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(54) **ET SYSTEM WITH ADJUSTMENT FOR NOISE**

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H01Q 11/12 (2006.01)
H04W 52/02 (2009.01)

(52) **U.S. Cl.**
CPC ***H04W 52/0238*** (2013.01); *Y02B 60/50* (2013.01)

(58) **Field of Classification Search**
CPC H04B 17/24; H02M 2001/0025; H04W 24/02
USPC 455/126, 127.1, 127.2
See application file for complete search history.

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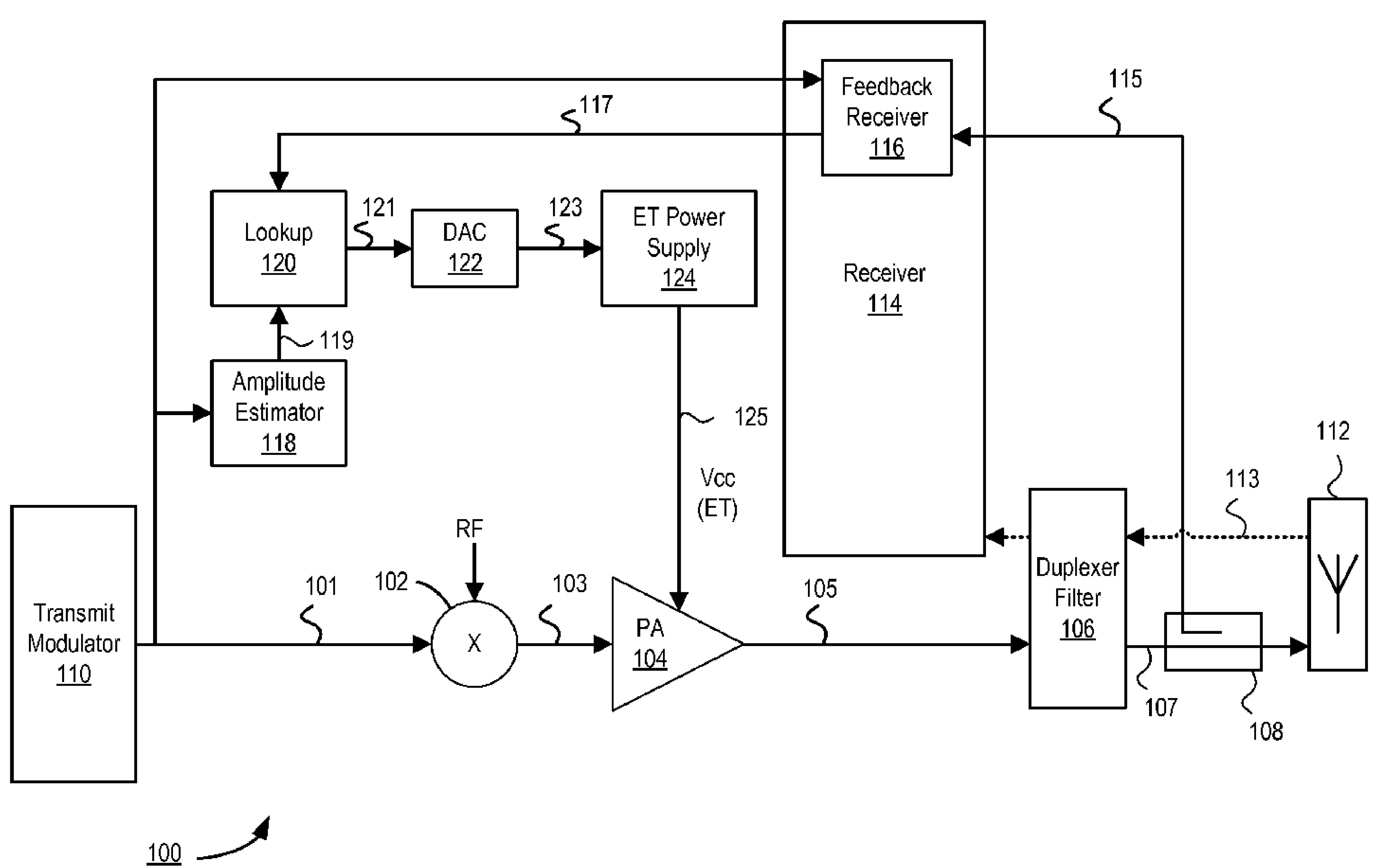
(57) **ABSTRACT**

An envelope tracking transceiver dynamically adjusts envelope tracking parameters to achieve the desired tradeoff between noise performance and power efficiency. When higher levels of noise are acceptable, the envelope tracking transceiver dynamically adjusts transmitter parameters to achieve better power efficiency while sacrificing noise performance. When lower levels of noise are desired, the envelope tracking transceiver dynamically adjusts parameters to achieve better noise performance while sacrificing efficiency.

20 Claims, 2 Drawing Sheets



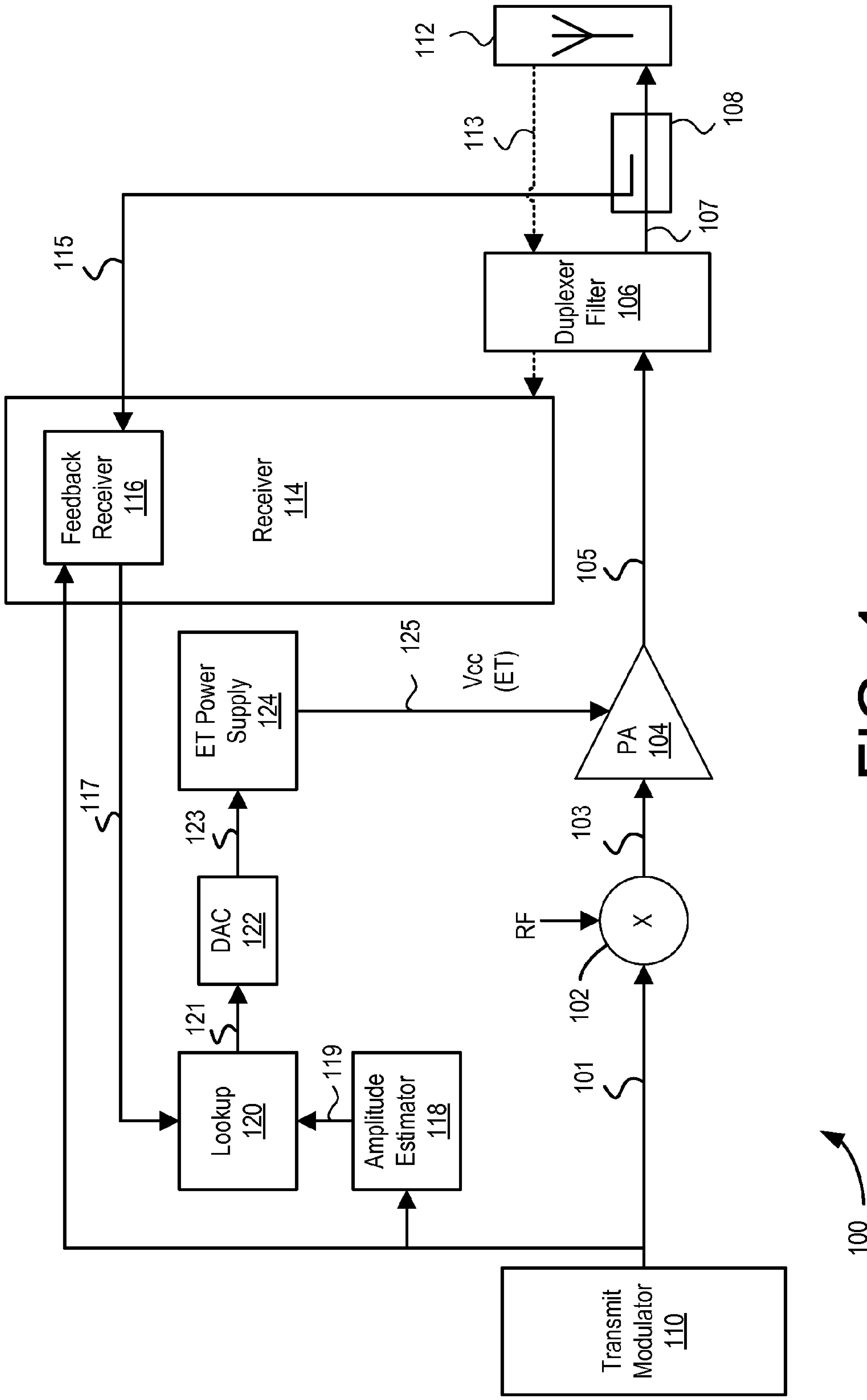

112
113
108
107
115
Duplexer
Filter
106
Feedback
Receiver
116
Receiver
114
105
125
Vcc
(ET)
ET Power
Supply
124
PA
104
117
123
103
DAC
122
RF
X
102
121
119
101
Lookup
120
Amplitude
Estimator
118
Transmit
Modulator
110
100

FIG. 1

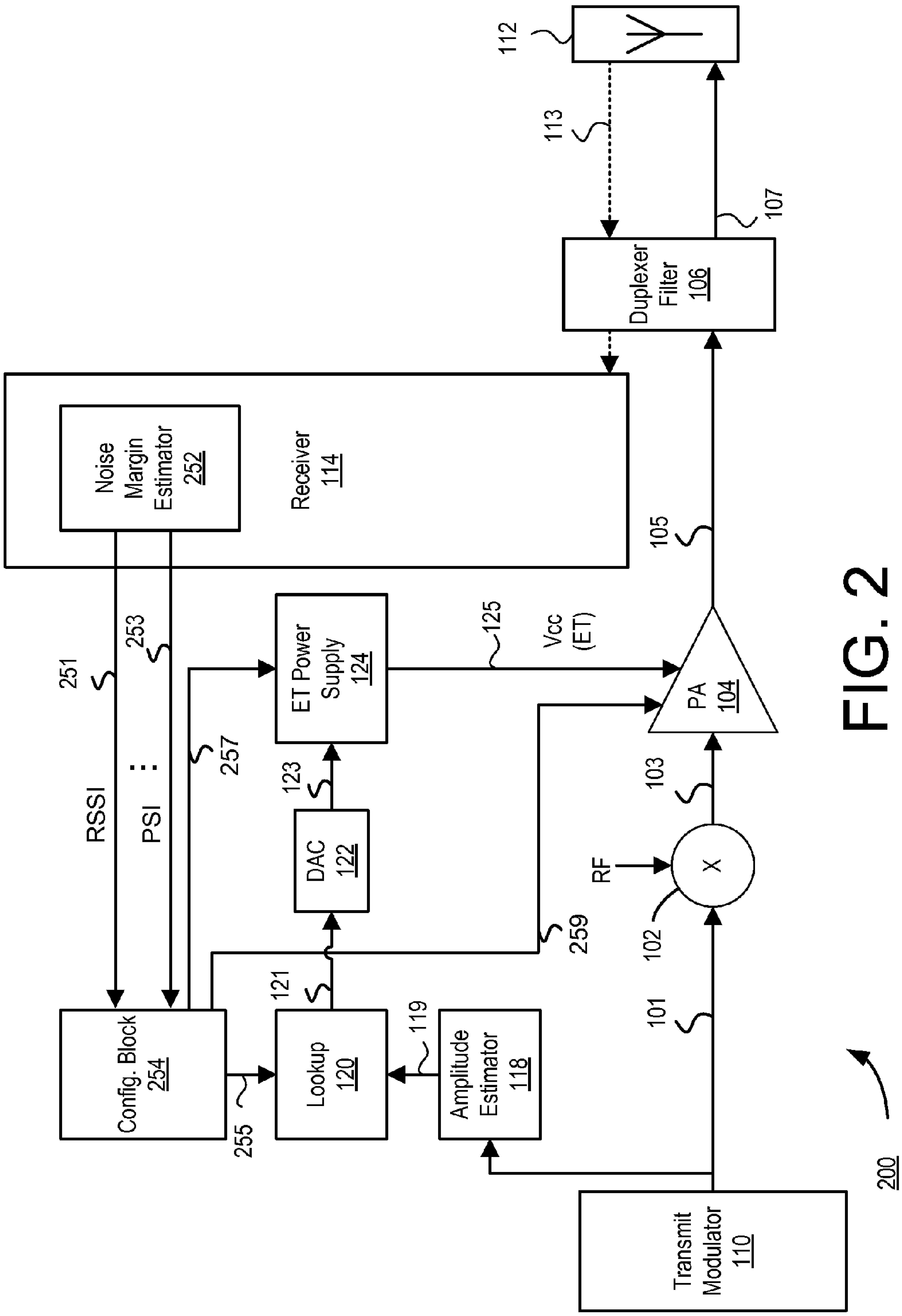

112
113
107
Duplexer Filter 106
Noise Margin Estimator 252
Receiver 114
105
251
253
ET Power Supply 124
125
Vcc (ET)
PA 104
RSSI
PSI
257
123
103
DAC 122
RF
102
259
121
101
Config. Block 254
Lookup 120
119
Amplitude Estimator 118
255
Transmit Modulator 110
200

FIG. 2

ET SYSTEM WITH ADJUSTMENT FOR NOISE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 61/783,665 filed on Mar. 14, 2013, entitled "ET System with Adjustment for Noise," which is incorporated by reference herein in its entirety.

BACKGROUND

This disclosure relates generally to a radio frequency transceiver, and more, specifically to an envelope tracking system in a radio frequency transceiver.

Envelope Tracking (ET) systems are commonly utilized in the radio frequency (RF) transmitter section of a radio where power efficiency is important such as in cellular radios used in mobile phones. A typical ET system includes an RF power amplifier (PA) utilizing a variable power supply, which supplies the PA with a dynamically changing supply voltage that tracks the amplitude of the modulation. The goal of such an ET system is generally to improve efficiency by operating the PA with low headroom.

SUMMARY

Embodiments include an envelope tracking transceiver that adjusts envelope tracking parameters to achieve desired noise performance and power efficiency. In a first embodiment, an envelope tracking transceiver comprises a power amplifier, a lookup circuit, a power supply, a receiver, and a configuration circuit. The power amplifier receives an input signal and generates an amplified output signal. The power amplifier also receives a supply voltage providing power to the power amplifier. The lookup circuit generates a power supply control signal based on an estimated amplitude of the input signal and a feedback signal indicating a compression level for operating the power amplifier. The power supply provides the supply voltage to the power amplifier based on the power supply control signal. The receiver receives a receive signal and generates a noise margin signal representative of a noise margin of the receive signal. The configuration circuit generates the feedback signal based on the noise margin signal.

In a second embodiment, the envelope tracking transceiver comprises a power amplifier, a lookup circuit, a power supply, a receiver, and a configuration circuit. The power amplifier receives an input signal and generates an amplified output signal. The power amplifier also receives a supply voltage providing power to the power amplifier. The lookup circuit generates a power supply control signal based on an estimated amplitude of the input signal. The power supply provides the supply voltage to the power amplifier based on the power supply control signal. The receiver receives a receive signal and generates a noise margin signal representative of a noise margin of the receive signal. The configuration circuit generates one or more control signals to control parameters of at least one of the power amplifier, the lookup circuit, and the power supply based on the noise margin signal.

In a third embodiment, the envelope tracking transceiver comprises a power amplifier, a lookup circuit, a power supply, and a feedback receiver. The power amplifier receives an input signal and generates an amplified output signal. The power amplifier also receives a supply voltage providing power to the power amplifier. The lookup circuit generates a power supply control signal based on an estimated amplitude of the input signal and a feedback signal indicating a compression level for operating the power amplifier. The power supply provides the supply voltage to the power amplifier based on the power supply control signal. The feedback receiver generates a noise measure in the amplified output signal and generates the feedback signal responsive to the noise measure.

The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings and specification. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the embodiments disclosed herein can be readily understood by considering the following detailed description in conjunction with the accompanying drawings.

FIG. **1** is a circuit diagram illustrating a first embodiment of an ET transceiver.

FIG. **2** is a circuit diagram illustrating a second embodiment of an ET transceiver.

DETAILED DESCRIPTION

The Figures (FIG.) and the following description relate to various embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles discussed herein.

Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict various embodiments for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

An envelope tracking transceiver dynamically adjusts envelope tracking parameters to achieve the desired tradeoff between noise performance and power efficiency. Particularly, better power efficiency of the transmitter can be obtained by sacrificing noise performance of the transmitted and received signals of the transceiver. When higher levels of noise are acceptable, the envelope tracking transceiver dynamically adjusts transmitter parameters to achieve better power efficiency while sacrificing noise performance. When lower levels of noise are desired, the envelope tracking transceiver dynamically adjusts parameters to achieve better noise performance while sacrificing efficiency.

FIG. **1** illustrates an embodiment of an RF transceiver **100** with an ET system. Transmit modulator **110** generates a digital transmit signal **101**, which is upconverted by RF upconverter **102** to upconverted input signal **103** provided to the input of PA **104**. PA **104** amplifies upconverted input signal **103** to generate amplified RF signal **105**. The amplified RF signal **105** from PA **104** reaches antenna **112** as output signal **107** after passing through duplexer filter **106**. Antenna **112** also receives a receive signal **113** which reaches receiver **114** after passing through duplexer filter **106**. Duplexer filter **106** provides filtering between amplified RF signal **105** and a received signal **113** received by antenna **112**. Coupler **108** provides a feedback signal **115** to feedback receiver **116** that is representative of output signal **107**.

Digital transmit signal **101** is also provided to amplitude estimator **118** which estimates the amplitude of digital transmit signal **101**. For example, in one embodiment, amplitude estimator **118** estimates the amplitude based on the equation Amplitude=sqrt(I^2+Q^2), where I and Q are the inphase and quadrature components respectively of the digital transmit signal **101**. An estimated amplitude signal **119** is provided as an index to lookup table **120**, which outputs signal **121** based on the estimated amplitude signal **119** and a feedback signal **117** from feedback receiver **116**. Lookup table **120** may be populated with PA supply voltage values which are appropriate for various values of estimated transmit signal amplitude signal **119** and feedback signal **117**, typically determined through PA characterization.

Digital-to-analog converter (DAC) **122** converts the outputted PA supply voltage values from lookup table **120** to an analog signal **123**, which controls ET power supply **124** to output specific voltages via supply voltage **125** to PA **104**, so that PA **104** may operate with low headroom for good efficiency. In one embodiment, a delay alignment circuit (not shown) inserts a time delay at ET power supply **124** or within RF upconverter **102** to ensure proper time alignment between supply voltage **125** provided by ET power supply **124** and the amplified RF signal **105** at the output of PA **104**.

The values in lookup table **120** may be adjusted for a desired level of compression specified by feedback signal **117**. Compression refers to the voltage operating headroom of PA **104**. For example, in one embodiment, values in lookup table **120** are adjusted by multiplying values in lookup table **120** by a value x. Compression increases when x is less than 1 and decreases when x is greater than 1. For example, if x=0.9, the supply voltage **125** supplied to PA **104** is effectively decreased by 10%. If x=1.1, the supply voltage **125** supplied to PA **104** is effectively increased by 10%. The desired compression levels are typically determined by PA and system characterization. For good efficiency, PA **104** may be operated with a high compression level, but the output signal from PA **104** should not exceed a level of acceptable distortion. Otherwise, if the acceptable level of distortion is exceeded, the compression level should be lowered until the acceptable level of distortion is met. Adjacent channel power (ACP) is a common indicator of distortion in PAs. Alternatively, instead of feedback signal **117** adjusting values in the lookup table **120**, the feedback signal **117** may instead adjust a parameter of the amplitude estimator **118** to control compression. For example, the output of the amplitude estimator may be multiplied by the value x to increase compression when x is less than 1 and decrease compression when x is greater than 1.

Feedback receiver **116** generates feedback signal **117** to control compression based on transmit signal **101** and coupled signal **115** received via coupler **108**. Feedback receiver **116** either operates continuously during normal transmitter operation, periodically during transmitter operation, or operates during a calibration mode. Feedback receiver **116** downconverts coupled signal **115** to recover a downconverted baseband signal. Feedback receiver **116** evaluates the downconverted signal, and measures distortion in signal **115**, representative of distortion in output signal **107**. For example, in one embodiment, feedback receiver **116** calculates ACP by observing the power in the adjacent channel (for example, by performing a fast Fourier transform and taking the ratio of the power of the desired frequency channel of signal **115** to the power of the adjacent channels). In one embodiment, feedback receiver **116** measures an error in the trajectory of coupled signal **115** as compared with the desired, baseband transmit signal **101** as generated by transmit modulator **110**, calculating the difference in these signals utilizing, for example, least-mean-squared techniques. Based on such distortion assessments, feedback receiver **116** provides feedback signal **117** to adjust the values in lookup table **120** to adjust the compression level just low enough to ensure distortion levels are acceptable.

In ET systems such as the transceiver **100** of FIG. **1**, PA **104** may generate some noise outside the desired RF transmit band. The noise is generated due to a number of factors, including (a) AM-AM and AM-PM characteristics inherent in PA **104**, (b) nonlinearities caused by operating PA **104** with low supply voltage headroom, (c) imperfections in the PA model for generating the variable power supply voltage, and (d) bandwidth limitations in the ET power supply **124**.

In particular, noise generated in the RF receive band can desensitize the RF receiver **114** of the transceiver to the receive signal **113**. In cellular radios used in mobile phones, the radio system is often full duplex (the RF receiver **114** operates at the same time as the transmitter). Thus noise generated by PA **104** can feed into receiver **114** during operation. Increased compression of PA **104** may increase noise in the receive band of receive signal **113**. Duplexer filter **106** functions to limit this noise, but the filtering may be insufficient.

FIG. **2** illustrates a second embodiment of a ET transceiver **200** in which parameters of the envelope tracking system are adjusted as a function of the tolerable noise in the receive path (receive noise margin), in order to limit the desensitization of the RF receiver **114**. The system is similar to that of FIG. **1**, but includes a configuration block **254** and noise margin estimator **252**, and omits some details previously described.

The radio link quality is typically monitored in modern radio systems, e.g., by a noise margin estimator **252**. The link quality may be assessed using parameters of the radio link such as receive signal strength, or bit or frame error rates. Thus the noise margin estimator **252** can estimate the receive noise margin at the RF receiver **114** and can provide one or more feedback signals **251**, **253** to a configuration block **254** that adjusts the parameters of the envelope tracking system accordingly.

The receive noise margin will typically change dynamically, as radio conditions change. For example, many systems operate with high receive noise margins when the transmitter is used for high data rate transmission; the highest data rates will rarely be used in poor or marginal receive conditions. It is at these high data rates where the transmitter will operate at the highest power levels; thus substantial overall power savings are realized from an efficient PA. Under these conditions, the configuration block **254** adjusts the parameters of the ET system to maximize efficiency, while allowing higher than nominal receive band noise since the receive noise margin is high. Conversely, when radio conditions are poor, and the receive noise margin is low, the configuration block **254** adjusts the parameters of the ET system to minimize receive band noise, even at the expense of degraded PA efficiency.

In one embodiment, noise margin estimator **252** provides a receive signal strength indicator (RSSI) level **251** to configuration block **254** as an estimate of the receive noise margin. When a high level of RSSI is detected via signal **251** (e.g., above a threshold noise margin), configuration block **254** adjusts the parameters of the ET system to increase efficiency, even at the expense of receive band noise, since a high level of

RSSI corresponds to a high receive noise margin at the RF receiver's input, and additional noise can be tolerated. For example, in one embodiment, configuration block **254** may adjust parameters in the lookup table **120** to increase compression, reduce filtering in the ET power supply **124** via control signal **257**, and/or adjust biasing of the power amplifier via control signal **259**. Effects of these adjustments on receive band noise and efficiency are described in further detail below.

Conversely, if a low level of RSSI is detected via signal **251** (e.g., below the threshold noise margin), configuration block **254** adjusts the parameters of the ET system to decrease receive band noise, even at the expense of efficiency, since a low level of RSSI corresponds to a low receive noise margin at the RF receiver's input, and much additional noise cannot be tolerated. For example, in one embodiment, configuration block **254** may adjust parameters in the lookup table **120** to decrease compression, increase filtering in the ET power supply **124** via control signal **257**, and/or adjust biasing of the power amplifier via control signal **259**. Effects of these adjustments on receive band noise and efficiency are described in further detail below.

In another embodiment, the noise margin estimator **252** detects if the system is in the presence of a public safety network. This indication may be communicated to the radio through a cellular basestation. In this case, additional emissions and noise requirements may be imposed on the radio. In one embodiment, the noise margin estimator **252** provides a public safety indicator (PSI) signal **253** to configuration block **254** which indicates to configuration block **254** that emissions and noise from PA **104** should be reduced. Configuration block **254** may adjust ET parameters in order to reduce emissions and noise, while trading off efficiency.

In yet other embodiments, a different signal representative of the noise margin can be provided to the configuration block **254**, such as, for example, a signal representing a bit or frame error rate, or a signal representing a combination of the above described factors.

Configuration block **254** can adjust various parameters of the ET system based on the noise margin. For example, configuration block **254** may increase or reduce the compression of PA **104** via the lookup table **120** via feedback signal **255** to increase or decrease efficiency (with a corresponding increase or decrease in receive noise), as described earlier. Alternatively, the configuration block **254** may control compression by adjusting a parameter of the amplitude estimator **118** as described earlier.

A less compressed PA sees its gain vary less with the supply voltage applied. Thus, errors in the path from lookup table **120** to supply voltage **125** which supplies PA **104**, which normally cause noise and distortion when they erroneously vary the gain of PA **104**, cause less noise and distortion when PA **104** is less compressed. However, when PA **104** is less compressed, PA **104** operates with lower efficiency. Conversely, a more compressed PA sees its gain vary more with the voltage applied. Thus, errors in the supply voltage for PA **104** cause more noise and distortion when PA **104** is more compressed. However, when PA **104** is more compressed, PA **104** operates with higher efficiency.

Configuration block **254** may also adjust the filtering of the voltage control signal **123** in ET power supply **124** via filtering control signal **257**. Filtering is used to limit the control bandwidth to envelope tracking power supply **124**, which reduces noise because it prevents envelope tracking power supply **124** from attempting to generate rapid voltage changes to PA **104**. Without the filtering, these rapid voltage changes are generated with inaccuracy due to inherent bandwidth limitations within the envelope tracking power supply **124**, causing PA **104** to generate noise. However, reducing filtering allows envelope tracking power supply **124** to achieve lower supply voltages to PA **104**, increasing efficiency. Thus, configuration block **254** may command greater or less filtering of voltage control signal **123** when a low or high receive noise margin, respectively, is indicated.

Configuration block **254** may also adjust the biasing of PA **104** via a bias control signal **259**. Controlling the bias of PA **104** changes its AM/AM and AM/PM characteristics. Some AM/AM shapes can be more susceptible to the generation of noise, but also have higher efficiency.

Configuration block **254** may also disable the dynamic ET system altogether, commanding envelope tracking power supply **124** to provide a static supply voltage to PA **104**. This may be accomplished by adjusting lookup table **120** to provide the same PA supply voltage value regardless of transmit power. Alternatively, the PA supply voltage may be held constant during certain transmit periods, and changed between periods if the output power of PA **104** changes. Disabling the dynamic ET system in this way reduces noise associated with the envelope power supply **124**, and can be commanded by configuration block **254** if a low receive noise margin is indicated.

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative designs for an envelope tracking system with adjustment for noise. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the embodiments discussed herein are not limited to the precise construction and components disclosed herein and that various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the scope of the disclosure.

What is claim is:

1. An envelope tracking transceiver comprising:

a power amplifier to receive an input signal and generate an amplified output signal, the power amplifier receiving a supply voltage providing power to the power amplifier;

a lookup circuit to generate a power supply control signal based on an estimated amplitude of the input signal and a feedback signal indicating a compression level for operating the power amplifier;

a power supply to provide the supply voltage to the power amplifier based on the power supply control signal;

a receiver to receive a receive signal and to generate a noise margin signal representative of a noise margin of the receive signal; and

a configuration circuit to generate the feedback signal based on the noise margin signal and generate a filter control signal to increase filtering of the power supply control signal responsive to the noise margin signal indicating a decrease in the noise margin and to decrease filtering of the power supply control signal responsive to the noise margin signal indicating an increase in the noise margin.

2. The envelope tracking transceiver of claim **1** wherein the noise margin signal is based on a receive signal strength indicator indicating a strength of the receive signal at the receiver.

3. The envelope tracking transceiver of claim **1** wherein the noise margin signal is based on a public safety indicator indicating that the receiver is communicating with a public safety network having specific noise specifications.

4. The envelope tracking transceiver of claim 1 wherein the noise margin signal is based on an error rate of the receive signal.

5. The envelope tracking transceiver of claim 1 wherein the configuration circuit is further configured to generate a bias control signal to adjust a bias of the power amplifier to increase a noise susceptibility of the power amplifier responsive to the noise margin signal indicating an increase in the noise margin and to adjust the bias of the power amplifier to decrease the noise susceptibility of the power amplifier response to the noise margin signal indicating a decrease in the noise margin.

6. The envelope tracking transceiver of claim 1 wherein the configuration circuit is further configured to generate a control signal that causes the power supply to hold the supply voltage constant during one or more transmit periods responsive to the noise margin signal indicating a decrease in the noise margin.

7. The envelope tracking transceiver of claim 1 wherein the configuration circuit is configured to generate the feedback signal to increase the compression level responsive to the noise margin increasing and to decrease the compression level responsive to the noise margin decreasing.

8. An envelope tracking transceiver comprising:

a power amplifier to receive an input signal and generate an amplified output signal, the power amplifier receiving a supply voltage providing power to the power amplifier;

a lookup circuit to generate a power supply control signal based on an estimated amplitude of the input signal;

a power supply to provide the supply voltage to the power amplifier based on the power supply control signal;

a receiver to receive a receive signal and to generate a noise margin signal representative of a noise margin of the receive signal; and

a configuration circuit to generate one or more control signals to control parameters of at least one of the power amplifier, the lookup circuit, and the power supply based on the noise margin signal, the one or more control signals including a filter control signal to control the power supply to increase filtering of the power supply control signal responsive to the noise margin signal indicating a decrease in the noise margin and to decrease filtering of the power supply control signal responsive to the noise margin signal indicating an increase in the noise margin.

9. The envelope tracking transceiver of claim 8 wherein the one or more control signals control the parameters to increase power efficiency of the power amplifier responsive to the noise margin increasing, and wherein the one or more control signals control the parameters to reduce noise in the amplified output signal responsive to the noise margin decreasing.

10. The envelope tracking transceiver of claim 8 wherein the noise margin signal is based on a receive signal strength indicator indicating a strength of the receive signal at the receiver.

11. The envelope tracking transceiver of claim 8 wherein the noise margin signal is based on a public safety indicator indicating that the receiver is communicating with a public safety network having specific noise specifications.

12. The envelope tracking transceiver of claim 8 wherein the noise margin signal is based on an error rate of the receive signal.

13. The envelope tracking transceiver of claim 8 wherein the configuration circuit is further configured to generate a bias control signal to increase a noise susceptibility of the power amplifier responsive to the noise margin signal indicating an increase in the noise margin and to adjust the bias of the power amplifier to decrease the noise susceptibility of the power amplifier response to the noise margin signal indicating a decrease in the noise margin.

14. An envelope tracking transceiver comprising:

a power amplifier to receive an input signal and generate an amplified output signal, the power amplifier receiving a supply voltage providing power to the power amplifier;

a lookup circuit to generate a power supply control signal based on an estimated amplitude of the input signal and a feedback signal indicating an amount of voltage headroom for operating the power amplifier;

a power supply to provide the supply voltage to the power amplifier based on the power supply control signal; and

a feedback receiver to generate a noise measure in the amplified output signal and to generate the feedback signal responsive to the noise measure, the feedback signal decreasing the amount of voltage headroom responsive to the noise measure falling below a threshold and increasing the amount of voltage headroom responsive to the noise measure exceeding the threshold.

15. The envelope tracking transceiver of claim 14 wherein the feedback receiver is configured to determine the noise measure based on the input signal and a signal representative of the amplified output signal.

16. The envelope tracking transceiver of claim 15 wherein the feedback receiver is further configured to downsample the signal representative of the amplified output signal and perform a comparison between the downsampled signal and the input signal.

17. The envelope tracking transceiver of claim 14 wherein the noise measure represents an adjacent channel power.

18. The envelope tracking transceiver of claim 14 further comprising a duplex filter coupled between an output of the power amplifier and at least one antenna.

19. The envelope tracking transceiver of claim 14 further comprising a coupler coupled between an output of the power amplifier and at least one antenna, the coupler configured to generate a coupled signal.

20. The envelope tracking transceiver of claim 19 wherein the feedback receiver generates the noise measure based on the input signal and the coupled signal.

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