



- (51) **International Patent Classification:**
H03F 1/32 (2006.01)
- (21) **International Application Number:**
PCT/CN2014/081513
- (22) **International Filing Date:**
2 July 2014 (02.07.2014)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (71) **Applicant:** NOKIA TECHNOLOGIES OY [FI/FI];
Karaportti 3, FI-02610 Espoo (FI).
- (71) **Applicant (for LC only):** NAVTEQ (SHANGHAI)
TRADING CO., LTD. [CN/CN]; Room 2930, 2933 and
2942, North Tower, Kerry Center, No. 1515 Nanjing Road
West, Jing'an District, Shanghai 200040 (CN).
- (72) **Inventor:** WANG, Zhancang; 32, Sun Wang Chang, Li
Yuan, Tongzhou District, Beijing 101121 (CN).
- (74) **Agent:** KING & WOOD MALLESONS; 20th Floor, East
Tower, World Financial Centre, No.1 Dongsanhuan Zhong-
glu, Chaoyang District, Beijing 100020 (CN).
- (81) **Designated States** (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

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

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

Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

Published:

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

(54) **Title:** METHOD AND APPARATUS FOR ENVELOPE SHAPING IN ENVELOPE TRACKING POWER AMPLIFICATION

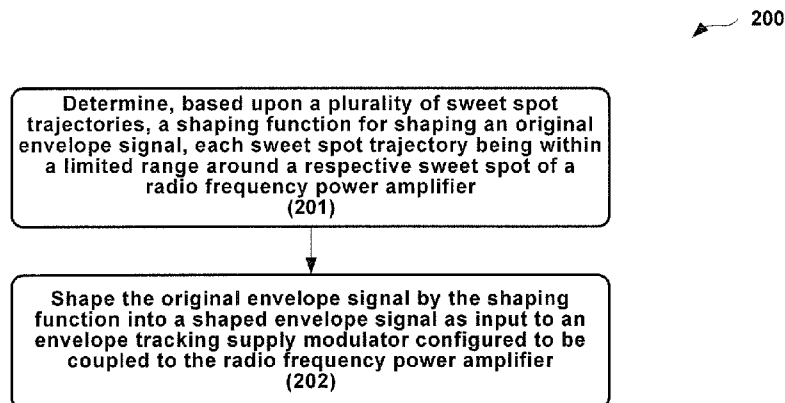


Fig. 2

(57) **Abstract:** A method, corresponding apparatuses, and a non-transitory computer readable medium for envelope shaping in envelope tracking power amplification are provided. The method comprises determining, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The method also comprises shaping the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier. With the claimed inventions, the efficiency and linearity of an envelope tracking power amplifier could be improved.

METHOD AND APPARATUS FOR ENVELOPE SHAPING IN ENVELOPE TRACKING POWER AMPLIFICATION

FIELD OF THE INVENTION

5

[0001] Example embodiments of the present disclosure generally relate to power amplification techniques. More particularly, example embodiments of the present disclosure relate to a method and apparatuses for envelope shaping in envelope tracking power amplification.

10

BACKGROUND OF THE INVENTION

[0002] The following description of background art may include insights, discoveries, understandings or disclosures, or associations together with disclosures not known to the relevant art prior to the present disclosure but provided by the present disclosure. Some such contributions of the present disclosure may be specifically pointed out below, while other such contributions of the present disclosure will be apparent from their context.

[0003] The efficiency of a Radio Frequency ("RF") Power Amplifier ("PA") is generally defined as a ratio between a desired transmitted radio power and a total power from a power supply and this ratio appears to be rather low in the future wideband applications if traditional power amplification architectures are still applied. For the purposes of enhancing the efficiency, an Envelope Tracking ("ET") technique has been proposed and utilized in the wireless communication industry and has been considered as a most promising efficiency enhancement solution for the fourth Generation ("4G") and beyond wireless communications.

[0004] It is known that in the ET PA, the power supply voltage applied to the PA is constantly adjusted according to the envelope version of an original input signal to ensure that the PA is operating at the peak efficiency over the output power range. However, when the PA's power supply is changed from low to high instantaneously and dynamically or vice-versa, the PA's operating point on the drain-side would change dramatically accordingly. This significant change of the operating point would give rise to undesirable distortions and memory effects, which may cause gain collapse and unpredictable and non-correctable distortions and adversely affect both efficiency and

linearity of an ET supply modulator which provides the modulated power supply voltage to the PA.

SUMMARY OF THE INVENTION

5

[0005] The following presents a simplified summary of the present disclosure in order to provide a basic understanding of some aspects of the present disclosure. It should be noted that this summary is not an extensive overview of the present disclosure and that it is not intended to identify key/critical elements of the present disclosure or to delineate the scope of the present disclosure. Its sole purpose is to present some concepts of the present disclosure in a simplified form as a prelude to the more detailed description that is presented later.

10

[0006] To diminish or eliminate at least one of the above-mentioned problems, various aspects of the present disclosure provide a method, apparatuses and a non-transitory computer readable medium for performing envelope tracking power amplification such that it is possible to provide a less memory effect and linearizable envelope tracking power amplifier.

15

[0007] According to an aspect of the present disclosure, there is provided a method. The method comprises determining, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The method also comprises shaping the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

20

25

[0008] In one embodiment, the method further comprises obtaining the plurality of sweet spot trajectories by observing intermodulation distortions under a plurality of radio frequency power amplifier supply voltages provided by the envelope tracking supply modulator and a plurality of radio frequency power amplifier input power levels.

30

[0009] In another embodiment, the shaping function comprises a plurality of piecewise envelope shaping functions, each of which corresponds to one of the plurality of sweet spot trajectories in a curve fitting form.

[0010] In yet another embodiment, each of the plurality of piecewise envelope

shaping functions is a linear shaping function or a non-linear shaping function.

[0011] In a further embodiment, the shaping the original envelope signal comprises shaping the original envelope signal whose amplitude is within a range corresponding to one of the plurality of sweet spot trajectories by a corresponding one of the plurality of piecewise envelope shaping functions.

[0012] In one embodiment, the shaping is implemented by a predetermined sweet spot mapping relationship established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories.

[0013] In one embodiment, the predetermined sweet spot mapping relationship is established by a predetermined look-up table or polynomials with changeable multipliers.

[0014] In another embodiment, a plurality of predetermined sweet spot mapping relationships are formed, each of which is formed under one of a plurality of temperatures.

[0015] In another embodiment, the limited range of each of the plurality of sweet spot trajectories is determined as a specific intermodulation distortion level degradation from a corresponding sweet spot.

[0016] In an additional embodiment, the number of the plurality of sweet spot trajectories corresponding to the plurality of the piecewise shaping functions is adjustable to meet requirements of different application scenarios.

[0017] According to an aspect of the present disclosure, there is provided an apparatus. The apparatus comprises at least one processor and at least one memory including computer program instructions. The memory and the computer program instructions are configured to, with the at least one processor, cause the apparatus at least to determine, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The memory and the computer program instructions are also configured to, with the at least one processor, cause the apparatus at least to shape the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

[0018] According to an aspect of the present disclosure, there is provided an apparatus. The apparatus comprises means for determining, based upon a plurality of

sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The apparatus also comprises means for shaping the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

[0019] According to an aspect of the present disclosure, there is provided a non-transitory computer readable medium having program code stored thereon, the program code configured to direct an apparatus, when executed, to determine, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The program code is also configured to direct the apparatus, when executed, to shape the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

[0020] The aspects and embodiments of the present disclosure as described above may be utilized separately or in combination and different combining forms may be established for addressing at least one of the problems as mentioned in the above and achieving some of the notable technical effects as set forth below.

[0021] By virtue of the method, apparatuses and the non-transitory computer readable medium according to multiple aspects of the present disclosure, flexible and adaptive envelope shaping may be realized and thereby a better tradeoff between ET PA efficiency and linearity could be achieved based upon the tracking of the sweet spot trajectories. Further, since the selection of the envelope shaping function could be done within a specified limited range of a corresponding sweet spot trajectory, the shaping of the original envelope signal may be done in a smooth manner, thereby reducing the sharpness of the shaped envelope signal and achieving higher linearity without sacrificing too much efficiency. Further, the Amplitude Modulation-Amplitude Modulation ("AM"-AM) or Amplitude Modulation to Phase Modulation ("AM-PM") distortions could be controlled and thus gains in this respect could be obtained due to proper selection of the piecewise shaping functions.

[0022] Also, the envelope shaping on the basis of the sweet spot trajectory tracking may result in negligible degradation of efficiency having regards to the gain increase in the low voltage region and may obtain higher efficiency of the ET supply

modulator attributable to the reduced Peak to Average Power Ratio ("PAPR") of the shaped envelope. In addition, dependent on different shaped waveforms of the envelope signal, it may be very flexible to compromise the ET supply modulator and RF PA design for efficiency, linearity and bandwidth. Furthermore, since the change of the PA's power supply is effectively controlled due to the controlled change of the envelope signal, the operating point of the ET PA may become more stable. In addition, since the solutions of the present disclosure may be easily implemented, the ET modulator design could be greatly simplified and cost could be significantly lowered.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The embodiments of the present disclosure that are presented in the sense of examples and their advantages are explained in greater detail below with reference to the accompanying drawings, in which:

[0024] Fig. 1 is a block diagram illustrating an exemplary envelope tracking radio frequency power amplifier system in which example embodiments of the present disclosure may be implemented;

[0025] Fig. 2 is a block diagram exemplarily illustrating a method for envelope shaping in envelope tracking power amplification according to an embodiment of the present disclosure;

[0026] Figs. 3a and 3b are plots exemplarily illustrating a plurality of sweet spot trajectories and a plurality of piecewise shaping functions corresponding thereto in a curve-fitting form, respectively, according to an embodiment of the present disclosure;

[0027] Fig. 4 is a plot exemplarily illustrating a waveform of the shaped envelope signal in a time domain according to example embodiments of the present disclosure versus a waveform of the shaped envelope signal in the existing envelope elimination and restoration ("EE&R") technique;

[0028] Fig. 5 is a plot exemplarily illustrating gain trajectory and efficiency trajectory versus output power curves for the example embodiments of the present disclosure as compared to the existing EE&R technique;

[0029] Fig. 6 is a simplified schematic block diagram illustrating a representative apparatus according to an embodiment of the present disclosure; and

[0030] Fig. 7 is a simplified schematic block diagram illustrating another representative apparatus according to an embodiment of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0031] The present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which certain embodiments of the present disclosure are shown. This disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the present disclosure to those skilled in the art. Like numbers refer to like elements throughout the specification.

[0032] Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to “a/an/the element, apparatus, component, means, or step” are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, or step unless explicitly stated otherwise. The steps of any method disclosed herein do not have to be performed in the exact order disclosed, unless explicitly stated. The discussion above and below in respect of any of the aspects of the present disclosure is also in applicable parts relevant to any other aspect of the present disclosure.

[0033] The following will discuss the details of the example embodiments of the present disclosure with reference to the accompanying drawings.

[0034] Fig. 1 is a block diagram illustrating an exemplary envelope tracking radio frequency power amplifier system 100 in which example embodiments of the present disclosure may be implemented. As illustrated in Fig. 1, the envelope tracking radio frequency power amplifier system 100 generally includes a digital front end, an analog front end, and digital-to-analog (“DAC”) branches connecting the digital front end and the analog front end.

[0035] The digital front end as shown includes a digital up converter (“DUC”) 101, a crest factor reduction block 102, an envelope extraction block 103, a timing alignment block 104, an adaptation block 105, a mapping table block 106, and an envelope shaping function block 107. The analog front end as shown includes a frequency modulation (“FMOD”) block 110, an ET supply modulator 111, an RF PA 112, a band pass filter (“BPF”) 113 and an antenna 114. It should be noted that the blocks

shown here is only illustrative and the system 100 should not be limited to this specific form. There may be more or less blocks, if necessary, or some blocks may be combined into a single block for implementing the example embodiments of the present disclosure.

5 [0036] The DUC 101 receives modulated base band input signal and increases a sampling rate by up sampling/interpolation applied in the context of digital signal processing and sample rate conversion. When up-sampling is performed on a sequence of samples of a continuous function or signal, it produces an approximation of the sequence of the base band input signals that have been obtained by sampling the
10 signal at a higher rate. Then, the up-converted signal is fed to the crest factor reduction block 102, which is used to reduce the PAPR of digitally modulated signals with a high crest factor by clipping the peak which is above some threshold. The reduction in crest factor reduction block 102 results in a system being capable of either transmitting more bits per second with the same hardware or transmitting the same bits
15 per second with lower-power hardware, thereby achieving lower electricity costs and less expensive hardware.

 [0037] Having been subject to the crest factor reduction, the signal is respectively provided to the envelope extraction block 103 and the timing alignment block 104. At the envelope extraction block 103, the amplitude of the input baseband
20 modulated signal is extracted and processed to generate the envelope signal at its output, as is known to those skilled in the art. Then, the resulting envelope signal, which is also referred to as the original envelope signal in the present application document, is fed to the adaptation block 105, at which the amplitude of the original envelope signal would be scaled such that it may satisfy the input level requirements for
25 sequential processing blocks.

 [0038] Then, the amplitude information of the scaled envelope signal is input to the mapping table block 106, in which a sweet spot mapping relationship has been established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories. Alternatively or
30 additionally, a plurality of sweet spot mapping relationships may be formed and each of the plurality of sweet spot mapping relationships may be established through measurements at one of a plurality of temperatures. In other words, one group of the plurality of sweet spot trajectories for one temperature may be observed and collected. In this manner, there would be a respective mapping table associated with a

corresponding one of the temperatures. The temperature herein may be used as address for entry or retrieve of the mapping table and determination of the shaped voltage.

[0039] Further, by curve-fitting of discrete temperature data sets, the sweet spot behavior or trajectories over the whole temperatures may be predicted and estimated. For example, based on high order polynomial fitting, a function/modeling of sweet spot trajectories may be obtained. Thereby, the sweet spot trajectories with respect to some untested temperatures are likely to be obtained based on the high order polynomial fitting.

[0040] The following will briefly discuss several details of the mapping table block 106 and more details would be given with reference to Figs. 3a and 3b later.

[0041] The mapping table block 106 may be formed based upon a characterization process for the output power of the RF PA 112, which may be established according to the input power level of the RF PA 112 such as the average power of the input signal, the power supply of the RF PA 112 provided by the ET supply modulator 111, and possible hardware properties, such as the types of dies applied, at a certain temperature, which is not discussed together herein for easy and illustrative description. With this characterization process, a number of curves with respect to intermodulation distortions ("IMDs") versus output power of the ET PA for different supply voltages from the ET supply modulator 111 could be depicted such as those illustrated in Fig. 3a, where a number of sweet spots are identified as the minima of the IMD curves and limited trajectories starting from the right sides of the respective sweet spots constitute the respective sweet spot trajectories according to the example embodiments of the present disclosure.

[0042] Upon obtaining a plurality of sweet spot trajectories, a plurality of shaping functions could be determined, each of which may match in a curve-fitting manner with a corresponding one of the plurality of sweet spot trajectories and shape the original envelope signal such that the shaped envelope signal as input to the ET supply modulator may lead to the output of the RF PA 112 follows the sweet spot trajectories. A sweet spot mapping relationship may be established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories by a look-up table in the mapping table block 106. Additionally or alternatively, the mapping relationships between the amplitude of the original envelope and the amplitude of the shaped envelope signal via the shaping

function could also be stored in a look-up table for retrieving for determination of the shaping function due to associations between the shaped envelope signal as input to the ET supply modulator and the output voltages of the ET supply modulator, for example, SSO1-SSO4 as shown in Fig. 3b. In this manner, the shaping function, such as one of those piecewise shaping function shown in Fig. 3b, could be selected based upon the instantaneous input parameters, e.g., the amplitude of the original envelope signal, and the resulting shaped envelope signal could lead to the expected output of the ET supply modulator and further engender that the output of the RF PA 112 follows the sweet spot trajectory, thereby reducing the IMD distortions as expected.

[0043] It should be noted the above look-up table is only one example for establishing the mapping relationship between the each of the piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories. This mapping relationship could also be done through the polynomials with changeable multipliers. By this approach, the piecewise shaping functions could be replaced with the polynomials and different piecewise shaping function may have different multipliers. That is, instead of the curve-fitting, the polynomial fitting is applied herein to match different piecewise shaping functions. In addition, once the polynome is determined, may only the multipliers be stored for identifying different piecewise shaping function. In this way, it may be easy to select proper shaping functions and further improve the shaping efficiency. As discussed before, since polynomial fitting may be done at different temperatures, different polynomials could be obtained corresponding to different temperatures.

[0044] The characterization processing of the RF PA 112 here may be carried out in a number of ways and the example embodiments of the present disclosure may not be limited to a specific characterization technique. For example, the characterization processing may be carried out using automated test equipments such that the sweet spot trajectories and corresponding curve-fitting shaping functions could be determined automatically and then the resulting shaping functions may be used for shaping the original envelope signal. Based upon the shaped envelope signal, the ET supply modulator could operate in an optimized manner and thereby the RF PA may reduce the IMDs and achieve significant performance advantages, such as a better tradeoff between the linearity and efficiency.

[0045] For example, as exemplarily depicted in Figs. 3a and 3b and discussed in detail later, the sweet spot trajectories SST1, SST2, SST3, SST4, and SST5

respectively correspond to the piecewise shaping functions SF1, SF2, SF3, SF4, and SF5, and their associations or correspondences may be stored in a mapping table, e.g., in the mapping table block 106. Also as shown in Fig. 3b, each piecewise shaping function has a shaping range which is associated with a particular range of the amplitude of the input envelope signal and a particular range of the amplitude of the shaped envelope signal. Therefore, once the piecewise shaping function is determined based upon the amplitude of the original envelope signal, the shaped amplitude of the envelope signal is also determined due to the association. Thus, a control signal as to which piecewise shaping function is to be selected may be generated by the mapping table block 106 and sent to the envelope shaping function block 107.

[0046] The envelope shaping function block 107 selects one of the piecewise shaping functions based upon the control signal and applies the selected piecewise shaping function to the envelope signal from the timing alignment block 104, which delays the envelope signal from the envelope extraction block 103 such that synchronization could be maintained between the shaping operations and input envelope signal. Thereafter, a shaped envelope signal is generated as input to the DAC 108 where the shaped envelope signal in the digital format is converted into an analog format. After that, in the analog front end, the analog shaped envelope signal is input to the ET supply modulator 111 together with the DC power supply V_{DC} , and the ET supply modulator 111 modulates the supply voltage substantially in line with the analog shaped envelope signal. Then, the modulated supply voltage is output from the ET supply modulator 111 to the RF PA (or ET PA) 112 as a power supply.

[0047] In another processing branch, the signal having been subject to the crest factor reduction may also be transmitted to the DAC 109 via the timing alignment block 104 due to the synchronization purpose. Upon conversion from the digital domain to the analog domain by the DAC 109 and thereafter entry into the analog front end, the analog baseband signal is modulated in the frequency domain by the FMOD 110 such that the analog baseband signal may be converted into an RF signal. Then, the RF signal is input into the RF PA 112 at which the RF PA 112 amplifies the RF signal using the output from the ET supply modulator 111 as the power supply to generate an amplified RF signal, which is then filtered by the BPF 113 and transferred to the antenna 114 for transmission via an air interface to a base station or a mobile terminal in a wireless network (not shown).

[0048] According to the example embodiments of the present disclosure, due to the introduction of the mapping table containing the mapping between the sweet spot trajectories and the plurality of piecewise shaping functions, the characteristic of output of the RF PA 112 would follow one of the sweet spot trajectories and therefore the IMDs could be effectively controlled.

[0049] By means of the exemplary envelope tracking radio frequency power amplifier system 100, the overall performance of the RF PA 112 determined by the envelope shaping function applied could be improved. For example, the envelope shaping function selected according to the amplitude of the original envelope signal in conjunction with the sweet spot trajectories or corresponding piecewise shaping function may stabilize the operating point of the RF PA and compromise systematically the overall efficiency and linearity. Further, since the shaping function may be adaptively and dynamically selected, it is possible to optimize the efficiency and linearity of the RF PA 112 under complex application scenarios, for example, multi-mode multi-band ET applications, with various types of RF PA designs etc.

[0050] Fig. 2 is a block diagram exemplarily illustrating a method 200 for envelope shaping in envelope tracking power amplification according to an embodiment of the present disclosure. As illustrated in Fig. 2, at block 201, the method 200 determines, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The sweet spot trajectories here are of the identical meaning as discussed above and shown in Fig. 3a, as will be discussed later. Then, at block 202, the method 200 shapes the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

[0051] In an example embodiment, the method 200 may obtain the plurality of sweet spot trajectories by observing the IMDs under a plurality of radio frequency power amplifier supply voltages provided by the envelope tracking supply modulator and a plurality of radio frequency power amplifier input power levels. In other words, by testing the characteristic of the power amplifier in terms of IMDs in advance or in an off-line manner, the plurality of sweet spot trajectories could be identified at which the minima of the IMD curve are located and the harmonics would be cancelled.

[0052] In another example embodiment, the shaping function here may

comprise a plurality of piecewise envelope shaping functions, each of which corresponds to one of the plurality of sweet spot trajectories in a curve fitting form. As exemplified above, each piecewise envelope shaping function could be an offset shaping function, such as SF1, SF2, SF3, SF4, or SF5 shown in Fig. 3b, and may
5 associate with a corresponding sweet spot trajectory, such as SST1, SST2, SST3, SST4 or SST5 in the curve fitting form.

[0053] In an example embodiment, each of the plurality of piecewise envelope shaping functions is a linear shaping function or a non-linear shaping function, both of which precisely reflect a sweep spot trajectory in a curve fitting form. Again, take Fig.
10 3b as example, the illustrated shaping function comprises a plurality of piecewise shaping function, that is, the SF1, SF2, SF3, SF4, and SF5, each of which, as shown, is an offset shaping function with respective limits as indicated by a respective line segment. It is to be understood by those skilled in the art that the offset shaping functions herein are linear functions and non-linear shaping functions, which may be
15 presented as segmented curve if depicted, may also be used for curve fitting for the sweet spot trajectories and thus be capable of providing more precise shaping functions than the linear shaping functions. For example, the shaping function may include but is not limited to UCSD soft de-trough, soft clipping, hard-clipping, Nujira Wilson envelope shaping function or Nujira N6 envelope shaping functions and etc.

[0054] In an example embodiment, the shaping the original envelope signal at
20 block 202 may comprise shaping the original envelope signal whose amplitude is within a range corresponding to one of the plurality of sweet spot trajectories by a corresponding one of the plurality of piecewise envelope shaping functions. Due to the correspondence of the sweet spot trajectory with the piecewise envelope shaping
25 function, the range of the amplitude of the envelope signal is associated with the range of the sweet spot trajectory. For example, as shown in Fig. 3b, the range of the amplitude of the original or input envelope signal from 0 to SS11 may correspond to the sweet spot trajectory SST1, and the range from SS11 to SS12 may correspond to the sweet spot trajectory SST2 and etc. Then, the corresponding piecewise shaping
30 function may be selected to shaping the envelope signal such as those output from the timing alignment block 104 shown in Fig.1.

[0055] For example, the SF1 is selected for the input envelope signal whose amplitude is within the range from 0 to SS11 (V) and the SF2 is selected for the input envelope signal whose amplitude is within the range from SS11 to SS12 and etc. It is to

be understood that the shaping herein may be implemented by the mapping table block 106 together with the envelope shaping function block 107 as shown in Fig. 1. Therefore, the determining of the shaping function at block 201 may be implemented by a predetermined sweet spot mapping relationship established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories, e.g., a look-up table, such as one in the mapping table block 106 in Fig. 1, where a sweet spot mapping relationship has been established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories. In one example, embodiment, the predetermined sweet spot mapping relationship may be established by predetermined polynomials with changeable multipliers. In another example embodiment, a plurality of predetermined sweet spot mapping relationships are formed, each of which is formed under one of a plurality of temperatures.

[0056] In an example embodiment, the limited range of each of the plurality of sweet spot trajectories is determined as a specific intermodulation distortion level degradation from a corresponding sweet spot. For example, the specific intermodulation distortion level degradation from a corresponding sweet spot is typically 3dB.

[0057] In another example embodiment, the number of the plurality of sweet spot trajectories corresponding to the piecewise shaping functions is adjustable to meet requirements of different application scenarios. For example, in one embodiment, the number of the plurality of sweet spot trajectories is within a range from 6 to 12 for a typical 20MHz long term evolution ("LTE") RF signal.

[0058] With the method 200 and its multiple extensions and variations as discussed in the example embodiments above, due to adaptive and dynamic shaping operations, the PAPR of the envelope signal prior to entering into the ET supply modulator may be reduced and more gains may be obtained at the output of the ET supply modulator since it is more likely to operate at the compression region for more efficient amplification with less back-off. Further, the shaping operations or functions as discussed above intend to maintain either constant gain for linearity or constant gain compression for maximum efficiency according to application scenarios.

[0059] Additionally, according to the example embodiments of the present disclosure, the utilization of a plurality of sweet spot trajectories instead of several sweet spots may provide an applicable range/scope for the shaping function to better trade off

efficiency and linearity. Meanwhile, the precision requirements for the alignment and mapping could be relaxed and thereby processing resource and cost in terms of hardware or software may be reduced. In addition, the example embodiments of the present disclosure are easy to be implemented since flexible and arbitrary individual
5 shaping functions could be selected to build sweet spot trajectory mapping as long as the linear and non-linear curve fitting may be able to characterize sweet spot behavior with compromise to the hardware computing resources.

[0060] Figs. 3a and 3b are plots exemplarily illustrating a plurality of sweet spot trajectories and a plurality of piecewise shaping functions corresponding thereto in
10 a curve-fitting form, respectively, according to an embodiment of the present disclosure. As illustrated, the horizontal axis of the Fig. 3a denotes the output of the RF PA in dBm, such as the output of the RF PA 112 shown in Fig. 1, and the vertical axis of the Fig. 3a denotes the IMD in dBc. For the purpose of easy discussion, five curves, which are generated under different supply voltages provided by the ET supply modulator, are
15 depicted based upon the observations at the output port of the RF PA. It can be seen from the curves that the output power of the RF PA progressively decreases as the supply voltages provided become smaller and smaller, as shown by a dashed arrow pointing from the right towards the left.

[0061] Also depicted in Fig. 3a are five sweet spots 1, 2, 3, 4, and 5, each of
20 which is indicative of local minimums of the IMDs. The sweet spot trajectory of the present disclosure suggests selecting a limited range around the corresponding sweet spot as a sweet spot trajectory. For example, 3dB degradation from local minimums of the IMDs may be defined as the sweet spot tracking trajectory. In this example, -50 dBc is an upper limit for each sweet spot trajectory as shown. Therefore, the ranges as
25 indicated by 1 to 1', 2 to 2', 3 to 3', 4 to 4' and 5 to 5' may constitute five sweet spot trajectories, which would be used for selection of various of shaping functions as shown in Fig. 3b.

[0062] It should be noted that the 3dB limit is only for illustrative purposes and a person skilled in the art, upon reading the specification of the present disclosure,
30 would understand that other limits may also be applied according to application scenario requirements in terms of, for example, the linearity or efficiency of the RF PA, the effective ranges of the shaping functions, such as the piecewise shaping functions, and the amplitude range of the envelope signals.

[0063] Based upon the output characteristics of the RF PA and supply

voltages of the ET supply modulator as shown in the IMD curves, the voltages of the shaped envelope signal as the input of the ET supply modulator, and the voltages of the original envelope signal, a plurality of piecewise shaping functions may be established to correspond to a plurality of sweet spot trajectories in a curve-fitting manner, as shown in Fig. 3b.

[0064] Fig. 3b illustrates an exemplary envelope shaping function which insists of a plurality of piecewise shaping functions and maps input envelope signals to the power amplifier's supply voltage with specific sweet spot input (SSI) transition points SSI1-SSI4 and maps the sweet spot output voltages of the ET supply modulator as SSO1-SSO4, respectively. Also shown in Fig. 3b is an offset level SSO0, which represents the minimum voltage which would be equal to or greater than a knee voltage of RF PA device, thereby providing minimum allowable distortions and PA operating point stabilizing effect.

[0065] It can be seen from Fig. 3b that each trajectory of the piecewise shaping function, such as SF1, SF2, SF3, SF4, or SF5, between sweet spot transition points (i.e., SSI1-SSI4) is an offset shaping function to maintain the superior linear performance of the envelope tracking. In dependence on different application scenarios, the number of the sweet spot trajectories and thus the number of the corresponding piecewise shaping functions could be predetermined and adjusted. For example, 6 to 12 sweet spot trajectories could be used a 20MHz long term evolution radio frequency signal and therefore 6 to 12 corresponding piecewise shaping functions could be established in a curve-fitting manner. Based upon the presence of the piecewise shaping functions, the operating space is divided into an allowed zone within which the shaping is allowed to perform and a forbidden zone within which the shaping cannot take place.

[0066] For a better understanding of the piecewise shaping function as illustrated herein, the following will discuss the specific implementation thereof by way of example.

[0067] With the example embodiments of the present disclosure, the shaped envelope of the drain/collector voltage of the RF PA may be expressed as follows:

$$V_{env_shaped}(t) = \begin{cases} ((V_{SSO1} - V_{SSO0})/V_{SSI1}) \cdot V_{env}(t) + V_{offset1} = k_1 \cdot V_{env}(t) + V_{offset1}, & 0 < V_{env}(t) < V_{SSI1}, V_{offset1} \geq V_{knee} \\ ((V_{SSO2} - V_{SSO1})/(V_{SSI2} - V_{SSI1})) \cdot V_{env}(t) + V_{offset2} = k_2 \cdot V_{env}(t) + V_{offset2}, & V_{SSI1} < V_{env}(t) < V_{SSI2}, V_{offset2} \geq V_{knee} \\ \dots \end{cases} \quad (1)$$

[0068] where k_n is the slope of each offset shaping section. By using the offset shaping function, the output power P_{out} of the RF PA is exactly proportional to the input power P_{in} , which may be expressed as follows:

$$P_{out} = (V_{env_shaped}(t) - V_{knee})^2 / (2 \cdot R_L) = (k \cdot V_{env}(t))^2 / (2 \cdot R_L) \propto P_{in} \quad (2)$$

5 [0069] where R_L is a load impedance of the RF PA, similar to that of the class-B PA. In this shaped operation, linearity is maintained and the drain efficiency is kept high. The knee voltage of the RF PA V_{knee} may be obtained from its DC I-V curves and the offset voltage for offset shaping should be equal to or greater than this value, as mentioned before. In some example embodiments, the highest knee voltage across
10 operating range may be used as the offset voltage to cover all scenarios to guarantee removing the supply voltage swing into the knee region.

[0070] As discussed before, the mapping between the sweet spot trajectories and the piecewise shaping function could be stored in the mapping table block 106 as illustrated in Fig. 1 in a table form. Thereafter, when a piecewise shaping function is
15 determined, the timing aligned envelope signal would be subject to the shaping and gains would be obtained according to the example embodiments of the present disclosure.

[0071] For example, the resulting power amplifier AM-AM gain characteristic may be improved by avoiding too much compression at low power regions. Further,
20 envelope PAPR reduction may also be achieved by selection of appropriate shaped SSO values, such as SSO1-SS04 as exemplarily shown and the efficiency of the ET supply modulator may be increased. Since the gain of the RF PA decreases according to the supply voltage drops, adaptive sweet spot tracking shaping provides higher supply voltage to the RF PA at the low power range.

25 [0072] Additionally, each offset shaping section in the present disclosure defines an optimum offset voltage to the original envelope signal for linearity and does not change the envelope bandwidth because it is a linear scaling operation to reduce the PAPR of the envelope signal. Each piecewise shaping function in Fig. 3b not only guarantees high efficiency over a broad range of output power but achieves the same
30 wide dynamic range as the conventional fixed supply linear RF PA. Therefore, piecewise shaping section (e.g., the offset shaping) maintains high linearity and efficiency over the wide power range because it allows linear operations of the highly

efficient RF PA by preventing the operation in the dangerous knee voltage region.

[0073] Take the RF PA implementation as example, according to the example embodiments of the present disclosure, the dynamic drain supply voltages are mapped to each sweet spot trajectory at the drain supply to form an envelope shaping function to
5 guarantee that the maximum linearity can be obtained for the RF PA. The envelope shaping trajectory may be tested/calibrated in advanced and stored in a memory for each the RF PA for ET, such as the mapping table block 106 in Fig. 1. With the pre-stored coefficient of sweet spot trajectories, the original envelope is shaped into the shaped envelope signal for linearity by the corresponding shaping function.

10 [0074] Fig. 4 is a plot exemplarily illustrating a waveform of the shaped envelope signal in a time domain according to example embodiments of the present disclosure versus the waveforms of the shaped envelope signal in the prior art techniques. As shown in Fig. 4, with the example embodiments of the present disclosure, each local peaks of the shaped envelope signal are guaranteed to “closely”
15 track the original envelope signal to maintain high efficiency. Further, the fast envelope transition region is also closely tracked to have further power saving for efficiency improvement. Compared to the existing EE&R technique as illustrated, the lower power regions below knee voltage V_{knee} are avoided with the embodiments of the present disclosure to further improve overall linearity of the RF PA.

20 [0075] Fig. 5 is a plot exemplarily illustrating efficiency versus output power curves for the example embodiments of the present disclosure as compared to the Envelope Elimination and Restoration (“EE&R”) technique. It would be understood by those skilled in the art that the mapping between the instantaneous RF envelope and the applied supply voltage profoundly influences characteristics such as sweet spot
25 trajectories and piecewise shaping functions, together with the linearity and efficiency.

[0076] In Fig. 5, the power gain trajectory and power efficiency trajectory as achieved by the existing EE&R and the present disclosure under the envelope tracking operation are illustrated, respectively.

30 [0077] From the power gain trajectory observations, it can be seen that the EE&R maintains constant gain compression during the ET to achieve high efficiency. However, it would increase the distortions due to operation in the deep compression region at all supply voltage levels. In contrast, in the present disclosure, to achieve sweet spot tracking, the mapping between the RF input envelope signals and the supply voltage is chosen to achieve a quasi-constant power gain (ripples are allowed to map

sweet spot trajectories) rather than the constant gain compression in the EE&R. With this feature, the ET PA system according to the example embodiments of the present disclosure achieves a low amplitude-modulation-to-amplitude-modulation (AM-AM) distortion despite operating in compression over much of the envelope cycle.

5 [0078] On the other hand, Fig. 5 also shows the equivalent trajectory for fixed-DC-supply operation. From the individual trajectory observation, it can be seen that the present disclosure provides much flatter frequency responses than that of the fixed DC supplied RF PA. Therefore, the present disclosure may easily linearize the RF PA by digital predistortion schemes, thereby reducing adjacent-channel power ratio
10 (ACPR) and error-vector magnitude (EVM).

 [0079] Fig. 6 is a simplified schematic block diagram illustrating a representative apparatus 600 according to an embodiment of the present disclosure. As illustrated in Fig. 6, the apparatus 600 includes at least one processor 601, such as a data processor, at least one memory (MEM) 602 coupled to the processor 601, and a
15 suitable RF transmitter TX and receiver RX 603 coupled to the processor 601. The MEM 602 stores a program (PROG) 604. The TX/RX 603 is for bidirectional wireless communications.

 [0080] The PROG 604 is assumed to include instructions that, when executed by the processor 601, enable the apparatus 600 to operate in accordance with the
20 exemplary embodiments of the present disclosure, such as discussed herein with the method 200. For example, the apparatus 600 may be embodied as a terminal device, base station, or a part thereof, or included therein as an amplification arrangement, or an amplification stage, when the example embodiments of the present disclosure are carried out in the terminal device, such as a mobile station, or a base station, such as an
25 evolved node B in the long term evolution system.

 [0081] In general, the embodiments of the present disclosure may be implemented by computer software executable by at least one processor 601 of the apparatus 600, or by hardware, or by a combination of software and hardware.

 [0082] The MEM 602 may be of any type suitable to the local technical
30 environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory, as non-limiting examples. While only one MEM is shown in the apparatus 600, there may be several physically distinct memory units in the apparatus 600. The processor 601

may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based upon multicore processor architecture, as non limiting examples. The apparatus 600 may have multiple
5 processors, such as for example an application specific integrated circuit chip that is slaved in time to a clock which synchronizes the main processor.

[0083] In one aspect of the present disclosure, the apparatus 600 may comprise at least one processor and at least one memory including compute program instructions, wherein the at least one memory and computer program instructions are
10 configured to, with the at least one processor, cause the apparatus 600 at least to determine, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The at least one memory and computer program instructions are configured to, with the at least
15 one processor, also cause the apparatus 600 at least to shape the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

[0084] In an example embodiment, the at least one memory and computer
20 program instructions are configured to, with the at least one processor, cause the apparatus 600 further to obtain the plurality of sweet spot trajectories by observing intermodulation distortions under a plurality of radio frequency power amplifier supply voltages provided by the envelope tracking supply modulator and a plurality of radio frequency power amplifier input power levels.

[0085] In another example embodiment, the shaping function comprises a
25 plurality of piecewise envelope shaping functions, each of which corresponds to one of the plurality of sweet spot trajectories in a curve-fitting form.

[0086] In yet another example embodiment, each of the plurality of piecewise
envelope shaping functions is a linear shaping function or a non-linear shaping function.

[0087] In an example embodiment, the at least one memory and computer
30 program instructions are configured to, with the at least one processor, cause the apparatus 600 further to shape the original envelope signal whose amplitude is within a range corresponding to one of the plurality of sweet spot trajectories by a corresponding one of the plurality of piecewise envelope shaping functions.

[0088] In another example embodiment, the shaping is implemented by a look-up table in which a sweet spot mapping relationship has been established between the amplitude of the original envelope signal and the amplitude of the shaped envelope signal via the shaping function. In a still further example embodiment, a plurality of predetermined look-up tables are formed, each of which is formed under one of a plurality of temperatures

[0089] In yet another example embodiment, the limited range of each of the plurality of sweet spot trajectories is determined as a specific intermodulation distortion level degradation from a corresponding sweet spot.

[0090] In a further example embodiment, the number of the plurality of sweet spot trajectories of composition of the piecewise shaping function is adjustable to meet requirements of different application scenarios.

[0091] In an additional example embodiment, the number of the plurality of sweet spot trajectories is within a range from 6 to 12 for a typical 20MHz long term evolution radio frequency signal.

[0092] Fig. 7 is a block diagram exemplarily illustrating RF signal amplification processing including an apparatus 700 according to various embodiments of the present disclosure. As illustrated in Fig. 7, the apparatus 700 comprises means 701 for determining, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier. The apparatus 700 also comprises means 702 for shaping the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

[0093] In an example embodiment, the apparatus 700 further comprises means for obtaining the plurality of sweet spot trajectories by observing intermodulation distortions under a plurality of radio frequency power amplifier supply voltages provided by the envelope tracking supply modulator and a plurality of radio frequency power amplifier input power levels.

[0094] In another example embodiment, the shaping function comprises a plurality of piecewise envelope shaping functions, each of which corresponds to one of the plurality of sweet spot trajectories in a curve fitting form. In yet another example embodiment, each of the plurality of piecewise envelope shaping functions is a linear shaping function or a non-linear shaping function.

[0095] In an additional example embodiment, the means 702 for shaping comprises means for shaping the original envelope signal whose amplitude is within a range corresponding to one of the plurality of sweet spot trajectories by a corresponding one of the plurality of piecewise envelope shaping functions.

5 [0096] In a further example embodiment, the means 701 for determining is implemented by a look-up table in which a sweet spot mapping relationship has been established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories. In a still further example embodiment, a plurality of predetermined look-up tables are formed, each of which is
10 formed under one of a plurality of temperatures.

[0097] In an example embodiment, the limited range of each of the plurality of sweet spot trajectories is determined as a specific intermodulation distortion level degradation from a corresponding sweet spot.

[0098] In another example embodiment, the number of the plurality of sweet
15 spot trajectories corresponding to the plurality of the piecewise shaping functions is adjustable to meet requirements of different application scenarios. In yet another example embodiment, the number of the plurality of sweet spot trajectories is within a range from 6 to 12 for a typical 20MHz long term evolution radio frequency signal.

[0099] It is to be understood that the apparatus 700 is able to carry out the
20 methods as discussed with respect to the accompanying drawings according to the embodiments of the present disclosure and may be embodied as another form of a terminal device, a base station, or a part thereof, or included therein as an amplification arrangement, or an RF PA, when the example embodiments of the present disclosure are implemented in the terminal device, such as a mobile station, or in the base station,
25 such as an evolved node B in the long term evolution system.

[00100] The techniques described herein may be implemented by various means so that an apparatus implementing one or more functions of a corresponding mobile entity described with an embodiment comprises not only prior art means, but also means for implementing the one or more functions of a corresponding apparatus
30 described with an embodiment and it may comprise separate means for each separate function, or means may be configured to perform two or more functions. For example, these techniques may be implemented in hardware (one or more apparatuses), firmware (one or more apparatuses), software (one or more modules), or combinations thereof. For a firmware or software, implementation can be through modules (for

example, procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in any suitable, processor/computer-readable data storage medium(s) or memory unit(s) or article(s) of manufacture and executed by one or more processors/computers. The data storage medium or the memory unit may be
5 implemented within the processor/computer or external to the processor/computer, in which case it can be communicatively coupled to the processor/computer via various means as is known in the art.

[00101] Many modifications and other embodiments of the disclosures set forth herein will come to mind to one skilled in the art to which these embodiments of the
10 disclosure pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the embodiments of the disclosure are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein,
15 they are used in a generic and descriptive sense only and not for purposes of limitation.

WHAT IS CLAIMED IS:

1. A method, comprising:

determining, based upon a plurality of sweet spot trajectories, a shaping function for
5 shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier; and

shaping the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

10 2. The method according to claim 1, further comprising:

obtaining the plurality of sweet spot trajectories by observing intermodulation distortions under a plurality of radio frequency power amplifier supply voltages provided by the envelope tracking supply modulator and a plurality of radio frequency power amplifier input power levels.

15 3. The method according to claim 1, wherein the shaping function comprises a plurality of piecewise envelope shaping functions, each of which corresponds to one of the plurality of sweet spot trajectories in a curve fitting form.

4. The method according to claim 3, wherein each of the plurality of piecewise envelope shaping functions is a linear shaping function or a non-linear shaping function.

20 5. The method according to claim 3 or 4, wherein the shaping the original envelope signal comprises:

shaping the original envelope signal whose amplitude is within a range corresponding to one of the plurality of sweet spot trajectories by a corresponding one of the plurality of piecewise envelope shaping functions.

25 6. The method according to claim 3 or 4, wherein the determining of the shaping function is implemented by a predetermined sweet spot mapping relationship established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories.

30 7. The method according to claim 6, wherein the predetermined sweet spot mapping relationship is established by a predetermined look-up table or polynomials with changeable multipliers.

8. The method according to claim 6, wherein a plurality of predetermined sweet spot mapping relationships are formed, each of which is formed under one of a plurality of temperatures.

9. The method according to any of preceding claims, wherein the limited range of each of the plurality of sweet spot trajectories is determined as a specific intermodulation distortion level degradation from a corresponding sweet spot.

10. The method according to claim 3 or 4, wherein the number of the plurality of sweet spot trajectories corresponding to the plurality of the piecewise shaping functions is adjustable to meet requirements of different application scenarios.

11. An apparatus, comprising:

at least one processor; and

at least one memory including compute program instructions,

wherein the at least one memory and computer program instructions are configured to, with the at least one processor, cause the apparatus at least to:

determine, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier; and

shape the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

12. The apparatus according to claim 11, wherein the at least one memory and computer program instructions are configured to, with the at least one processor, cause the apparatus further to:

obtain the plurality of sweet spot trajectories by observing intermodulation distortions under a plurality of radio frequency power amplifier supply voltages provided by the envelope tracking supply modulator and a plurality of radio frequency power amplifier input power levels.

13. The apparatus according to claim 11, wherein the shaping function comprises a plurality of piecewise envelope shaping functions, each of which corresponds to one of the plurality of sweet spot trajectories in a curve fitting form.

14. The apparatus according to claim 13, wherein each of the plurality of piecewise envelope shaping functions is a linear shaping function or a non-linear shaping function.

15. The apparatus according to claim 13 or 14, wherein the shaping the original envelope signal comprises:

shaping the original envelope signal whose amplitude is within a range corresponding to one of the plurality of sweet spot trajectories by a corresponding one of the plurality of piecewise envelope shaping functions.

16. The apparatus according to claim 13 or 14, wherein the shaping is implemented by a predetermined sweet spot mapping relationship established between each of the plurality of piecewise envelope shaping functions and a corresponding one of the plurality of sweet spot trajectories.

5 17. The apparatus according to claim 16, wherein the predetermined sweet spot mapping relationship is established by a predetermined look-up table or polynomials with changeable multipliers.

18. The apparatus according to claim 16, wherein a plurality of predetermined sweet spot mapping relationships are formed, each of which is formed under one of a
10 plurality of temperatures.

19. The apparatus according to any of preceding claims, wherein the limited range of each of the plurality of sweet spot trajectories is determined as a specific intermodulation distortion level degradation from a corresponding sweet spot.

20. The apparatus according to claim 13 or 14, wherein the number of the plurality
15 of sweet spot trajectories of composition of the piecewise shaping function is adjustable to meet requirements of different application scenarios.

21. An apparatus, comprising:

means for determining, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within
20 a limited range around a respective sweet spot of a radio frequency power amplifier; and

means for shaping the original envelope signal by the shaping function into a shaped envelope signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

22. A non-transitory computer readable medium having program code stored
25 thereon, the program code configured to direct an apparatus, when executed, to:

determine, based upon a plurality of sweet spot trajectories, a shaping function for shaping an original envelope signal, each sweet spot trajectory being within a limited range around a respective sweet spot of a radio frequency power amplifier; and

shape the original envelope signal by the shaping function into a shaped envelope
30 signal as input to an envelope tracking supply modulator configured to be coupled to the radio frequency power amplifier.

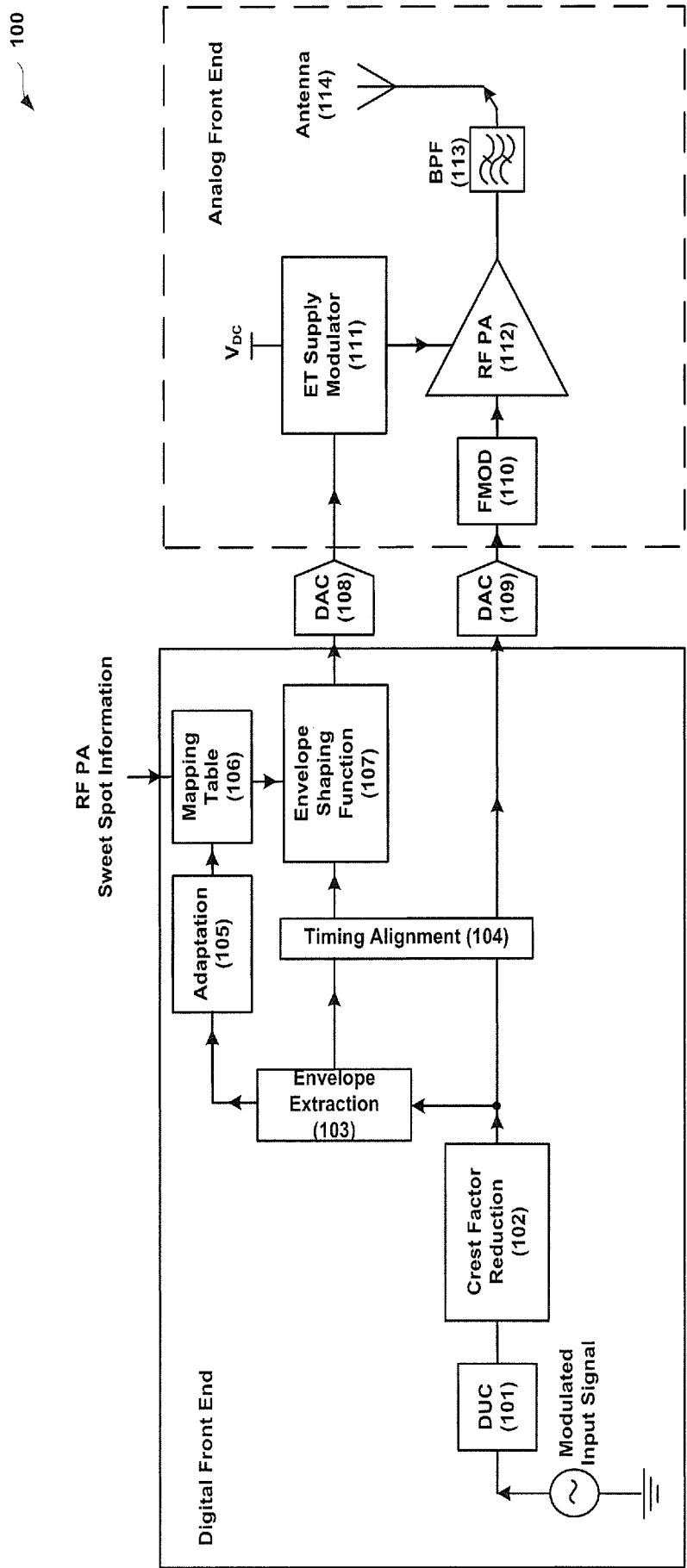


Fig. 1

200

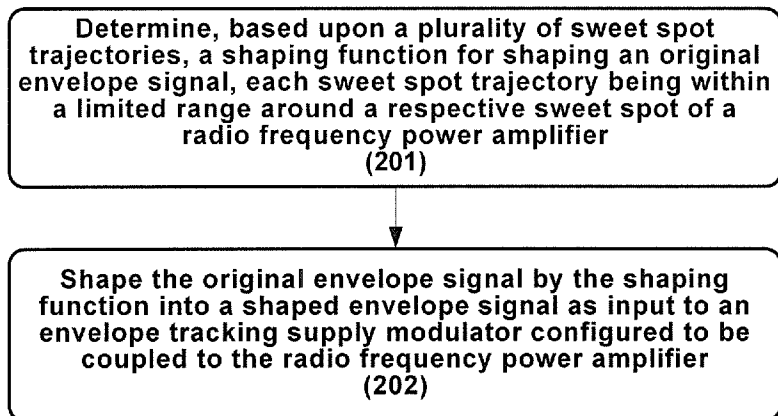


Fig. 2

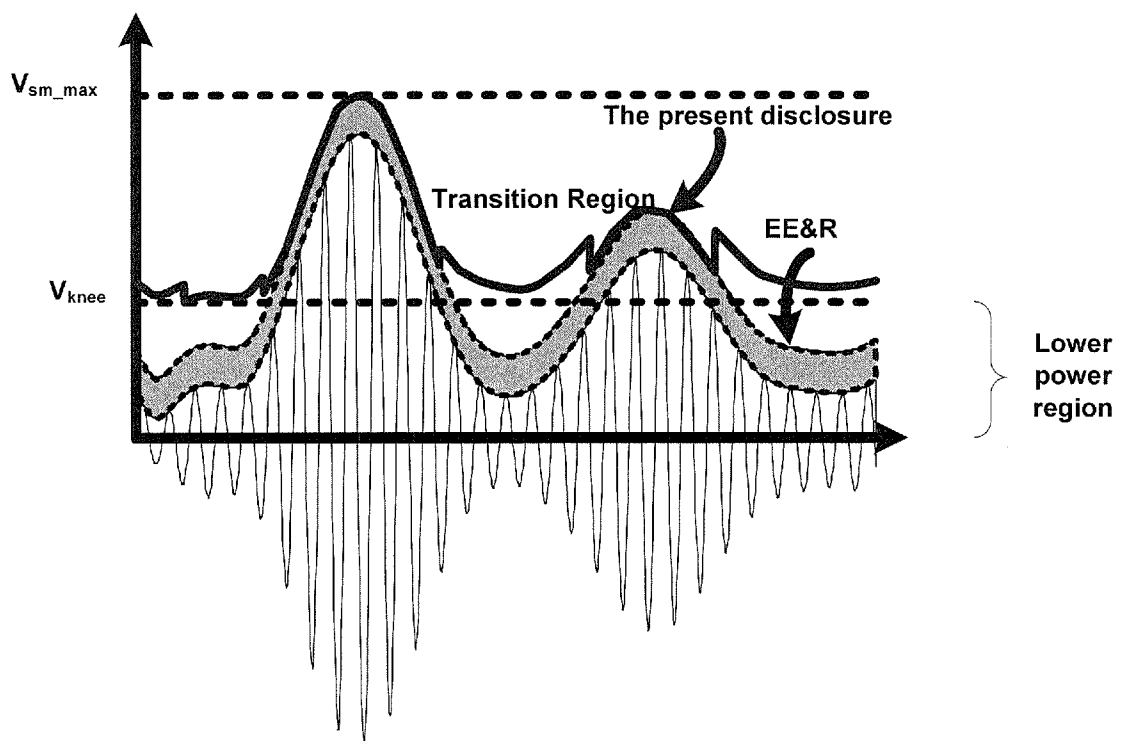


Fig. 4

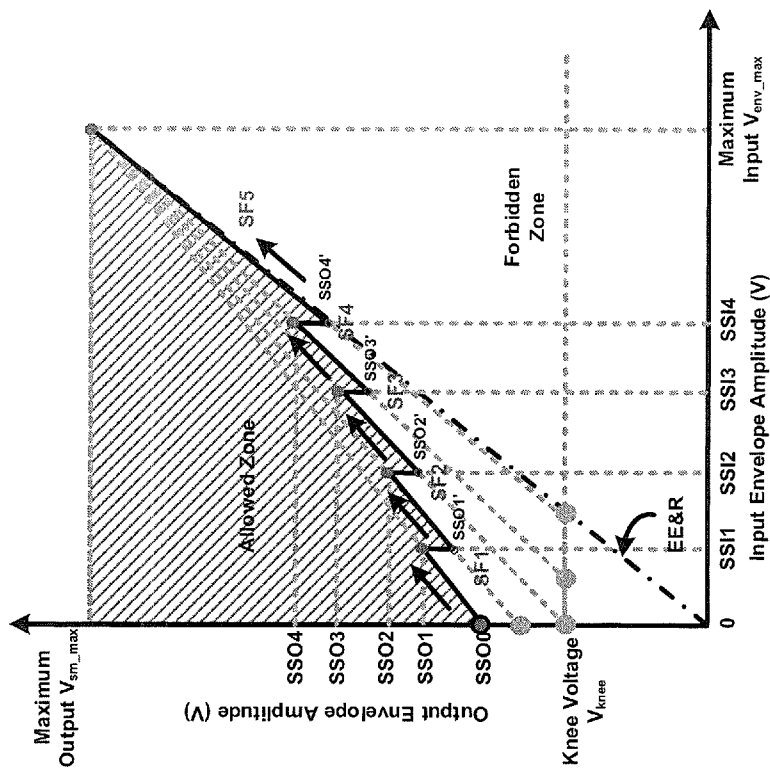


Fig. 3b

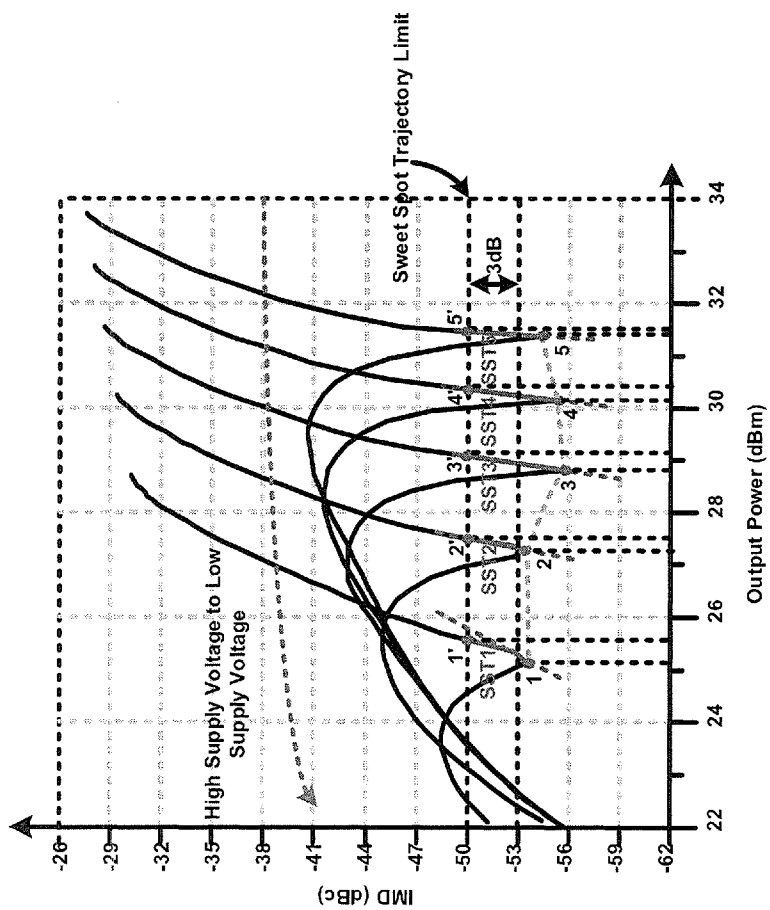


Fig. 3a

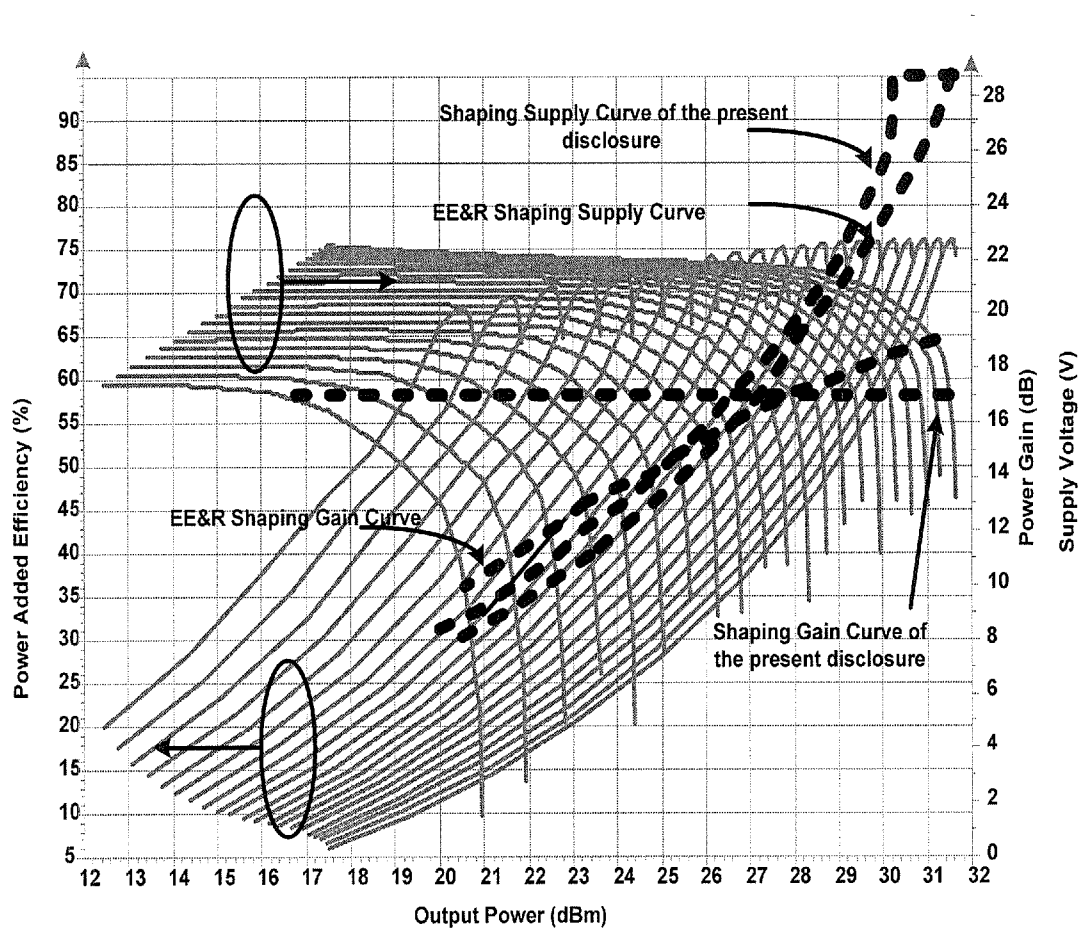


Fig. 5

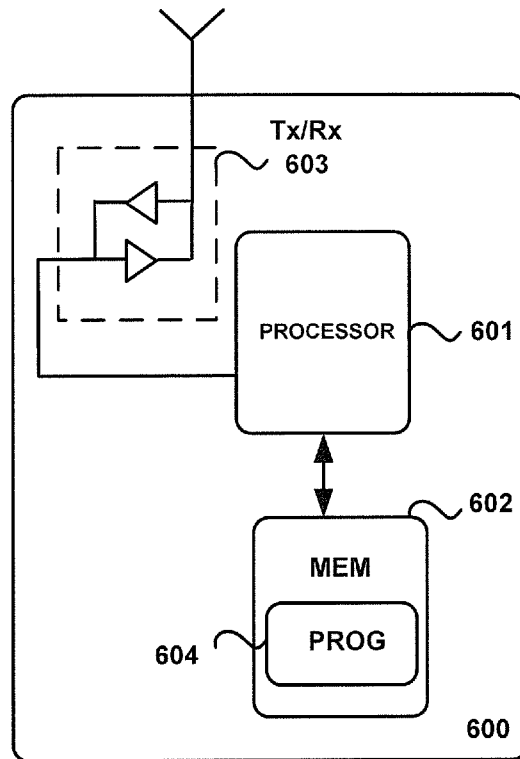


Fig. 6

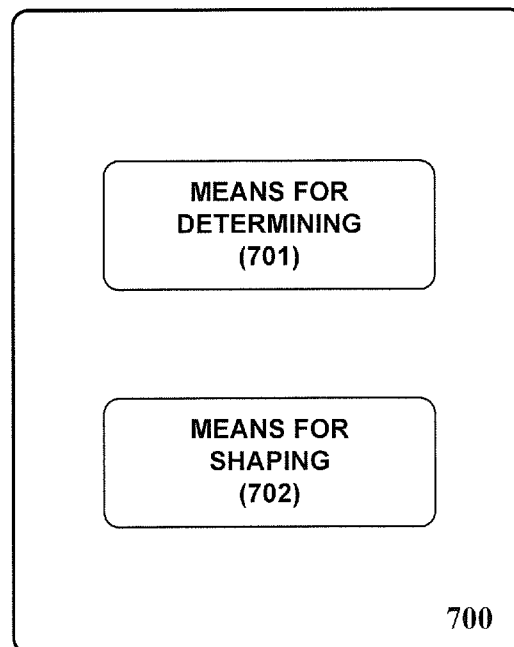


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2014/081513

A. CLASSIFICATION OF SUBJECT MATTER

H03F 1/32(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H03F

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

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

CNPAT, EPODOC, WPI, CNKI, IEEE:RF, ET, PA, radio, frequency, envelop+, track+, power, amplifier, sweet w spot?, shap
+, convert+, table, map, curve,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 101128485 B1 (POSTECH ACADEMY-INDUSTRY FOUNDATION) 27 March 2012 (2012-03-27) description, paragraphs [0018]-[0024], figures 1-9 and abstract	1-22
A	GB 2500708 A (NUJIRA LTD.) 02 October 2013 (2013-10-02) the whole document	1-22
A	GB 2498392 A (NUJIRA LTD.) 17 July 2013 (2013-07-17) the whole document	1-22
A	US 2014028392 A1 (NUJIRA LTD.) 30 January 2014 (2014-01-30) the whole document	1-22



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

“&” document member of the same patent family

Date of the actual completion of the international search

30 January 2015

Date of mailing of the international search report

03 April 2015

Name and mailing address of the ISA/CN

STATE INTELLECTUAL PROPERTY OFFICE OF THE
P.R.CHINA(ISA/CN)
6,Xitucheng Rd., Jimen Bridge, Haidian District, Beijing
100088, China

Facsimile No. (86-10)62019451

Authorized officer

SONG,Chao

Telephone No. (86-10)82245412

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2014/081513

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
KR	101128485	B1	27 March 2012	None			
GB	2500708	A	02 October 2013	WO	2013144277	A1	03 October 2013
				EP	2834915	A1	11 February 2015
				US	2015061761	A1	05 March 2015
GB	2498392	A	17 July 2013	CN	104221282	A	17 December 2014
				US	2014028370	A1	30 January 2014
				KR	20140116493	A	02 October 2014
				EP	2792065	A1	22 October 2014
				WO	2013107755	A1	25 July 2013
US	2014028392	A1	30 January 2014	WO	2013107756	A1	25 July 2013
				KR	20140116494	A	02 October 2014
				CN	104170250	A	26 November 2014
				EP	2792066	A1	22 October 2014
				GB	2498391	A	17 July 2013
				JP	2015504286	A	05 February 2015