# RADIO FREQUENCY COMMUNICATION SYSTEMS WITH COEXISTENCE MANAGEMENT

## BACKGROUND

### Field

**[0001]** Embodiments of the invention relate to electronic systems, and in particular, to radio frequency electronics.

### Description of Related Technology

**[0002]** Radio frequency (RF) communication systems can be used for transmitting and/or receiving signals of a wide range of frequencies. For example, an RF communication system can be used to wirelessly communicate RF signals in a frequency range of about 30 kHz to 300 GHz, such as in the range of about 410 MHz to about 7.125 GHz for fifth generation (5G) frequency range 1 (FR1) communications.

**[0003]** Examples of RF communication systems include, but are not limited to, mobile phones, tablets, base stations, network access points, customer-premises equipment (CPE), laptops, and wearable electronics.

## SUMMARY

[0003a] In an aspect, the present disclosure refers to a mobile device comprising: a plurality of antennas including a first antenna and a second antenna; a plurality of front end systems including a first front end system and a second front end system, the first front end system configured to receive a radio frequency receive signal from the first antenna and to generate a first observation signal based on observing the radio frequency receive signal, the second front end system configured to provide a radio frequency transmit signal to the second antenna and to generate a second observation signal based on observing the radio frequency transmit signal; and a first transceiver configured to downconvert the radio frequency receive signal to generate a first baseband receive signal, the first transceiver including a leakage correction circuit configured to compensate the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal, the first front end system generating the first observation signal

based on sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.

[0003b] In another aspect, the present disclosure refers to a radio frequency communication system comprising: a first front end system configured receive a first incoming radio frequency receive signal and to output a first outgoing radio frequency transmit signal, the first front end system further configured to generate a first observation signal based on observing the first incoming radio frequency receive signal; a second front end system configured to receive a second incoming radio frequency receive signal and to output a second outgoing radio frequency transmit signal, the second front end system further configured to generate a second observation signal based on observing the second outgoing radio frequency transmit signal; and a first transceiver configured to downconvert the first incoming radio frequency receive signal to generate a first baseband receive signal, the first transceiver including a leakage correction circuit configured to compensate the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal, the first front end system generating the first observation signal based on sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.

[0003c] In another aspect, the present disclosure refers to a method of coexistence management in a mobile device, the method comprising: generating a first observation signal based on processing a radio frequency receive signal using a first front end system including sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal; generating a second observation signal based on processing a radio frequency transmit signal using a second front end system; downconverting the radio frequency receive signal to generate a first baseband receive signal using a first transceiver; and compensating the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal using a leakage correction circuit of the first transceiver.

**[0004]** In certain ~~embodiments~~examples, the present disclosure relates to a mobile device. The mobile device includes a plurality of antennas including a first antenna and a second antenna, and a plurality of front end systems including a first front end system and a second front end system. The first front end system is configured to receive a radio frequency receive signal from the first antenna and to generate a first observation signal based on observing the radio frequency receive signal, and the second front end system is

configured to provide a radio frequency transmit signal to the second antenna and to generate a second observation signal based on observing the radio frequency transmit signal. The mobile device further includes a first transceiver configured to downconvert the radio frequency receive signal to generate a first baseband receive signal, and the first transceiver includes a leakage correction circuit configured to compensate the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal.

**[0005]** In some examples~~embodiments~~, the first front end system generates the first observation signal based on sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.

**[0006]** In various examples~~embodiments~~, the second front end system generates the second observation signal based on sensing an amount of direct transmit leakage present in the radio frequency transmit signal.

**[0007]** In several examples~~embodiments~~, the first front end system includes a first directional coupler configured to generate the first observation signal, and the second front end system includes a second directional coupler configured to generate the second observation signal. According to a number of examples~~embodiments~~, the first directional coupler generates the first observation signal based on a reverse coupled path to the first antenna, and the second directional coupler generates the second observation signal based on a forward coupled path to the second antenna. In accordance with some examples~~embodiments~~, the first front end system includes a duplexer, and the first directional coupler positioned between an output of the duplexer and the first antenna. According to various examples~~embodiments~~, the first front end system includes a duplexer and a power amplifier, and the first directional coupler is positioned between an output of the power amplifier and an input to the duplexer.

**[0008]** In some examples~~embodiments~~, the first front end system is a cellular front end system and the second front end system is a WiFi front end system.

**[0009]** In several examples~~embodiments~~, the first front end system is a WiFi front end system and the second front end system is a cellular front end system.

**[0010]** In various examples~~embodiments~~, the mobile device further includes a second transceiver coupled to the second front end system and configured to compensate a second baseband receive signal for radio frequency signal leakage based on a third observation signal and a fourth observation signal. According to a number of examples~~embodiments~~, the first front end system includes a first directional coupler configured to generate the first observation signal and the fourth observation signal, and the second front end system includes a second directional coupler configured to generate the second observation signal and the third observation signal.

**[0011]** In several examples~~embodiments~~, the leakage correction circuit includes a discrete time cancellation circuit.

**[0012]** In certain examples~~embodiments~~, the present disclosure relates to a radio frequency communication system. The radio frequency communication system includes a first front end system configured receive a first incoming radio frequency receive signal and to output a first outgoing radio frequency transmit signal, the first front end system further configured to generate a first observation signal based on observing the first incoming radio frequency receive signal. The radio frequency communication system further includes a second front end system configured to receive a second incoming radio frequency receive signal and to output a second outgoing radio frequency transmit signal, the second front end system further configured to generate a second observation signal based on observing the second outgoing radio frequency transmit signal. The radio frequency communication system further includes a first transceiver configured to downconvert the first incoming radio frequency receive signal to generate a first baseband receive signal, the first transceiver including a leakage correction circuit configured to compensate the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal.

**[0013]** In various examples~~embodiments~~, the first front end system generates the first observation signal based on sensing an amount of aggressor spectral regrowth present in the first incoming radio frequency receive signal.

**[0014]** In several examples~~embodiments~~, the second front end system generates the second observation signal based on sensing an amount of direct transmit leakage present in the second outgoing radio frequency transmit signal.

**[0015]** In some examples~~embodiments~~, the first front end system includes a first directional coupler configured to generate the first observation signal, and the second front end system includes a second directional coupler configured to generate the second observation signal. According to several examples~~embodiments~~, the first directional coupler generates the first observation signal based on a reverse coupled path to the first antenna, and the second directional coupler generates the second observation signal based on a forward coupled path to the second antenna. In accordance with a number of examples~~embodiments~~, the first front end system includes a duplexer and an antenna switch, and the first directional coupler is positioned between an output of the duplexer and an input to the antenna switch. According to various examples~~embodiments~~, the first front end system includes a duplexer and a power amplifier, and the first directional coupler is positioned between an output of the power amplifier and an input to the duplexer.

**[0016]** In several examples~~embodiments~~, the first front end system is a cellular front end system and the second front end system is a WiFi front end system.

**[0017]** In various examples~~embodiments~~, the first front end system is a WiFi front end system and the second front end system is a cellular front end system.

**[0018]** In some examples~~embodiments~~, the radio frequency communication system further includes a second transceiver configured to downconvert the second incoming radio frequency receive signal to generate a second baseband receive signal, and the second transceiver includes a leakage correction circuit configured to compensate the second baseband receive signal for radio frequency signal leakage based on a third observation signal and a fourth observation signal. In a number of examples~~embodiments~~, the first front end system includes a first directional coupler configured to generate the first observation signal and the fourth observation signal, and the second front end system includes a second directional coupler configured to generate the second observation signal and the third observation signal.

**[0019]** In several examples~~embodiments~~, the leakage correction circuit includes a discrete time cancellation circuit.

**[0020]** In certain examples~~embodiments~~, the present disclosure relates to a method of coexistence management in a mobile device. The method includes generating a first observation signal based on processing a radio frequency receive signal using a first front end system, generating a second observation signal based on processing a radio frequency transmit signal using a second front end system, downconverting the radio frequency receive signal to generate a first baseband receive signal using a first transceiver, and compensating the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal using a leakage correction circuit of the first transceiver.

**[0021]** In some examples~~embodiments~~, generating the first observation signal includes sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.

**[0022]** In several examples~~embodiments~~, generating the second observation signal includes sensing an amount of direct transmit leakage present in the radio frequency transmit signal.

**[0023]** In various examples~~embodiments~~, the method further includes generating the first observation signal using a first directional coupler of the first front end system, and

generating the second observation signal using a second directional coupler of the second front end system.

**[0024]** In some examples~~embodiments~~, the radio frequency receive signal is a cellular signal and the radio frequency transmit signal is a WiFi signal.

**[0025]** In several examples~~embodiments~~, the radio frequency receive signal is a WiFi signal and the radio frequency transmit signal is a cellular signal.

**[0026]** In various examples~~embodiments~~, the method further includes downconverting a radio frequency signal from the second front end system to generate a second baseband receive signal, and compensating the second baseband receive signal for radio frequency signal leakage based on a third observation signal and a fourth observation signal. According to a number of examples~~embodiments~~, the method further includes generating the first observation signal and the fourth observation signal using a first directional coupler of the first front end system, and generating the second observation signal and the third observation signal using a second directional coupler of the second front end system.

**[0027]** In several examples~~embodiments~~, compensating the first baseband receive signal for radio frequency signal leakage includes providing discrete time cancellation based on the first observation signal and the second observation signal.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0028]** Figure 1 is a schematic diagram of one example of a mobile device communicating via cellular and WiFi networks.

**[0029]** Figure 2 is a schematic diagram of one example of signal leakage for an RF communication system.

**[0030]** Figure 3A is a schematic diagram of one example of direct transmit leakage for an RF communication system.

**[0031]** Figure 3B is a schematic diagram of one example of regrowth leakage for an RF communication system.

**[0032]** Figure 4A is a schematic diagram of an RF communication system with coexistence management according to one embodiment.

**[0033]** Figure 4B is a schematic diagram of an RF communication system with coexistence management according to another embodiment.

**[0034]** Figure 5 is a schematic diagram of an RF communication system with coexistence management according to another embodiment.

WHAT IS CLAIMED IS:

1. A mobile device comprising:

a plurality of antennas including a first antenna and a second antenna;

a plurality of front end systems including a first front end system and a second front end system, the first front end system configured to receive a radio frequency receive signal from the first antenna and to generate a first observation signal based on observing the radio frequency receive signal, the second front end system configured to provide a radio frequency transmit signal to the second antenna and to generate a second observation signal based on observing the radio frequency transmit signal; and

a first transceiver configured to downconvert the radio frequency receive signal to generate a first baseband receive signal, the first transceiver including a leakage correction circuit configured to compensate the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal, the first front end system generating the first observation signal based on sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.

~~2. The mobile device of claim 1 wherein the first front end system generates the first observation signal based on sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.~~

~~3.~~2. The mobile device of claim 1 wherein the second front end system generates the second observation signal based on sensing an amount of direct transmit leakage present in the radio frequency transmit signal.

~~4.~~3. The mobile device of claim 1 wherein the first front end system includes a first directional coupler configured to generate the first observation signal, and the second front end system includes a second directional coupler configured to generate the second observation signal.

~~5.~~4. The mobile device of claim ~~4~~ 3 wherein the first directional coupler generates the first observation signal based on a reverse coupled path to the first antenna, and the second directional coupler generates the second observation signal based on a forward coupled path to the second antenna.

~~6.~~5. The mobile device of claim ~~4~~ 3 wherein the first front end system includes a duplexer, the first directional coupler positioned between an output of the duplexer and the first antenna.

~~7.~~6. The mobile device of claim ~~4~~ 3 wherein the first front end system includes a duplexer and a power amplifier, the first directional coupler positioned between an output of the power amplifier and an input to the duplexer.

~~8.~~7. The mobile device of claim 1 wherein the first front end system is a cellular front end system and the second front end system is a WiFi front end system.

~~9.~~8. The mobile device of claim 1 wherein the first front end system is a WiFi front end system and the second front end system is a cellular front end system.

~~10.~~9. The mobile device of claim 1 further comprising a second transceiver coupled to the second front end system and configured to compensate a second baseband receive signal for radio frequency signal leakage based on a third observation signal and a fourth observation signal.

~~11.~~10. The mobile device of claim ~~10~~ 9 wherein the first front end system includes a first directional coupler configured to generate the first observation signal and the fourth observation signal, and the second front end system includes a second directional coupler configured to generate the second observation signal and the third observation signal.

~~12.~~11. A radio frequency communication system comprising:

a first front end system configured receive a first incoming radio frequency receive signal and to output a first outgoing radio frequency transmit signal, the first front end system further configured to generate a first observation signal based on observing the first incoming radio frequency receive signal;

a second front end system configured to receive a second incoming radio frequency receive signal and to output a second outgoing radio frequency transmit signal, the second front end system further configured to generate a second observation signal based on observing the second outgoing radio frequency transmit signal; and

a first transceiver configured to downconvert the first incoming radio frequency receive signal to generate a first baseband receive signal, the first transceiver including a leakage correction circuit configured to compensate the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal, the first front end system generating the first observation signal based on sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.

~~13. The radio frequency communication system of claim 12 wherein the first front end system generates the first observation signal based on sensing an amount of aggressor spectral regrowth present in the first incoming radio frequency receive signal.~~

~~14.~~12. The radio frequency communication system of claim ~~12~~ 11 wherein the second front end system generates the second observation signal based on sensing an amount of direct transmit leakage present in the second outgoing radio frequency transmit signal.

~~15.~~13. The radio frequency communication system of claim ~~12~~ 11 wherein the first front end system includes a first directional coupler configured to generate the first observation signal, and the second front end system includes a second directional coupler configured to generate the second observation signal.

~~16.~~14. The radio frequency communication system of claim ~~15~~ 13 wherein the first directional coupler generates the first observation signal based on a reverse coupled path to the first antenna, and the second directional coupler generates the second observation signal based on a forward coupled path to the second antenna.

~~17.~~15. A method of coexistence management in a mobile device, the method comprising:

generating a first observation signal based on processing a radio frequency receive signal using a first front end system including sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal;

generating a second observation signal based on processing a radio frequency transmit signal using a second front end system;

downconverting the radio frequency receive signal to generate a first baseband receive signal using a first transceiver; and

compensating the first baseband receive signal for radio frequency signal leakage based on the first observation signal and the second observation signal using a leakage correction circuit of the first transceiver.

~~18. The method of claim 17 wherein generating the first observation signal includes sensing an amount of aggressor spectral regrowth present in the radio frequency receive signal.~~

~~19.~~16. The method of claim ~~17~~ 15 wherein generating the second observation signal includes sensing an amount of direct transmit leakage present in the radio frequency transmit signal.

~~20.~~17. The method of claim ~~17~~ 15 further comprising generating the first observation signal using a first directional coupler of the first front end system, and generating the second observation signal using a second directional coupler of the second front end system.