using Digital Predistortion, EDA Tools and Test Hardware", by Kelly Mekechuk et al, April 2004, *High Frequency Electronics* journal. The TOR 38 preferably comprises a frequency agile  
25 multiband capability, for example a wideband reduced dynamic range version of a DRF receiver, such that it can measure the output signal of the transmitter, including the distortion components. It is noted that the dynamic range can be reduced relative to an ordinary RBS receiver as the transmitter signal is measured directly at the output of the transmitter without the additional path  
30 loss added in a real system. The digital TOR (DTOR) is reused for all carriers in all frequency bands. Thus, this embodiment of the invention has the advantage of enabling a common DTOR to be used for the multiple frequency band signals.

Figure 6 shows a further embodiment of a radio communication transmitter apparatus 20, similar to those shown in Figures 2a, 3, 4 and 5. The radio communication transmitter apparatus 20 of Figure 6 is further adapted such that  
5 unwanted RF signals from the DAC 27 are filtered out in a common filter unit 43, for example a filter unit that performs an anti aliasing filtering function combined with selection of frequency bands of operation. The radio communication transmitter apparatus 20 of Figure 6 therefore comprises a wide band filter unit 43 coupled to the output of the digital to analogue converter 27,  
10 the wide band filter unit 43 being adapted to perform an anti aliasing function combined with a selection of operating frequency bands on the analogue radio frequency signal 28 comprising multiple radio frequency bands. The wide band filter unit 43 has the advantage of being physically small and low cost (that is, small or having an insignificant size in relation to the DAC and the overall  
15 transmitter implementation).

Figure 7 shows a typical application of the embodiments described above, whereby the radio communication transmitter apparatus further comprises a plurality of output filter units  $45_1$  to  $45_N$  coupled to the output of a wide band  
20 power amplifier 29. Each of the plurality of output filter units is adapted to receive the amplified analogue radio frequency signal 28 comprising multiple radio frequency bands, and adapted to filter a required radio frequency band for coupling to an antenna 47. The frequency specific output filter units filter out respective wanted RF signals, which are combined and fed to the transmitter  
25 antenna 47.

Figure 8 shows yet a further embodiment of a radio communication transmitter apparatus 20, similar to those shown in Figures 2a, 3, 4, 5, 6 and 7. The communication transmitter apparatus 20 of Figure 8 further comprises a  
30 plurality of base band carrier processing units  $49_1$  to  $49_N$ , each base band carrier processing unit adapted to process a base band carrier signal prior to being processed by the common processing unit 30. The plurality of base band carrier processing units  $49_1$  to  $49_N$  may perform, for example, PreCoder

functions or Inverse Fast Fourier Transforms (IFFT) on the base band signals. The plurality of base band carrier processing units  $49_1$  to  $49_N$  are fed by base band signals, for different carriers and frequency bands.

- 5 As can be seen from the above, the embodiments of the invention have the advantage of providing power efficiency due to common component utilization.

The embodiments of the invention also provide the advantages of enabling a frequency agnostic transmitter to be realised, and providing a multi band, multi  
10 carrier and multi antenna transmitter.

It is noted that the various features shown in each of the embodiments of Figures 2a, 3, 4, 5, 6, 7 and 8 may be combined or interchanged in any manner. For example, an embodiment having a feedback unit 41 may be used without  
15 any DPD unit 33 or filter unit 43, or an embodiment having a filter unit 43 may be used without any DPD 33 or feedback unit 41, and so forth.

The embodiments above can use Direct RF, direct digital to RF conversion, to provide RF re-configurability over wide RF bandwidths. The embodiments can  
20 be used in various kinds of wireless base stations where wide RF bandwidth operation, carrier aggregation, wide instantaneous bandwidth, small size and low power consumption are desirable. Examples of such base stations are advanced active antennas, main -remote base stations with many transmit/receive branches (2-4-8 for example). Future wireless base stations  
25 should preferably be able to operate over many frequency bands that are widely separated in frequency. The frequency band combinations used will be different in different countries/regions and thus the high RF frequency setting flexibility provided by the proposed embodiments based on DRF based architectures has many advantages.

30

In the DRF based solutions the up/down conversion is moved from the analogue parts to the digital parts, and can be integrated into ASIC's. Digital

signal processing also provides high accuracy and flexibility compared to analogue solutions that suffer from impairments that limit the useful bandwidths.

It should be noted that the above-mentioned embodiments illustrate rather than  
5 limit the invention, and that those skilled in the art will be able to design many  
alternative embodiments without departing from the scope of the appended  
claims. The word “comprising” does not exclude the presence of elements or  
steps other than those listed in a claim, “a” or “an” does not exclude a plurality,  
and a single processor or other unit may fulfil the functions of several units  
10 recited in the claims. Any reference signs in the claims shall not be construed  
so as to limit their scope.

**CLAIMS**

- 5 1. A radio communication transmitter apparatus operable to transmit multiple radio frequency bands in a telecommunication system, the apparatus comprising:
- a plurality of digital transmitter chains, wherein each digital transmitter chain is coupled to receive a digital representation of a base band
- 10 signal, and wherein each digital transmitter chain comprises a digital transmitter that is configured to convert a respective digital base band signal directly into a digital representation of a radio frequency signal;
- a digital combining unit coupled to receive the output of each digital transmitter chain, and adapted to combine the digital representation of a radio
- 15 frequency signal received from each digital transmitter chain into a digital representation of a radio frequency signal comprising multiple radio frequency bands; and
- a digital to analogue converter coupled to receive the digital representation of a radio frequency signal comprising multiple radio frequency
- 20 bands, and adapted to convert the digital representation of a radio frequency signal into an analogue radio frequency signal comprising multiple radio frequency bands.
- 25 2. A radio communication transmitter apparatus as claimed in claim 1, further comprising a common processing unit, the common processing unit coupled to receive a plurality of base band carrier signals, and adapted to digitally process the plurality of base band carrier signals to produce the digital representation of each base band signal for each of the digital receiver chains.
- 30 3. A radio communication transmitter apparatus as claimed in claim 1 or 2, further comprising a digital pre-distortion unit, DPD, coupled between the digital combining unit and the digital to analogue converter, for modifying the digital

representation of a radio frequency signal comprising multiple radio frequency bands prior to conversion by the digital to analogue converter.

4. A radio communication transmitter apparatus as claimed in claim 3 when  
5 dependent on claim 2, further comprising a look-up table for controlling the operating parameters of the pre-distortion unit, wherein the look-up table is controlled by the common processing unit.
5. A radio communication transmitter apparatus as claimed in any one of  
10 claims 1 to 4, further comprising a wide band power amplifier for amplifying the analogue radio frequency signal comprising multiple radio frequency bands.
6. A radio communication transmitter apparatus as claimed in claim 5, further comprising a feedback unit coupled to monitor the output of the power amplifier,  
15 and adapted to provide a feedback signal to the common processing unit (30).
7. A radio communication transmitter apparatus as claimed in claim 6, wherein the feedback unit comprises:  
a digital receiver coupled to the output of the power amplifier; and  
20 a transmitter observation receiver coupled to receive an output of the digital receiver.
8. A radio communication transmitter apparatus as claimed in any one of the preceding claims, further comprising a wide band filter unit coupled to the output  
25 of the digital to analogue converter, the wide band filter unit being adapted to perform an anti aliasing function on the analogue radio frequency signal comprising multiple radio frequency bands.
9. A radio communication transmitter apparatus as claimed in any one of  
30 claims 5 to 8, further comprising a plurality of output filter units coupled to the output of the wide band power amplifier, each of the plurality of output filter units being adapted to receive the amplified analogue radio frequency signal

comprising multiple radio frequency bands, and adapted to filter a required radio frequency band for coupling to an antenna.

10. A radio communication transmitter apparatus as claimed in any one of  
5 claims 2 to 9, further comprising a plurality of base band carrier processing units, each base band carrier processing unit adapted to process a base band carrier signal prior to being processed by the common processing unit.

11. A method in a radio communication transmitter apparatus that is operable  
10 to transmit multiple radio frequency bands in a telecommunication system, the method comprising the steps of:

receiving in each of a plurality of digital transmitter chains a digital representation of a respective base band signal for processing by a respective digital transmitter chain;

15 converting at each digital transmitter chain a respective digital radio base band signal directly into a digital representation of a radio frequency signal;

combining the digital representation of a radio frequency signal of each digital transmitter chain into a digital representation of a radio frequency  
20 signal comprising multiple radio frequency bands; and

converting the digital representation of a radio frequency signal comprising multiple radio frequency bands into an analogue radio frequency signal comprising multiple radio frequency bands.

25 12. A method as claimed in claim 11, further comprising the step of receiving a plurality of base band carrier signals at a common processing unit, and digitally processing the plurality of base band carrier signals to produce the digital representation of each base band signal for each of the digital receiver chains.

30 13. A method as claimed in claim 11 or 12, further comprising the steps of digitally pre-distorting the output of the combining unit prior to converting the digital representation of a radio frequency signal comprising multiple radio frequency bands into an analogue signal.

14. A method as claimed in claim 13, further comprising the step of controlling the operating parameters of the pre-distortion unit using a look-up table, wherein the look-up table is controlled by the common processing unit.

5

15. A method as claimed in any one of claims 11 to 14, further comprising the step of amplifying the analogue radio frequency signal comprising multiple radio frequency bands using a wide band power amplifier.

10 16. A method as claimed in claim 15, further comprising the step of monitoring the output of the power amplifier to provide a feedback signal, and controlling the operation of the common processing unit based on the feedback signal.

15 17. A method as claimed in claim 16, wherein the step of monitoring comprises the steps of:  
coupling a digital receiver to the output of the power amplifier; and  
coupling a transmitter observation receiver to an output of the digital receiver, such that the output of the transmitter observation receiver forms the feedback signal for the common processing unit.

20

18. A method as claimed in any one of claims 11 to 17, further comprising the step of filtering the output of the digital to analogue converter using a wide band filter unit, wherein the filtering step comprising performing an anti aliasing function on the analogue radio frequency signal comprising multiple radio  
25 frequency bands.

19. A method as claimed in any one of claims 15 to 18, further comprising the steps of filtering the output of the wide band power amplifier using a plurality of output filter units, each of the plurality of output filter units being adapted to  
30 receive the amplified analogue radio frequency signal comprising multiple radio frequency bands, and filter a corresponding radio frequency band for coupling to an antenna.

20. A method as claimed in any one of claims 12 to 19, further comprising the steps of processing each base band carrier signal prior to being processed by the common processing unit, using a plurality of base band carrier processing units.

1/9

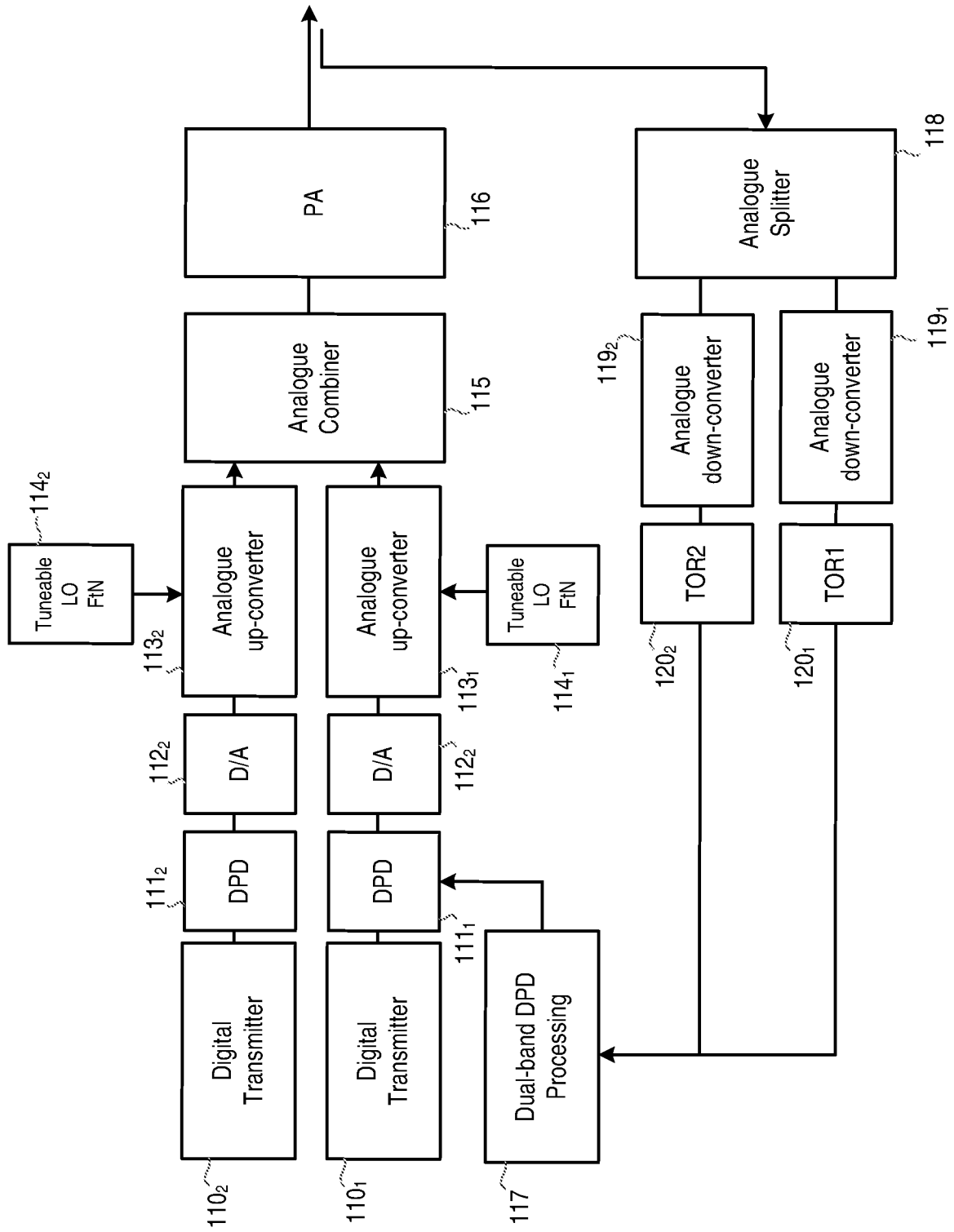


Figure 1

2/9

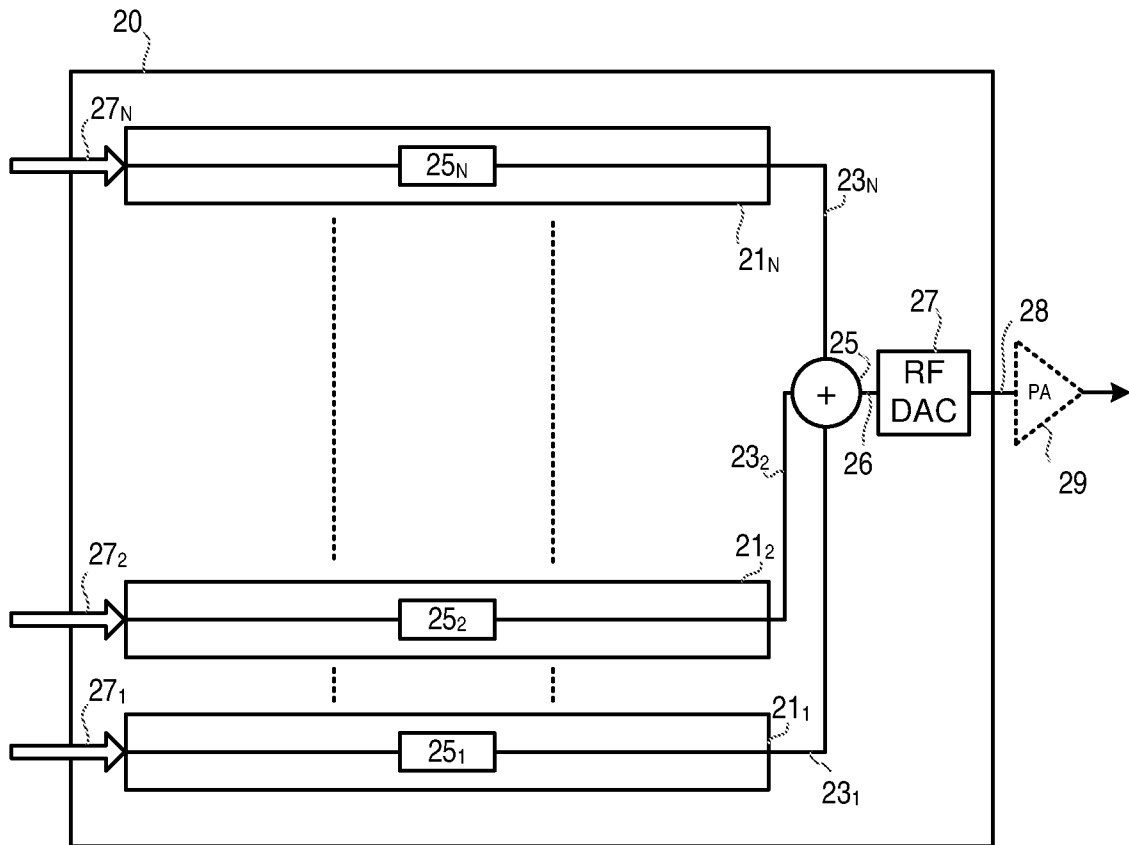


Figure 2a

3/9

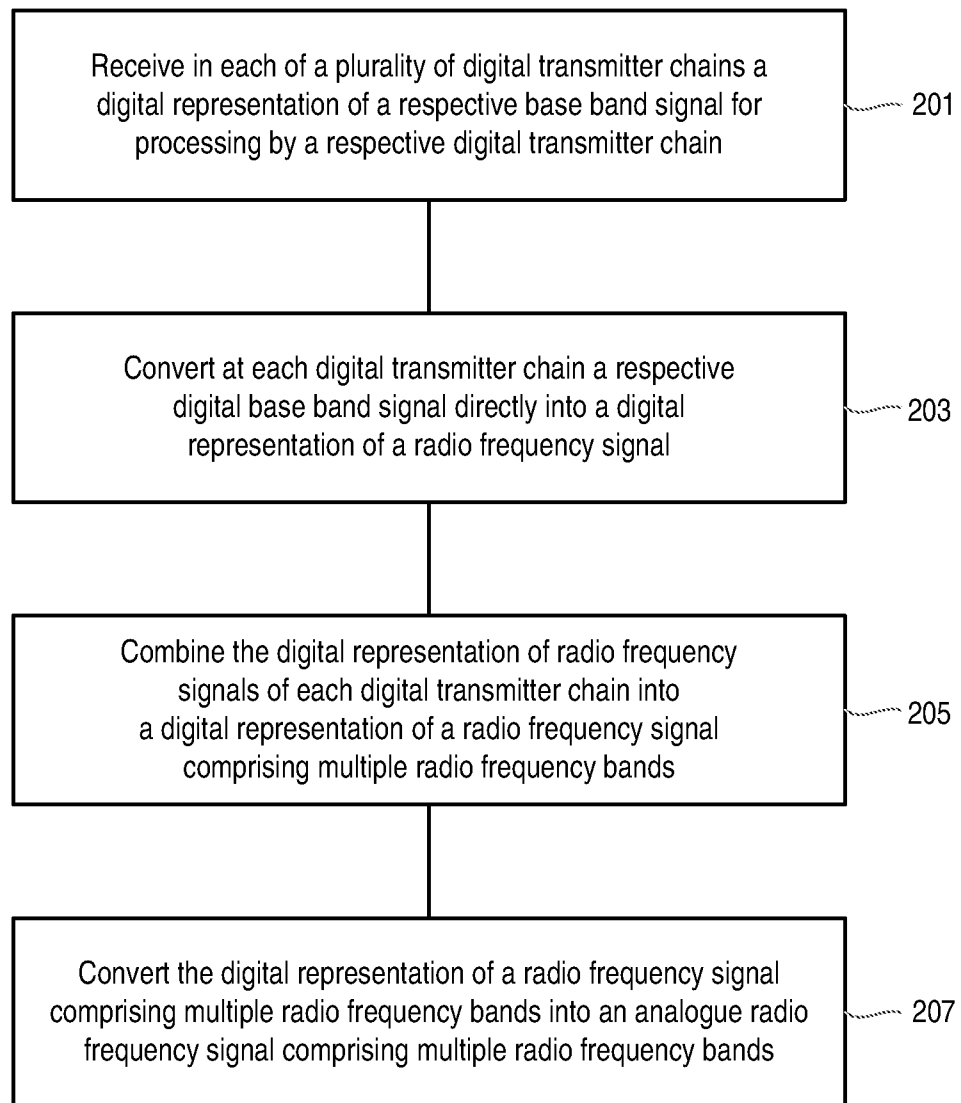


Figure 2b

4/9

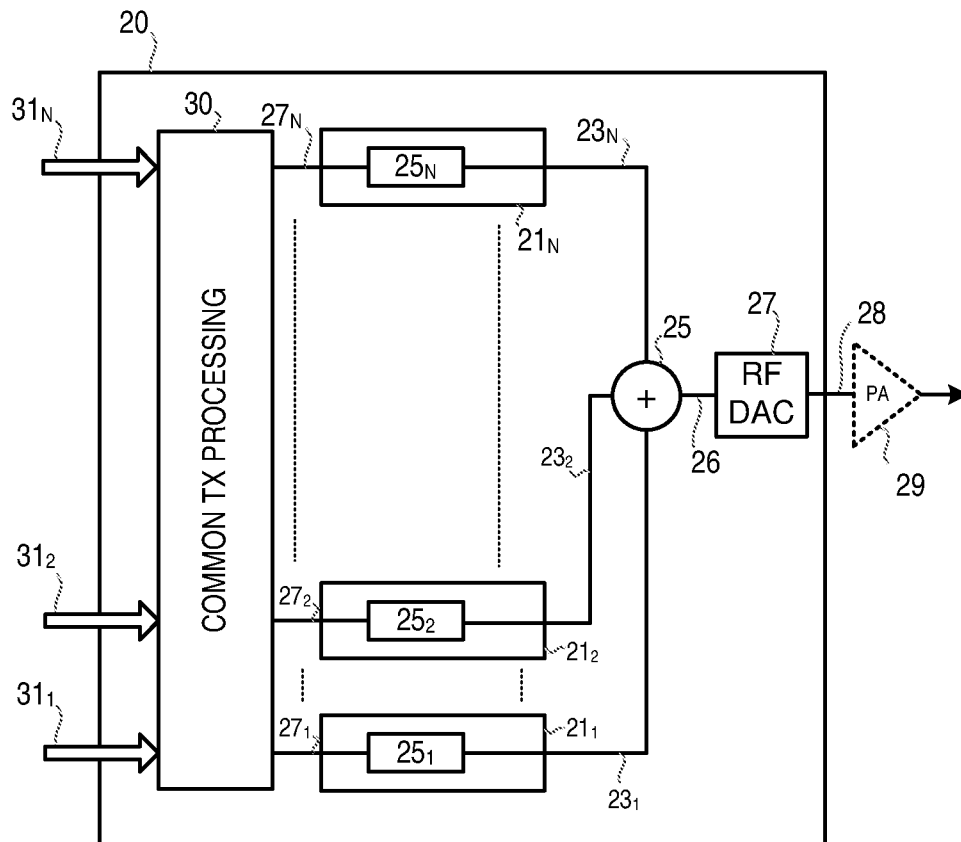


Figure 3

5/9

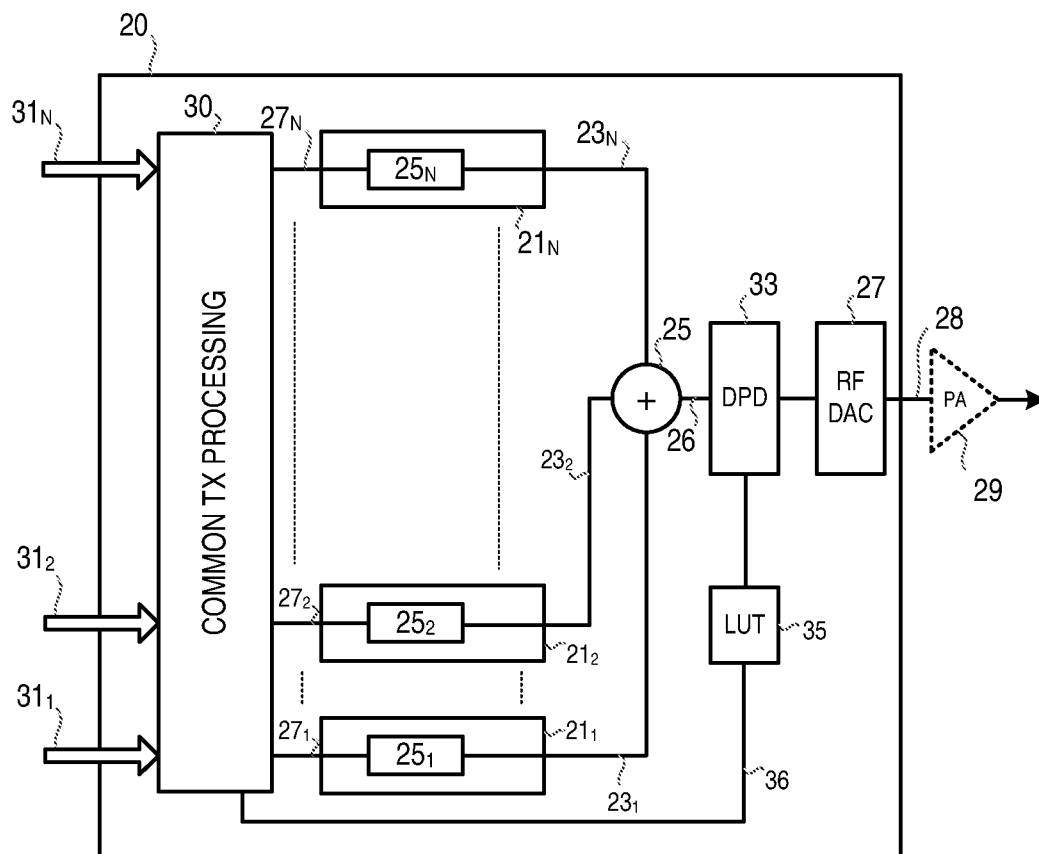


Figure 4

6/9

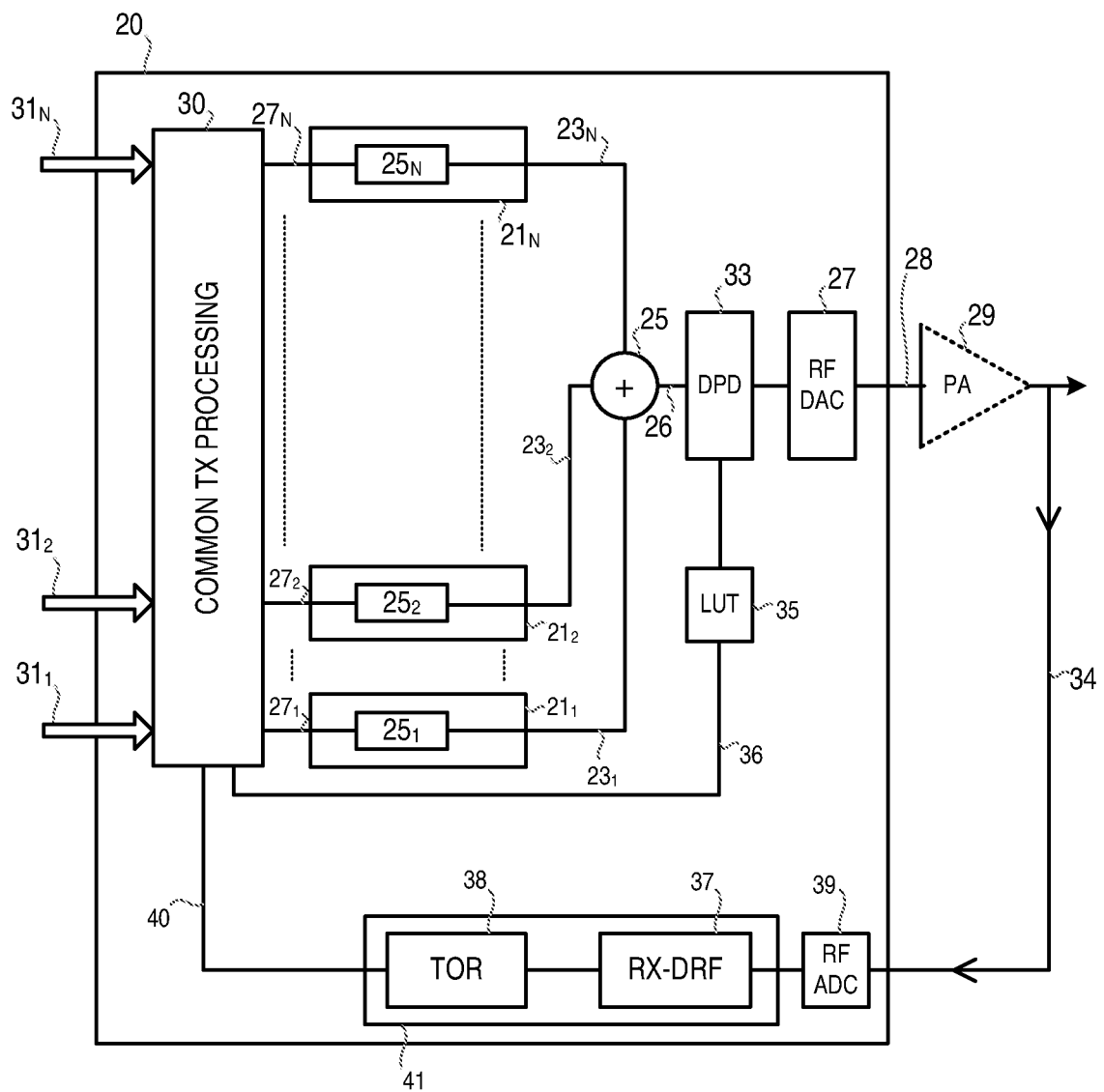


Figure 5

7/9

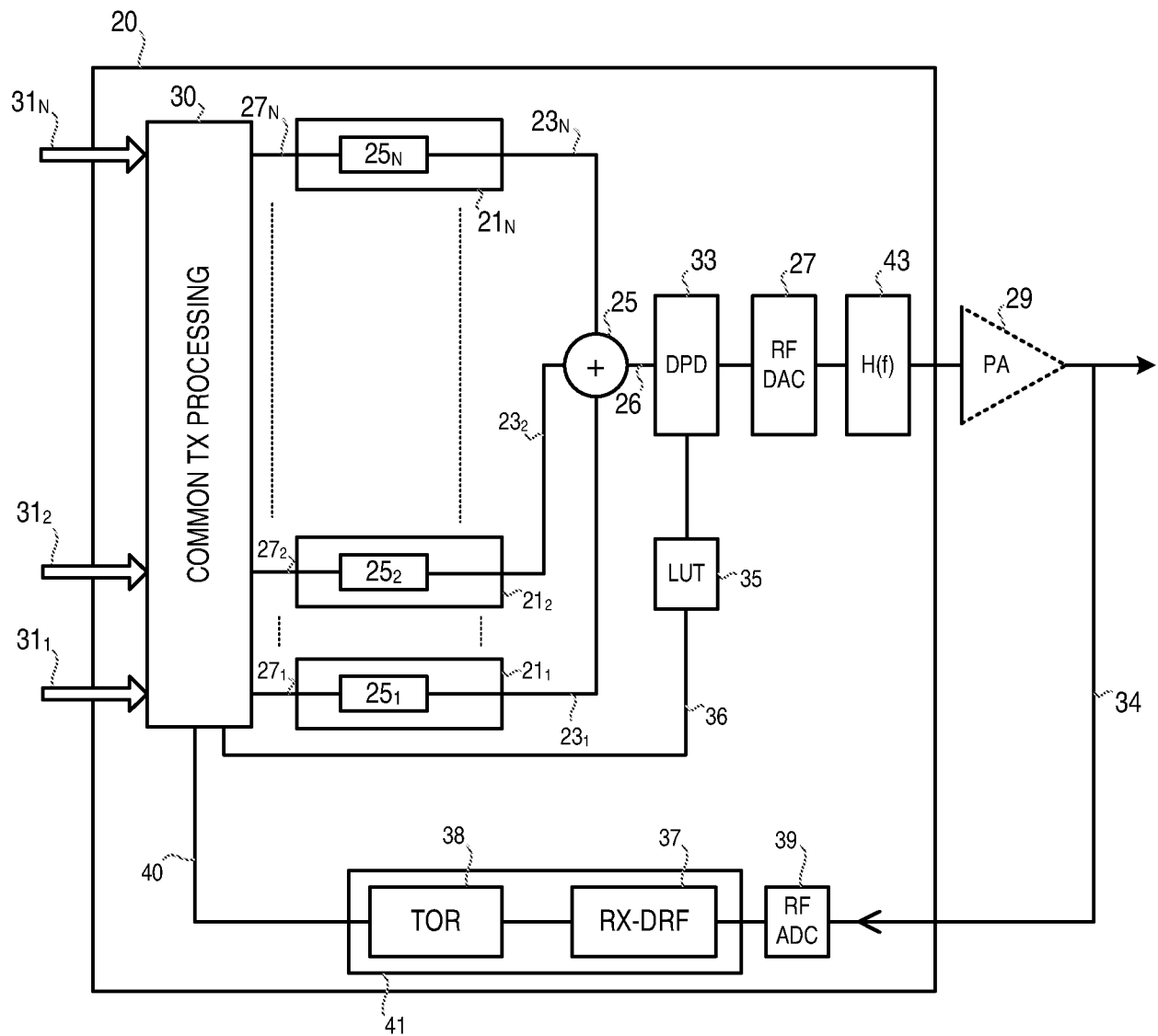


Figure 6

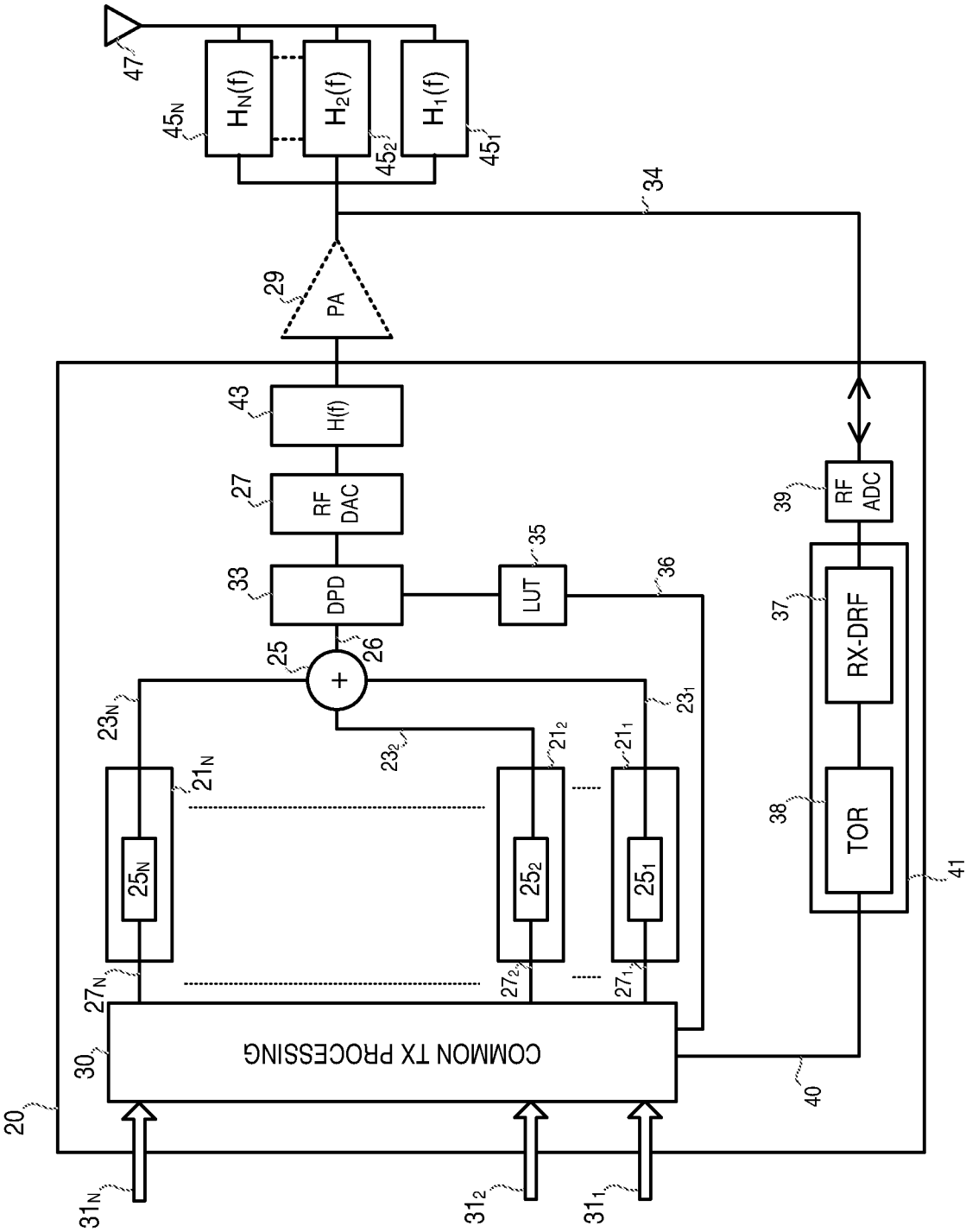


Figure 7

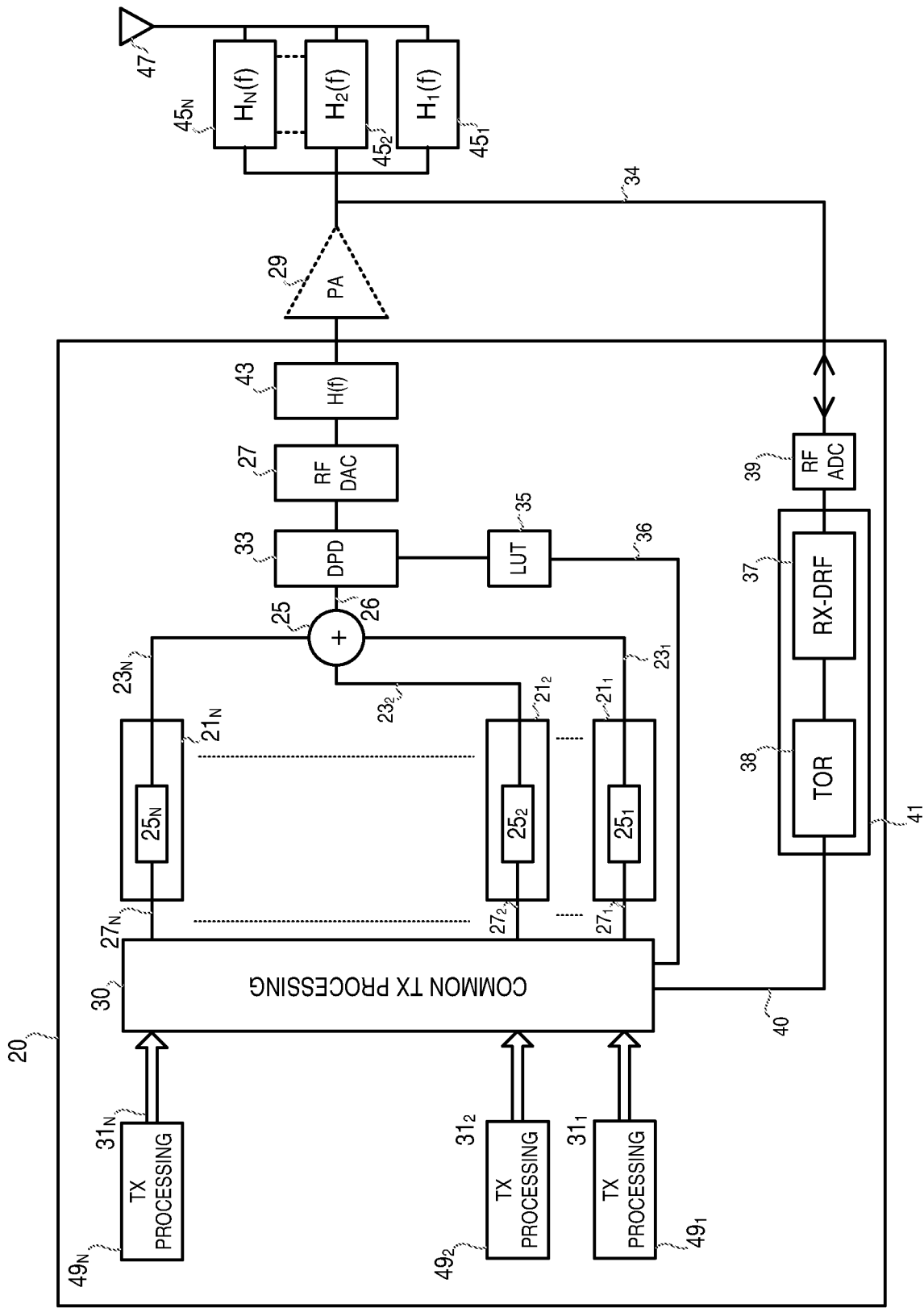


Figure 8

## INTERNATIONAL SEARCH REPORT

 International application No.  
 PCT/SE2012/050464

## A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: H04B, H04L

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                        | Relevant to claim No. |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 20050136859 A1 (ANVARI KIOMARS), 23 June 2005<br>(2005-06-23); paragraphs [0015]-[0029]; figures 1;3-7; claim 1<br>--                                                  | 1-20                  |
| X         | US 20050085198 A1 (ANVARI KIOMARS), 21 April 2005<br>(2005-04-21); abstract; paragraphs [0014]-[0028]; figures 1;3-7; claim 1<br>--                                       | 1-20                  |
| A         | US 20110156815 A1 (KIM WAN JONG ET AL), 30 June 2011<br>(2011-06-30); abstract; paragraphs [0013]-[0016], [0018]-[0022], [0034], [0061], [0063]-[0064]; figures 7-8<br>-- | 1-20                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

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

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

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

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

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

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

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

“&amp;” document member of the same patent family

Date of the actual completion of the international search

26-04-2013

Date of mailing of the international search report

29-04-2013

Name and mailing address of the ISA/SE

 Patent- och registreringsverket  
 Box 5055  
 S-102 42 STOCKHOLM  
 Facsimile No. + 46 8 666 02 86

Authorized officer

Sebastian Diskay

Telephone No. + 46 8 782 25 00

## INTERNATIONAL SEARCH REPORT

 International application No.  
 PCT/SE2012/050464

| C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                                               |                       |
|-------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                             | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                            | Relevant to claim No. |
| A                                                     | WO 2010124297 A1 (DALI SYSTEMS CO LTD ET AL), 28 October 2010 (2010-10-28); abstract; paragraphs [0024]-[0030]; figures 4-5<br>--                                                                             | 1-20                  |
| A                                                     | WO 2007076495 A2 (CRESTCOM INC ET AL), 5 July 2007 (2007-07-05); page 5, line 3 - line 6; page 7, line 22 - page 8, line 13; page 11, line 3 - line 11; page 15, line 1 - line 3<br>--                        | 1-20                  |
| A                                                     | "Linearizing Power Amplifiers Using Digital Predistortion, EDA Tools<br><br>and Test Hardware", by Kelly Mekechuk et al, April 2004, High Frequency<br><br>Electronics journal.; whole document<br>--         | 1-20                  |
| E                                                     | EP 2528293 A1 (HUAWEI TECH CO LTD), 28 November 2012 (2012-11-28); abstract; paragraphs [0003]-[0006], [0020]-[0023], [0025]-[0026], [0036], [0039]-[0041], [0043]-[0045], [0047]-[0056]; figures 1,5-9<br>-- | 1-20                  |
| E                                                     | US 20120155572 A1 (KIM WAN JONG ET AL), 21 June 2012 (2012-06-21); paragraphs [0085]-[0087], [0095]-[0096]<br>--                                                                                              | 1, 11                 |
| E                                                     | US 20120128099 A1 (MORRIS BRADLEY JOHN ET AL), 24 May 2012 (2012-05-24); abstract; claims 1-8<br>--                                                                                                           | 1-20                  |
| E                                                     | WO 2012092647 A1 (UNIV JAMES COOK ET AL), 12 July 2012 (2012-07-12); abstract; page 11, line 9 - page 12, line 15<br>--                                                                                       | 1-20                  |
| E                                                     | WO 2012119178 A1 (COMMW SCIENT IND RES ORG ET AL), 13 September 2012 (2012-09-13); abstract; page 8, paragraph [0016] - page 9, paragraph [0009]<br>--<br>-----                                               | 1-20                  |

**Continuation of:** second sheet

**International Patent Classification (IPC)**

**H04B 1/04** (2006.01)

**H04L 27/36** (2006.01)

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SE2012/050464

|    |                |            |      |                |            |
|----|----------------|------------|------|----------------|------------|
| US | 20050136859 A1 | 23/06/2005 | US   | 7142831 B2     | 28/11/2006 |
| US | 20050085198 A1 | 21/04/2005 | US   | 7146138 B2     | 05/12/2006 |
| US | 20110156815 A1 | 30/06/2011 | EP   | 2524568 A1     | 21/11/2012 |
|    |                |            | EP   | 2517353 A2     | 31/10/2012 |
|    |                |            | US   | 20110158081 A1 | 30/06/2011 |
|    |                |            | WO   | 2011077246 A2  | 30/06/2011 |
|    |                |            | WO   | 2011077247 A3  | 18/08/2011 |
|    |                |            | WO   | 2011098861 A8  | 22/09/2011 |
|    |                |            | WO   | 2011077249 A8  | 22/09/2011 |
| WO | 2010124297 A1  | 28/10/2010 | EP   | 2430531 A1     | 21/03/2012 |
|    |                |            | KR   | 20120014001 A  | 15/02/2012 |
| WO | 2007076495 A2  | 05/07/2007 | EP   | 1966923 A2     | 10/09/2008 |
|    |                |            | US   | 20070165743 A1 | 19/07/2007 |
|    |                |            | US   | 7542519 B2     | 02/06/2009 |
| EP | 2528293 A1     | 28/11/2012 | CN   | 102130697 A    | 20/07/2011 |
|    |                |            | US   | 20120281550 A1 | 08/11/2012 |
|    |                |            | WO   | 2011088792 A1  | 28/07/2011 |
| US | 20120155572 A1 | 21/06/2012 | NONE |                |            |
| US | 20120128099 A1 | 24/05/2012 | WO   | 2012066370 A1  | 24/05/2012 |
| WO | 2012092647 A1  | 12/07/2012 | NONE |                |            |
| WO | 2012119178 A1  | 13/09/2012 | NONE |                |            |