LOW NOISE AMPLIFIERS FOR CARRIER AGGREGATION

I. Claim of Priority under 35 U.S.C. §119

[0001] The present Application for Patent claims priority to Provisional U.S. Application Serial No. 61/652,064, entitled "LOW NOISE AMPLIFIERS FOR CARRIER AGGREGATION," filed May 25, 2012, assigned to the assignee hereof, and expressly incorporated herein by reference.

BACKGROUND

I. Field

[0002] The present disclosure relates generally to electronics, and more specifically to low noise amplifiers (LNAs).

II. Background

[0003] A wireless device (e.g., a cellular phone or a smartphone) in a wireless communication system may transmit and receive data for two-way communication. The wireless device may include a transmitter for data transmission and a receiver for data reception. For data transmission, the transmitter may modulate a radio frequency (RF) carrier signal with data to obtain a modulated RF signal, amplify the modulated RF signal to obtain an amplified RF signal having the proper output power level, and transmit the amplified RF signal via an antenna to a base station. For data reception, the receiver may obtain a received RF signal via the antenna and may amplify and process the received RF signal to recover data sent by the base station.

[0004] A wireless device may support carrier aggregation, which is simultaneous operation on multiple carriers. A carrier may refer to a range of frequencies used for communication and may be associated with certain characteristics. For example, a carrier may be associated with system information describing operation on the carrier. A carrier may also be referred to as a component carrier (CC), a frequency channel, a cell, etc. It is desirable to efficiently support carrier aggregation by the wireless device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 shows a wireless device communicating with a wireless system.

[0006] FIGS. 2A to 2D show four examples of carrier aggregation (CA).

[0007] FIG. 3 shows a block diagram of the wireless device in FIG. 1.

[0008] FIGS. 4A and 4B show a receiver supporting intra-band CA.

[0009] FIGS. 5A and 5B show a receiver supporting intra-band CA and inter-band CA.

[0010] FIGS. 6A to 6C show an LNA with inductive degeneration and cascode shutoff.

[0011] FIG. 7 shows an LNA with inductive degeneration, cascode shutoff, and resistive feedback.

[0012] FIG. 8A shows an LNA with a separate input attenuation circuit for each amplifier stage.

[0013] FIG. 8B shows an LNA with a shared input attenuation circuit for two amplifier stages.

[0014] FIG. 9 shows an LNA with a tunable input matching circuit.

[0015] FIGS. 10 to 11C show several exemplary designs of a multiple-input multiple-output (MIMO) LNA.

[0016] FIGS. 12A to 12F show six exemplary designs of a tunable input matching circuit.

[0017] FIG. 13 shows a process for receiving signals in a wireless system.

DETAILED DESCRIPTION

[0018] The detailed description set forth below is intended as a description of exemplary designs of the present disclosure and is not intended to represent the only designs in which the present disclosure can be practiced. The term "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other designs. The detailed description includes specific details for the purpose of providing a thorough understanding of the exemplary designs of the present disclosure. It will be apparent to those skilled in the art that the exemplary designs described herein may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form in order to avoid obscuring the novelty of the exemplary designs presented herein.

[0019] LNAs supporting carrier aggregation are disclosed herein. These LNAs may have better performance and may be used for various types of electronic devices such as wireless communication devices.

[0020] **FIG. 1** shows a wireless device 110 communicating with a wireless communication system 120. Wireless system 120 may be a Long Term Evolution (LTE) system, a Code Division Multiple Access (CDMA) system, a Global System for Mobile Communications (GSM) system, a wireless local area network (WLAN) system, or some other wireless system. A CDMA system may implement Wideband CDMA (WCDMA), cdma2000, or some other version of CDMA. For simplicity, FIG. 1 shows wireless system 120 including two base stations 130 and 132 and one system controller 140. In general, a wireless system may include any number of base stations and any set of network entities.

[0021] Wireless device 110 may also be referred to as a user equipment (UE), a mobile station, a terminal, an access terminal, a subscriber unit, a station, etc. Wireless device 110 may be a cellular phone, a smartphone, a tablet, a wireless modem, a personal digital assistant (PDA), a handheld device, a laptop computer, a smartbook, a netbook, a cordless phone, a wireless local loop (WLL) station, a Bluetooth device, etc. Wireless device 110 may be capable of communicating with wireless system 120. Wireless device 110 may also be capable of receiving signals from broadcast stations (e.g., a broadcast station 134), signals from satellites (e.g., a satellite 150) in one or more global navigation satellite systems (GNSS), etc. Wireless device 110 may support one or more radio technologies for wireless communication such as LTE, cdma2000, WCDMA, GSM, 802.11, etc.

[0022] Wireless device 110 may support carrier aggregation, which is operation on multiple carriers. Carrier aggregation may also be referred to as multi-carrier operation. Wireless device 110 may be able to operate in low-band from 698 to 960 megahertz (MHz), mid-band from 1475 to 2170 MHz, and/or high-band from 2300 to 2690 and 3400 to 3800 MHz. Low-band, mid-band, and high-band refer to three groups of bands (or band groups), with each band group including a number of frequency bands (or simply, "bands"). Each band may cover up to 200 MHz and may include one or more carriers. Each carrier may cover up to 20 MHz in LTE. LTE Release 11 supports 35 bands, which are referred to as LTE/UMTS bands and are listed in 3GPP TS 36.101.

Wireless device 110 may be configured with up to 5 carriers in one or two bands in LTE Release 11.

[0023] In general, carrier aggregation (CA) may be categorized into two types - intra-band CA and inter-band CA. Intra-band CA refers to operation on multiple carriers within the same band. Inter-band CA refers to operation on multiple carriers in different bands.

[0024] **FIG. 2A** shows an example of contiguous intra-band CA. In the example shown in FIG. 2A, wireless device 110 is configured with four contiguous carriers in the same band, which is a band in low-band. Wireless device 110 may receive transmissions on multiple contiguous carriers within the same band.

[0025] **FIG. 2B** shows an example of non-contiguous intra-band CA. In the example shown in FIG. 2B, wireless device 110 is configured with four non-contiguous carriers in the same band, which is a band in low-band. The carriers may be separated by 5 MHz, 10 MHz, or some other amount. Wireless device 110 may receive transmissions on multiple non-contiguous carriers within the same band.

[0026] **FIG. 2C** shows an example of inter-band CA in the same band group. In the example shown in FIG. 2C, wireless device 110 is configured with four carriers in two bands in the same band group, which is low-band. Wireless device 110 may receive transmissions on multiple carriers in different bands in the same band group (e.g., low-band in FIG. 2C).

[0027] **FIG. 2D** shows an example of inter-band CA in different band groups. In the example shown in FIG. 2D, wireless device 110 is configured with four carriers in two bands in different band groups, which include two carriers in one band in low-band and two additional carriers in another band in mid-band. Wireless device 110 may receive transmissions on multiple carriers in different bands in different band groups (e.g., low-band and mid-band in FIG. 2D).

[0028] FIGS. 2A to 2D show four examples of carrier aggregation. Carrier aggregation may also be supported for other combinations of bands and band groups. For example, carrier aggregation may be supported for low-band and high-band, mid-band and high-band, high-band and high-band, etc.

[0029] **FIG. 3** shows a block diagram of an exemplary design of wireless device 110 in FIG. 1. In this exemplary design, wireless device 110 includes a transceiver 320 coupled to a primary antenna 310, receivers 322 coupled to a secondary antenna 312,

and a data processor/controller 380. Transceiver 320 includes multiple (K) receivers 330aa to 330ak and multiple (K) transmitters 360a to 360k to support multiple bands, carrier aggregation, multiple radio technologies, etc. Receivers 322 include multiple (M) receivers 330ba to 330bm to support multiple bands, carrier aggregation, multiple radio technologies, receive diversity, MIMO transmission, etc.

[0030] In the exemplary design shown in FIG. 3, each receiver 330 includes input circuits 332, an LNA 340, and receive circuits 342. For data reception, antenna 310 receives signals from base stations and/or other transmitter stations and provides a received RF signal, which is routed through switches/duplexers 324 and provided to a selected receiver. The description below assumes that receiver 330aa is the selected receiver. Within receiver 330aa, the received RF signal is passed through input circuits 332aa, which provides an input RF signal to an LNA 340aa. Input circuits 332aa may include a matching circuit, a receive filter, etc. LNA 340aa amplifies the input RF signal and provides an output RF signal. Receive circuits 342aa amplify, filter, and downconvert the output RF signal from RF to baseband and provide an analog input signal to data processor 380. Receive circuits 332aa may include mixers, a filter, an amplifier, a matching circuit, an oscillator, a local oscillator (LO) generator, a phase locked loop (PLL), etc. Each remaining receiver 330 in transceiver 320 and each receiver 330 in receivers 322 may operate in similar manner as receiver 330aa in transceiver 320.

[0031] In the exemplary design shown in FIG. 3, each transmitter 360 includes transmit circuits 362, a power amplifier (PA) 364, and output circuits 366. For data transmission, data processor 380 processes (e.g., encodes and modulates) data to be transmitted and provides an analog output signal to a selected transmitter. The description below assumes that transmitter 360a is the selected transmitter. Within transmitter 360a, transmit circuits 362a amplify, filter, and upconvert the analog output signal from baseband to RF and provide a modulated RF signal. Transmit circuits 362a may include mixers, an amplifier, a filter, a matching circuit, an oscillator, an LO generator, a PLL, etc. A PA 364a receives and amplifies the modulated RF signal and provides an amplified RF signal having the proper output power level. The amplified RF signal is passed through output circuits 366a, routed through switches/duplexers 324, and transmitted via antenna 310. Output circuits 366a may include a matching circuit, a transmit filter, a directional coupler, etc.

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