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(54) **ADAPTIVE RADIO-FREQUENCY INTERFERENCE CANCELLING DEVICE, METHOD, AND RECEIVER**

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(30) **Foreign Application Priority Data**

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H04B 1/10 (2006.01)

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CPC . ***H04B 1/10*** (2013.01); ***H04B 1/109*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 1/10; H04B 1/109
See application file for complete search history.

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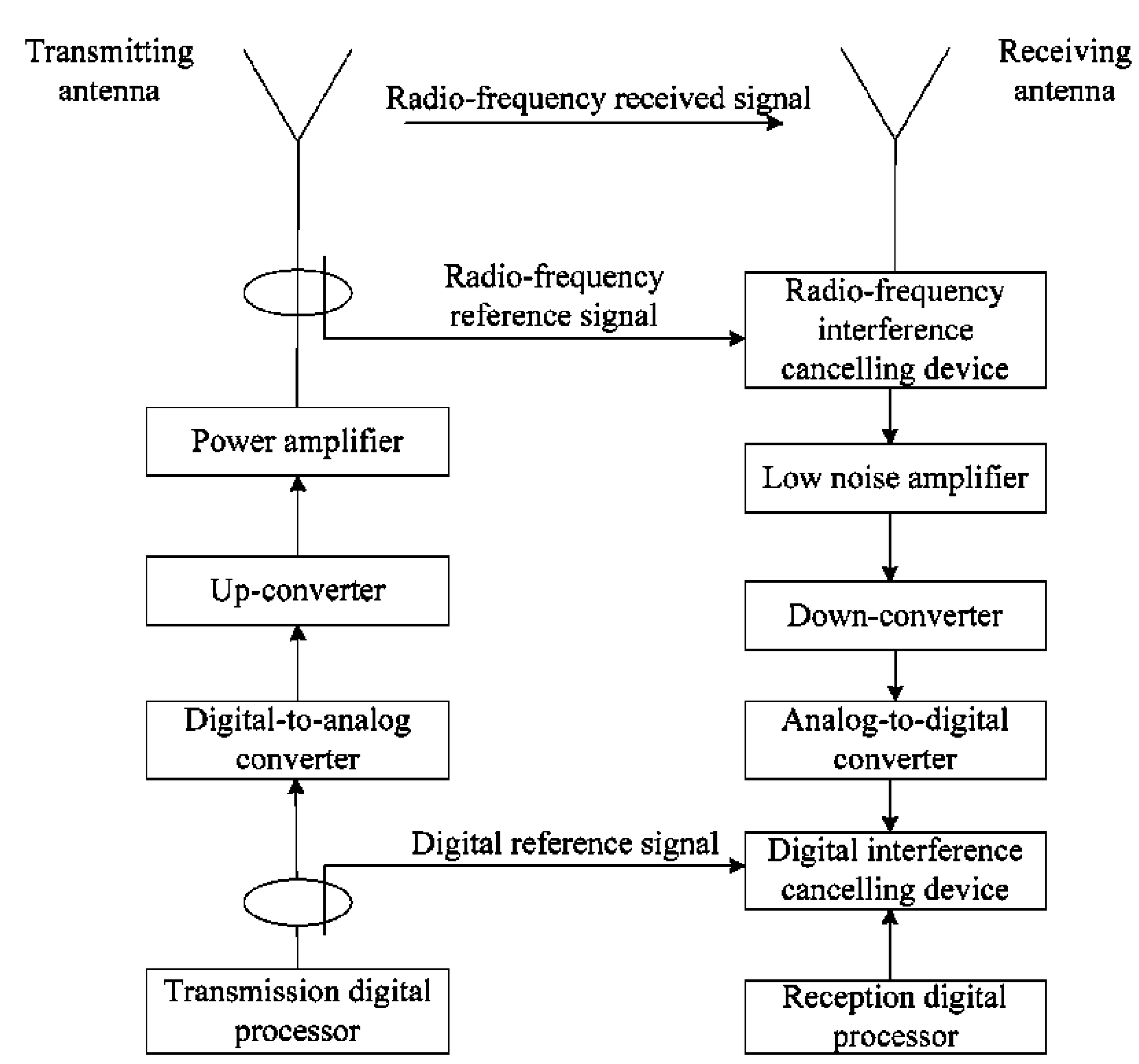
Primary Examiner — Erin File
(74) *Attorney, Agent, or Firm* — Leydig, Voit & Mayer, Ltd.

(57) **ABSTRACT**

The present invention provides an adaptive radio-interference cancelling device and method, a receiver, and a wireless full duplex communication system. The device includes an amplitude phase adjusting module, configured to adjust an amplitude and a phase of a radio-frequency reference signal and output a radio-frequency adjustment signal to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal; a subtractor, configured to output a radio-frequency residual signal, where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal; and a baseband extracting and filtering module, configured to receive the radio-frequency reference signal and the radio-frequency residual signal output by the subtractor, extract baseband signals and perform least mean squares adaptive filtering processing on the baseband signals to obtain an amplitude phase control signal and output to the amplitude phase adjusting module.

7 Claims, 7 Drawing Sheets



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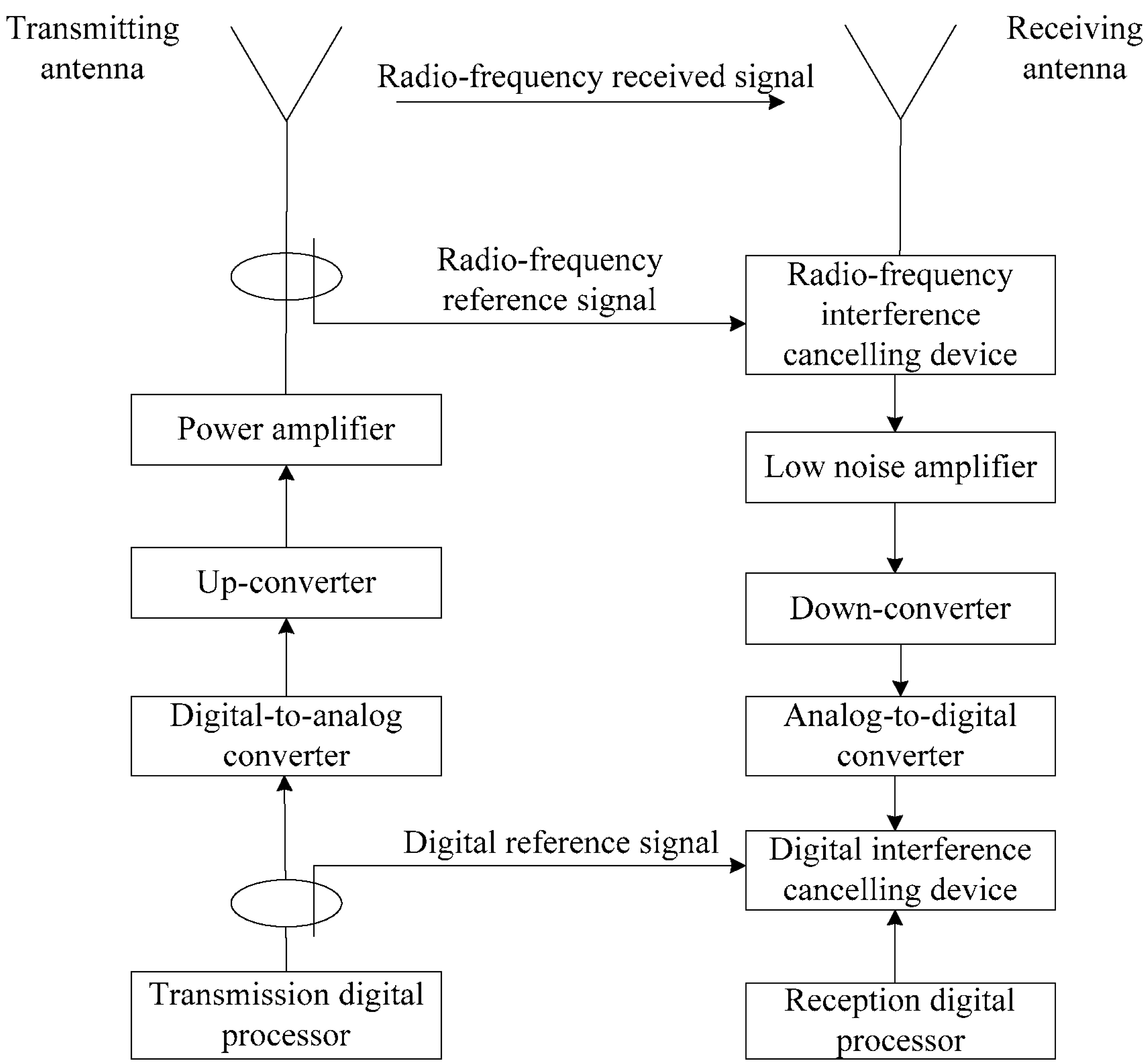
Transmitting antenna
Radio-frequency received signal
Receiving antenna
Radio-frequency reference signal
Radio-frequency interference cancelling device
Power amplifier
Low noise amplifier
Up-converter
Down-converter
Digital-to-analog converter
Analog-to-digital converter
Digital reference signal
Digital interference cancelling device
Transmission digital processor
Reception digital processor

FIG. 1

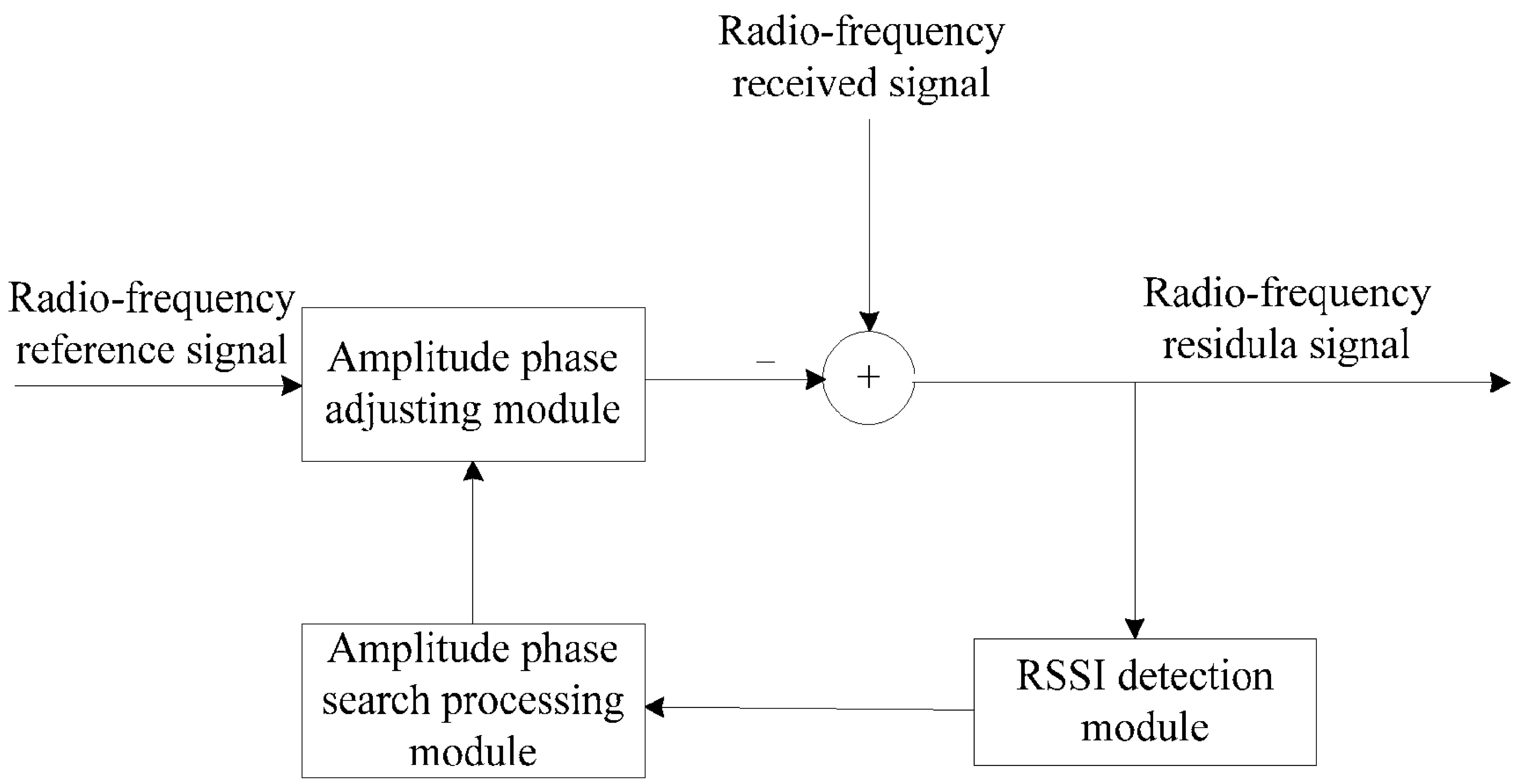
Radio-frequency received signal
Radio-frequency reference signal
Amplitude phase adjusting module
−
+
Radio-frequency residula signal
Amplitude phase search processing module
RSSI detection module

FIG. 2

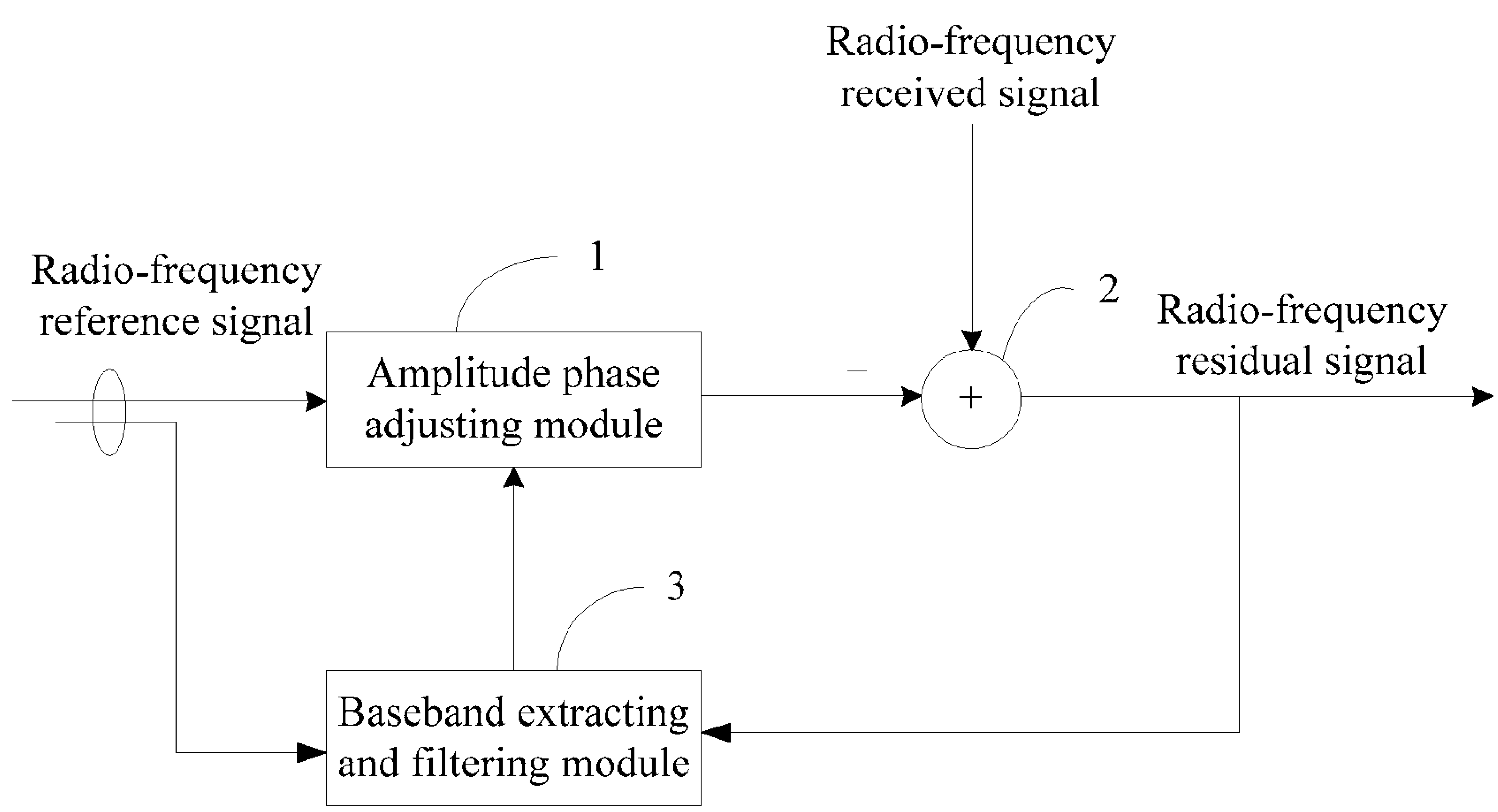
Radio-frequency received signal
1
2
Radio-frequency reference signal
Amplitude phase adjusting module
−
+
Radio-frequency residual signal
3
Baseband extracting and filtering module

FIG. 3

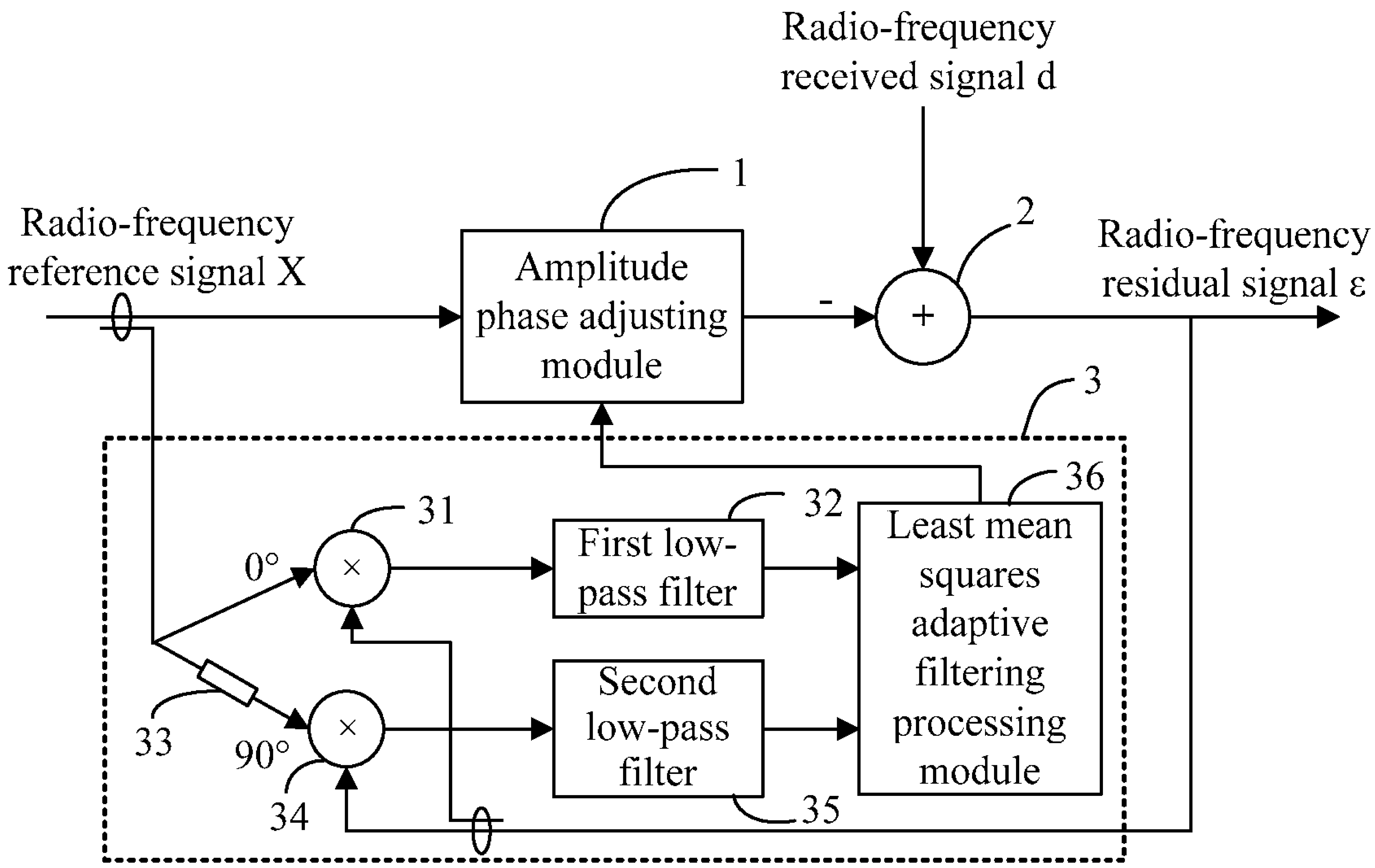
Radio-frequency received signal d
1
2
Radio-frequency reference signal X
Amplitude phase adjusting module
-
+
Radio-frequency residual signal ε
3
36
31
32
First low-pass filter
Least mean squares adaptive filtering processing module
0°
Second low-pass filter
33
90°
34
35

FIG. 4

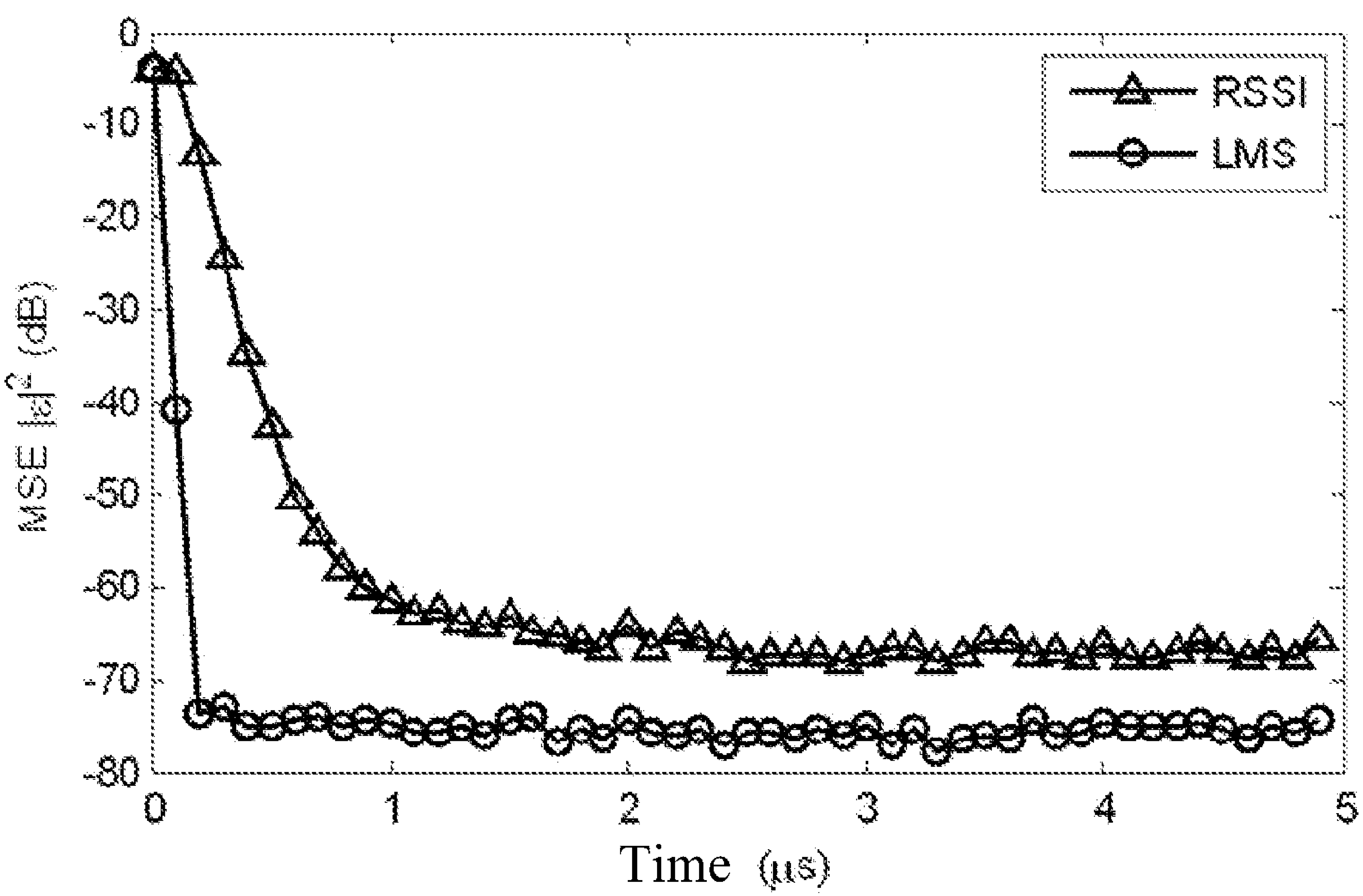
RSSI
LMS
MSE $|\varepsilon|^2$ (dB)
Time (μs)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
1
2
3
4
5

FIG. 5

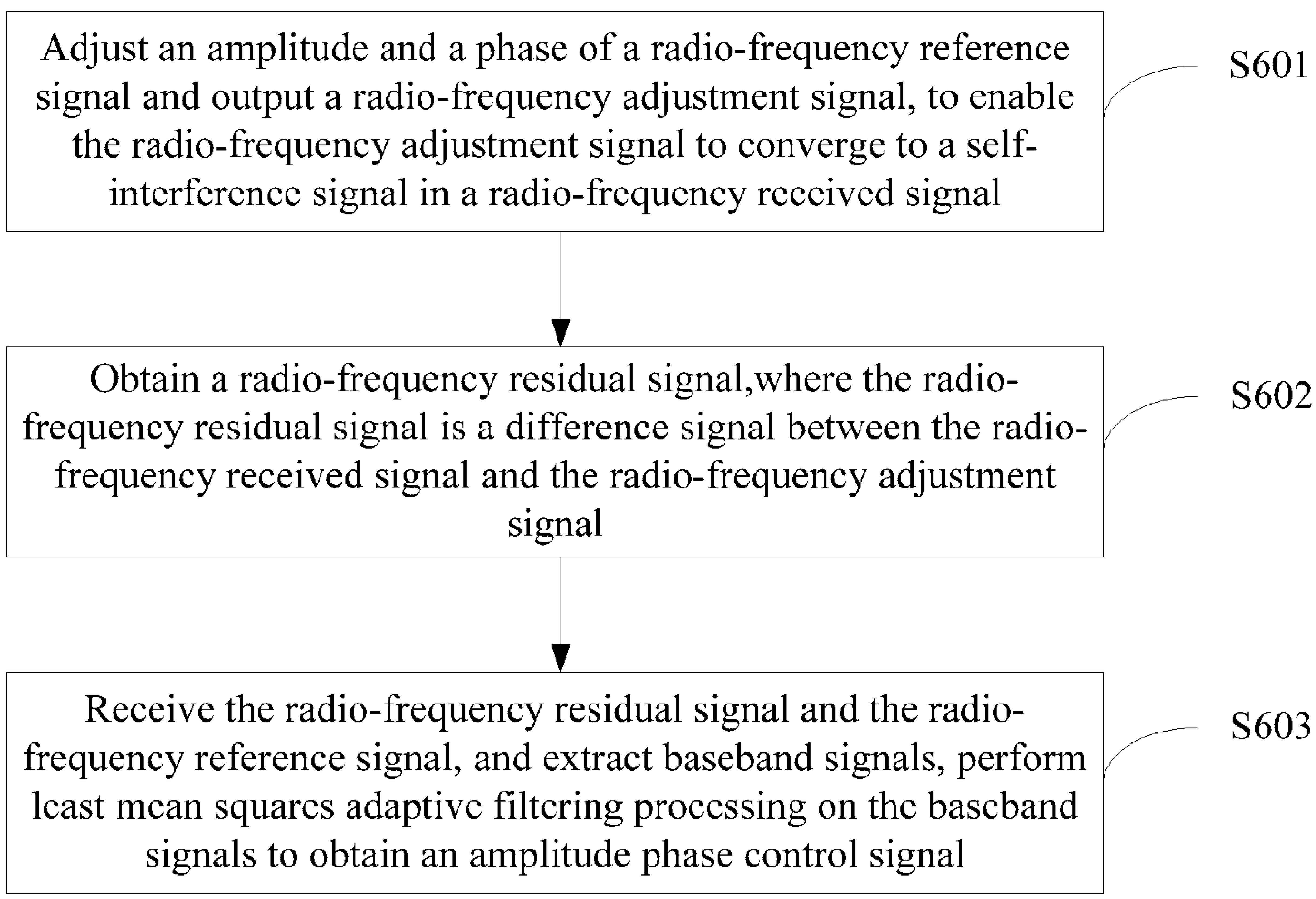
Adjust an amplitude and a phase of a radio-frequency reference signal and output a radio-frequency adjustment signal, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal
S601
Obtain a radio-frequency residual signal,where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal
S602
Receive the radio-frequency residual signal and the radio-frequency reference signal, and extract baseband signals, perform least mean squares adaptive filtering processing on the baseband signals to obtain an amplitude phase control signal
S603

FIG. 6

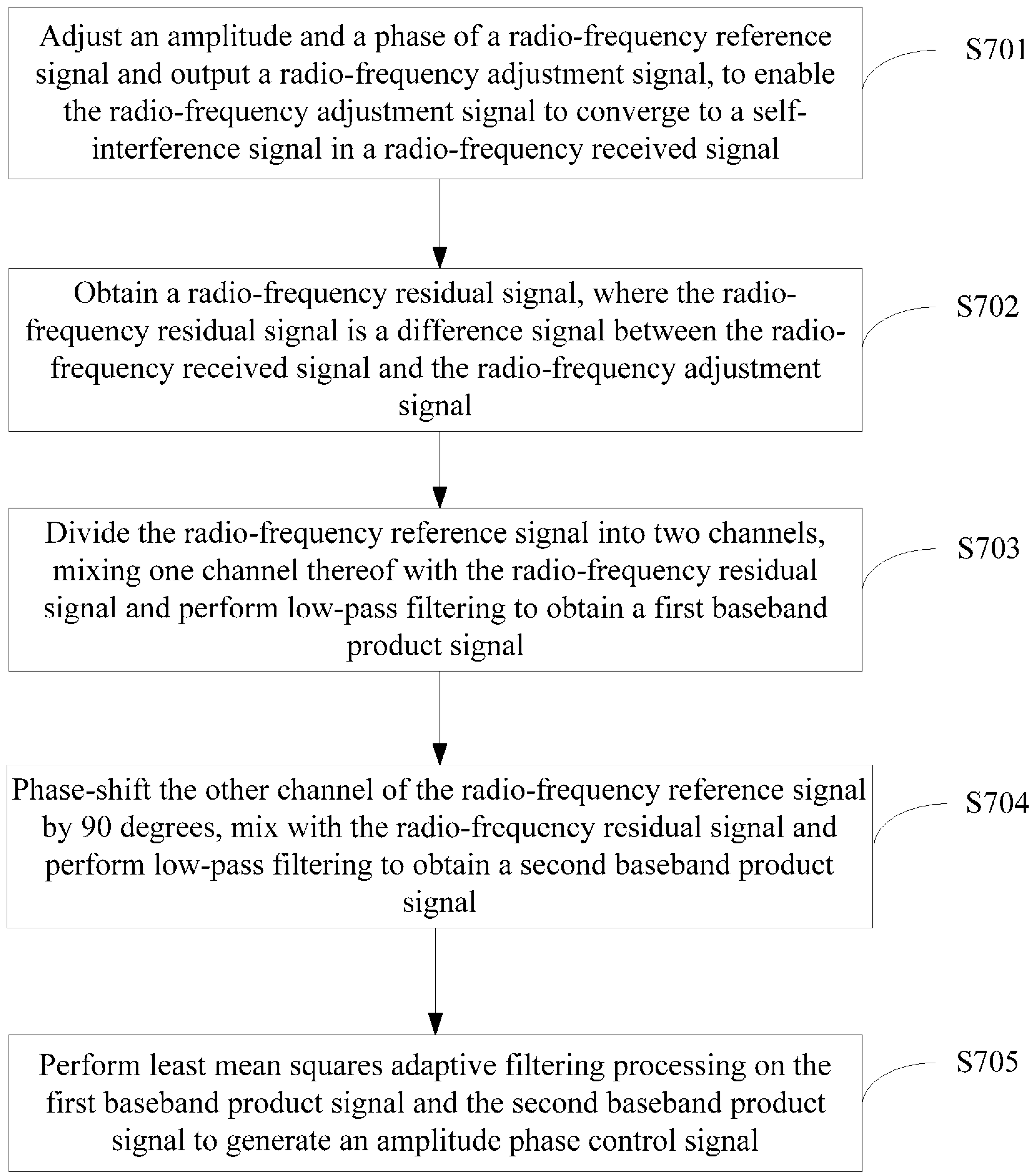
Adjust an amplitude and a phase of a radio-frequency reference signal and output a radio-frequency adjustment signal, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal
S701
Obtain a radio-frequency residual signal, where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal
S702
Divide the radio-frequency reference signal into two channels, mixing one channel thereof with the radio-frequency residual signal and perform low-pass filtering to obtain a first baseband product signal
S703
Phase-shift the other channel of the radio-frequency reference signal by 90 degrees, mix with the radio-frequency residual signal and perform low-pass filtering to obtain a second baseband product signal
S704
Perform least mean squares adaptive filtering processing on the first baseband product signal and the second baseband product signal to generate an amplitude phase control signal
S705

FIG. 7

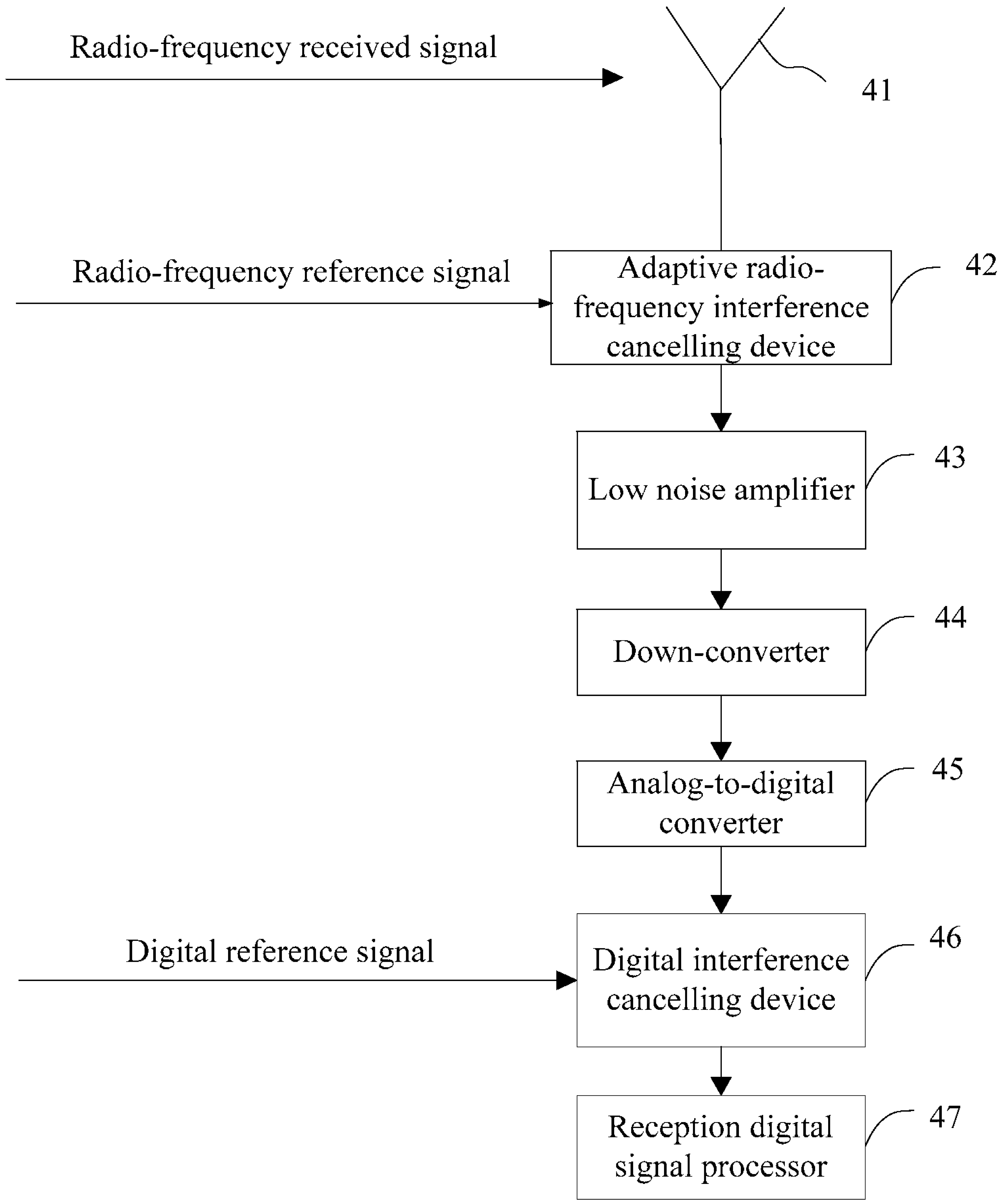
Radio-frequency received signal
41
Radio-frequency reference signal
Adaptive radio-frequency interference cancelling device
42
Low noise amplifier
43
Down-converter
44
Analog-to-digital converter
45
Digital reference signal
Digital interference cancelling device
46
Reception digital signal processor
47

FIG. 8

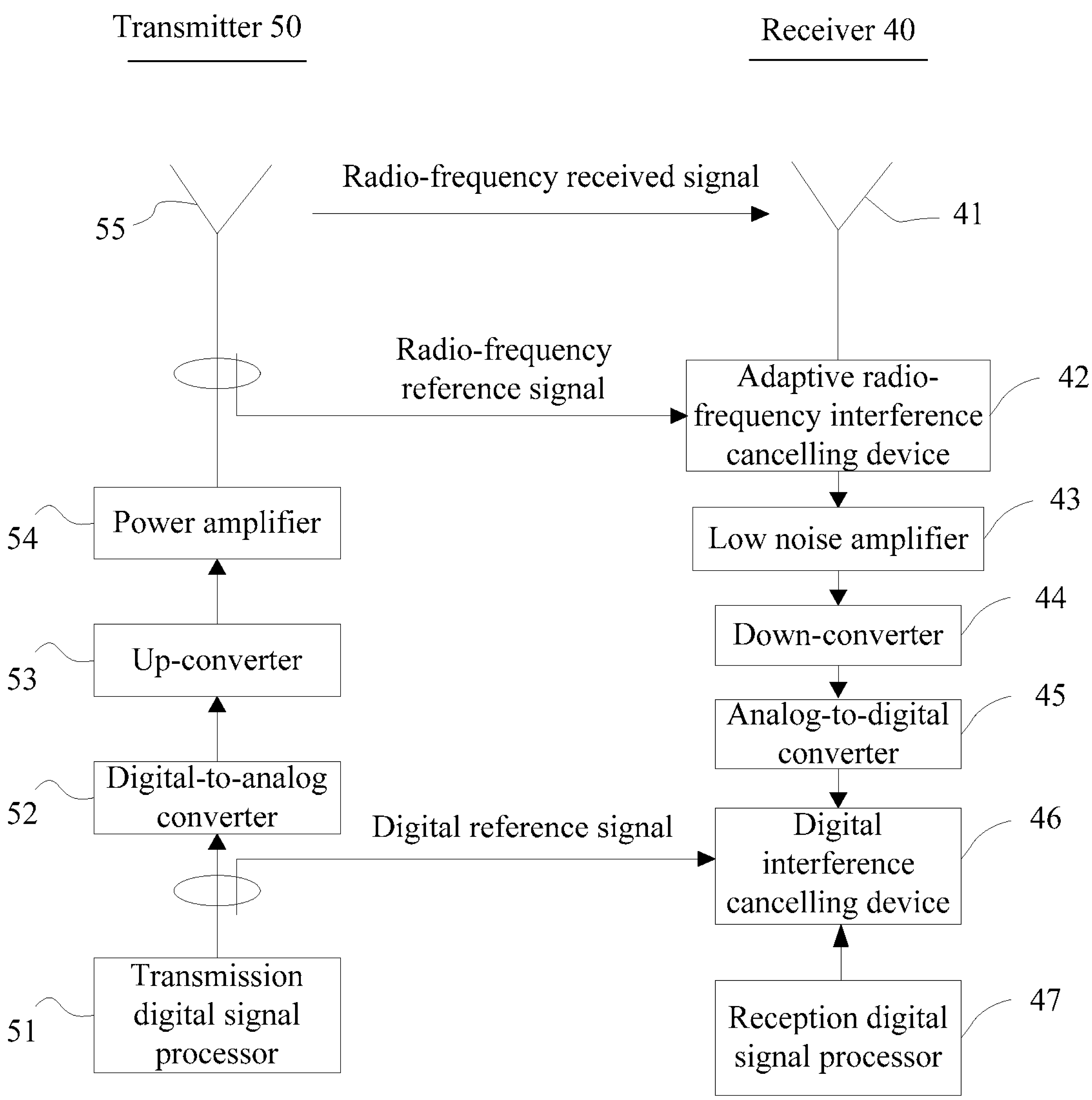
Transmitter 50
Receiver 40
Radio-frequency received signal
55
41
Radio-frequency reference signal
Adaptive radio-frequency interference cancelling device
42
Power amplifier
54
Low noise amplifier
43
Down-converter
44
Up-converter
53
Analog-to-digital converter
45
Digital-to-analog converter
52
Digital reference signal
Digital interference cancelling device
46
Transmission digital signal processor
51
Reception digital signal processor
47

FIG. 9

ADAPTIVE RADIO-FREQUENCY INTERFERENCE CANCELLING DEVICE, METHOD, AND RECEIVER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of International Patent Application No. PCT/CN2014/070181, filed on Jan. 6, 2014, which claims priority to Chinese Patent Application No. 201310002205.9, filed on Jan. 5, 2013, both of which are hereby incorporated by reference in their entireties.

TECHNICAL FIELD

The present invention relates to radio full duplex system technologies and, in particular, to an adaptive radio-frequency cancelling device and method, and a receiver.

BACKGROUND

In a wireless communication system, such as a mobile cellular communication system, a wireless local area network (Wireless Local Area Network, WLAN), and a fixed wireless access (Fixed Wireless Access, FWA) etc., a communication node, such as a base station (Base Station, BS) or an access point (Access Point, AP), a relay station (Relay Station, RS), and a user equipment (User Equipment, UE) etc. usually has capability of transmitting its own signals and receiving signals of other communicating nodes. Since a radio signal is attenuated greatly in a radio communication channel, and compared to the transmitted signals, signals received from a communication peer have become very weak when arriving at a receiving end. For example, power difference between transmitted and received signals of a communication node in the mobile cellular communication system is 80 dB-140 dB, or even greater. Therefore, in order to avoid interference of the transmitted signals to the received signal of the same transceiver, radio signals are usually transmitted and received on different frequencies or in different time periods. For example, in frequency division duplex (Frequency Division Duplex, FDD), transmission and reception are performed by using different frequency bands separated with a guard band. In time division duplex (Time Division Duplex, TDD), transmission and reception are performed by using different time periods separated with a guard interval. Where the guard band in FDD and the guard interval in TDD are both used for ensuring that the receiving and transmitting are fully isolated, to prevent the transmitting from interfering the receiving.

Different from the existing FDD or TDD technology, wireless full duplex technology can simultaneously perform receiving and transmitting on a same radio channel. Thus, in theory, frequency spectrum efficiency of wireless full duplex is double of FDD or TDD technology. Obviously, it is a precondition for realizing the wireless full duplex technology that strong interference (called self-interference, Self-interface) from a transmitted signal to a received signal of a same transceiver is avoided, decreased, or eliminated as much as possible, so that the self-interference doesn't affect correct reception of useful signals.

FIG. **1** shows a structure of an existing wireless full duplex communication system, including a transmitter and a receiver. The transmitter includes a transmission digital processor, a digital-to-analog converter, an up-converter, a power amplifier, and a transmitting antenna. The receiver includes a receiving antenna, a radio-frequency interference cancelling device, a low noise amplifier (Low Noise Amplifier, LNA), a down-converter, an analog-to-digital converter, a digital interference cancelling device, and a reception digital processor. Radio-frequency received signals received by the receiver includes self-interference signals and useful signals, and the power of the self-interference signals is much higher than that of the useful signals. Therefore, the self-interference signals need to be cancelled from the radio-frequency received signals, otherwise modules of the receiver front end, such as LNA etc, will be blocked. Hence, in the prior art, before the LNA, the radio-frequency interference cancelling device takes a radio-frequency signal, which is input after being amplified by the power amplifier of the transmitter, as a reference signal, estimates a channel parameter from a local transmitting antenna to a receiving antenna, such as amplitude and phase etc, and adjusts the reference signal to make it as close as possible to the self-interference signal consisted in the received signal, so as to cancel the local self-interference signal received by the receiving antenna in analog domain. Specifically, the radio-frequency interference cancelling device in the existing receiver performs corresponding adjustment of the radio-frequency reference signal, including amplitude and phase etc, mainly based on a received signal strength indicator (Received Signal Strength Indicator, RSSI) method, and then performs cancellation operation on the radio-frequency received signal. As shown in FIG. **2**, it shows a structure of an existing radio-frequency interference cancelling device based on RSSI detection, including an amplitude phase adjusting module, a subtractor, an RSSI detecting module, and an amplitude phase search processing module. The radio-frequency reference signal is adjusted by the amplitude phase adjusting module and then is cancelled from the radio-frequency received signal. After the cancellation, the radio-frequency residual signal is detected by the RSSI detection module. The amplitude phased search processing module processes a feedback RSSI detection result using an amplitude and phase search algorithm, generates an amplitude phase control signal, adjusts a search step size, and updates the amplitude and the phase for the next adjustment.

However, in the existing self-interference cancelling method based on RSSI detection, the RSSI detection module can only obtain an absolute value of the adjusted search step size, the amplitude phase search processing module further needs to search for an orientation for adjustment, to determine whether to increase or decrease the current amplitude and phase by the corresponding step size. Here, the orientations of the amplitude and the phase need to be simultaneously searched and determined. Therefore, this amplitude phase search algorithm converges slowly and is only applicable to a situation with few parameters to be adjusted, thus it cannot follow parameters variation in time due to low convergence speed, and estimation accuracy thereof is affected.

SUMMARY

In view of the above problems, an objective of the present invention is to provide an adaptive radio-interference cancelling device and method, a receiver and a wireless full duplex communication system, to solve the technology problems of slow convergence speed and inaccurate estimation on the amplitude and the phase of the self-interference signal relative to the radio-frequency reference signal, which exist in the existing self-interference cancellation search method based on RSSI detection.

In a first aspect, the adaptive radio-frequency interference cancelling device includes:

an amplitude phase adjusting module, configured to adjust an amplitude and a phase of a radio-frequency reference signal, output a radio-frequency adjustment signal to a subtractor, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal;

the subtractor, configured to receive the radio-frequency received signal and the radio-frequency adjustment signal output by the amplitude phase adjusting module (**1**), and output a radio-frequency residual signal, where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal; and

a baseband extracting and filtering module, configured to receive the radio-frequency reference signal and the radio-frequency residual signal output by the subtractor, and extract a baseband signal, perform least mean squares adaptive filtering processing on the baseband signal to obtain an amplitude phase control, and output to the amplitude phase adjusting module, where the amplitude phase control signal is used to control the amplitude phase adjusting module to adjust the amplitude and the phase of the radio-frequency reference signal.

In a first possible implementation manner of the first aspect, the baseband extracting and filtering module includes a first multiplier, a first low-pass filter, a phase shifter, a second multiplier, a second low-pass filter, and a least mean squares adaptive filtering processing module, the radio-frequency reference signal is split into two signals, of which one is mixed with the radio-frequency residual signal by the first multiplier and then passes through the first low-pass filter to obtain a first baseband product signal, and the other split radio-frequency reference signal is phase shifted by 90 degrees via the phase shifter, mixed with the radio-frequency residual signal by the second multiplier and filtered by the second low-pass filter to obtain a second baseband product signal, and the first baseband product signal and the second baseband product signal are input to the least mean squares adaptive filtering processing module to generate the amplitude phase control signal used to control the amplitude phase adjusting module.

According to the first possible implementation manner of the first aspect, in a second possible implementation manner, the amplitude phase control signal is a adjustment coefficient signal, and the amplitude phase adjusting module adjusts the amplitude and the phase of the radio-frequency reference signal according to the received adjustment coefficient signal.

In a second aspect, the adaptive radio-frequency interference cancelling method includes:

adjusting an amplitude and a phase of a radio-frequency reference signal and outputting a radio-frequency adjustment signal, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal;

obtaining a radio-frequency residual signal, where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal;

receiving the radio-frequency residual signal and the radio-frequency reference signal, extracting a baseband signal, and performing least mean squares adaptive filtering processing on the baseband signal to obtain an amplitude phase control signal, where the amplitude phase control signal is used to control adjustment of the amplitude and the phase of the radio-frequency reference signal.

In a first possible implementation manner of the second aspect, the receiving the radio-frequency residual signal and the radio-frequency reference signal, extracting a baseband signal, and performing least mean squares adaptive filtering processing on the baseband signal to obtain an amplitude phase control signal, includes:

splitting the radio-frequency reference signal into two signals, mixing one of the two split signals with the radio-frequency residual signal and then performing low-pass filtering, to obtain a first baseband product signal;

phase-shifting the other split radio-frequency reference signal by 90 degrees, mixing with the radio-frequency residual signal and performing low-pass filtering to obtain a second baseband product signal; and performing least mean squares adaptive filtering processing on the first baseband product signal and the second baseband product signal to generate the amplitude phase control signal, where the amplitude phase control signal is used to control the adjustment of the amplitude and the phase of the radio-frequency reference signal.

In a third aspect, the receiver includes a receiving antenna, a low noise amplifier, a down-converter, an analog-to-digital converter, a digital interference cancelling device and a reception digital signal processor, the receiver further includes an adaptive radio-frequency interference cancelling device, the receiving antenna, the adaptive radio-frequency interference cancelling device, the low noise amplifier, the down-converter, the analog-to-digital converter, the digital interference cancelling device and the reception digital signal processor are connected sequentially, the adaptive radio-frequency interference cancelling device is further input with a radio-frequency reference signal from a transmitter and the digital interference cancelling device is further input with a digital reference signal from the transmitter.

In a fourth aspect, the wireless full duplex communication system includes a transmitter and the aforesaid receiver, the transmitter includes a transmission digital signal processor, a digital-to-analog converter, an up-converter, a power amplifier and a transmitting antenna that are connected sequentially. a radio-frequency reference signal output by the power amplifier is input to the adaptive radio-frequency interference cancelling device of the receiver, and a digital reference signal output by the transmission digital signal processor is input to the digital interference cancelling device of the receiver.

The present invention adopts a radio-frequency interference cancellation solution based on least mean squares (Least mean squares, LMS) adaptive filtering algorithm. Since the LMS adaptive filtering algorithm is executed in radio-frequency analog domain, it cannot directly sample a high-frequency radio-frequency signal, so the algorithm can only be implemented in digital baseband generally. Therefore in the present invention, the baseband extracting and filtering module directly extracts baseband signals from the radio-frequency reference signal and the radio-frequency residual signal, estimates the amplitude and the phase of the self-interference signal relative to the reference signal using the LMS adaptive filtering algorithm to generate a amplitude phase control signal, so as to adjust the amplitude and the phase of the radio-frequency reference signal and make it converge to the self-reference signal in the radio-frequency received signal. Compared to the existing algorithm based on RSSI detection, the LMS adaptive filtering algorithm has a faster convergence speed and provides a more accurate estimated result.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a structural diagram of an existing wireless full duplex communication system;

FIG. **2** is a structural diagram of an existing radio-frequency interference cancelling device based on RSSI detection;

FIG. **3** is a structural diagram of an adaptive radio-frequency interference cancelling device according to a first embodiment of the present invention;

FIG. **4** is a structural diagram of an adaptive radio-frequency interference cancelling device according to a second embodiment of the present invention;

FIG. **5** is an MSE performance comparing diagram of an LMS adaptive filtering algorithm and an amplitude phase search algorithm based on RSSI detection;

FIG. **6** is a flow diagram of an adaptive radio-frequency interference cancelling method according to a third embodiment of the present invention;

FIG. **7** is a flow diagram of an adaptive radio-frequency interference cancelling method according to a fourth embodiment of the present invention;

FIG. **8** is a structural diagram of a receiver according to a fifth embodiment of the present invention;

FIG. **9** is a structural diagram of a wireless full duplex communication system according to a sixth embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

In order to make the purposes, technical solutions, and advantages of the present invention more clearly, the present invention is further described in detail with reference to the accompanying drawings and embodiments. It should be understood that, the embodiments described herein are merely used to explain the invention, but not intended to limit the invention.

The technical solutions of the present invention are described via the following embodiments.

First Embodiment

FIG. **3** shows a structure of an adaptive radio-frequency interference cancelling device according to a first embodiment of the present invention. Only parts related to the embodiment of the invention are shown for convenience of explanation.

The adaptive radio-frequency interference cancelling device according to this embodiment includes:

an amplitude phase adjusting module **1**, configured to adjust an amplitude and a phase of a radio-frequency reference signal, output a radio-frequency adjustment signal to a subtractor **2**, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal;

the subtractor **2**, configured to receive the radio-frequency received signal and the radio-frequency adjustment signal output by the amplitude phase adjusting module **1**, and output a radio-frequency residual signal, where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal; and

a baseband extracting and filtering module **3**, configured to receive the radio-frequency reference signal and the radio-frequency residual signal output by the subtractor **2**, and extract baseband signals, perform least mean squares adaptive filtering processing on the baseband signals to obtain an amplitude phase control signal and output to the amplitude phase adjusting module **1**, where the amplitude phase control signal is used to control the amplitude phase adjusting module **1** to adjust the amplitude and the phase of the radio-frequency reference signal.

In order to apply an LMS adaptive filtering algorithm to this embodiment, since the LMS adaptive filtering algorithm cannot directly sample a high frequency radio-frequency signal, in the present embodiment, the baseband extracting and filtering module **3** extracts base signals from the radio-frequency reference signal and radio-frequency residual signal, and processes the baseband signals using the LMS adaptive filtering algorithm to obtain the amplitude phase control signal, and then, controls the amplitude phase control module **1** according to the amplitude phase control signal to complement gradual adjustment of the amplitude and the phase of the radio-frequency reference signal, to enable the radio-frequency reference signal to converge to the self-interference signal in the radio-frequency received signal through continuous iteration control. Compared to the existing algorithm based on RSSI detection, the LMS adaptive filtering algorithm has a faster convergence speed and provides a more accurate estimation result.

Second Embodiment

FIG. **4** shows a structure of an adaptive radio-frequency interference cancelling device according to a second embodiment of the present invention. Only parts related to this embodiment of the present invention are shown for convenience of explanation.

The adaptive radio-frequency interference cancelling device provided by this embodiment includes an amplitude phase adjusting module **1**, a subtractor **2**, and a baseband extracting and filtering module **3** as described in the first embodiment. As shown in FIG. **4**, the baseband extracting and filtering module **3** includes a first multiplier **31**, a first low-pass filter **32**, a phase shifter **33**, a second multiplier **34**, a second low-pass filter **35** and a least mean squares adaptive filtering processing module **36**. The radio-frequency reference signal is split into two signals, of which one is mixed with the radio-frequency residual signal by the first multiplier **31** and then passes through the first low-pass filter **32** to obtain a first baseband product signal, while the other split radio-frequency reference signal is phase-shifted by 90 degrees via the phase shifter **33**, and then is mixed with the radio-frequency residual signal by the second multiplier **34** and is filtered by the second low-pass filter **35** to obtain a second baseband product signal. The first baseband product signal and the second baseband product signal are input to the least mean squares adaptive filtering processing module **36** to generate an amplitude phase control signal used to control the amplitude phase adjusting module **1**.

This embodiment discloses a preferred structure of the baseband extracting and filtering module **3** based on the first embodiment. In this embodiment, adjustment of the amplitude and the phase is based on the products of the radio-frequency reference signal X and the radio-frequency residual signal ϵ. Specifically, the radio-frequency reference signal X is split into two signals, one of which is phase-shifted by 90 degrees. The two split signals of the radio-frequency reference signal are mixed with the radio-frequency residual signal c and pass through the low-pass filters to obtain the baseband products of the two signals. And then, the amplitude and the phase of the self-interference signal relative to the reference signal, i.e. adjustment coefficient W of the amplitude and the phase, are estimated using the LMS adaptive filtering algorithm, to complete corresponding adjustment of the amplitude and the phase of the radio-frequency reference signal X. The adjusted radio-frequency signal is cancelled from the radio-frequency received signal d again to obtain a new radio-frequency residual signal c.

In the aforementioned technical solution, assuming that the K-th iteration is prepared to be performed, that is, being at the K-th sampling moment, here a radio-frequency reference signal vector is represented by X^k, namely

$$X^k=[I_{ref}\cos(\omega t)+Q_{ref}\sin(\omega t),\ -I_{ref}\sin(\omega t)+Q_{ref}\cos(\omega t)]^T, \tag{1}$$

where I_{ref} and Q_{ref} represent baseband in-phase/quadrature signal (i.e. I/Q signal) respectively, $\int$ is carrier frequency, T represents matrix transposition, $I_{ref}\cos(\omega t)+Q_{ref}\sin(\omega t)$ is an original signal of the radio-frequency reference signal, $-I_{ref}\sin(\omega t)+Q_{ref}\cos(\omega t)$ is the radio-frequency reference signal phase-shifted by 90 degrees.

The radio-frequency received signal d^k can be expressed as

$$\begin{aligned} d^k &= aI_{ref}\cos(\omega t+\varphi)+aQ_{ref}\sin(\omega t+\varphi)+n(t) \\ &= a\cos(\varphi)[I_{ref}\cos(\omega t)+Q_{ref}\sin(\omega t)]+ \\ &\quad a\sin(\varphi)[-I_{ref}\sin(\omega t)+Q_{ref}\cos(\omega t)]+n(t), \end{aligned} \tag{2}$$

where a and ϕ respectively represent amplitude and phase variations of the radio-frequency received signal, and n(t) is white noise.

In this embodiment, it is assumed that a filter coefficient of the least mean squares adaptive filtering processing module **36** is

$$W^k=[\hat{a}^k\cos(\hat{\phi}^k),\ \hat{a}\sin(\hat{\phi}^k)]^T \tag{3}$$

where, $\hat{a}^k$ and $\hat{\phi}^k$ represent estimation values of the amplitude a and the phase ϕ at the K-th sampling moment respectively. According to the formulas (1), (2) and (3), it can be known that the radio-frequency residual signal

$$\begin{aligned} \varepsilon^k &= d^k-(W^k)^TX^k \\ &= \left[a\cos(\varphi)-\hat{a}^k\cos(\hat{\varphi}^k)\right][I_{ref}\cos(\omega t)+Q_{ref}\sin(\omega t)]+ \\ &\quad \left[a\sin(\varphi)-\hat{a}^k\sin(\hat{\varphi}^k)\right][-I_{ref}\sin(\omega t)+Q_{ref}\cos(\omega t)]+n(t) \\ &= e_1[I_{ref}\cos(\omega t)+Q_{ref}\sin(\omega t)]+e_2[-I_{ref}\sin(\omega t)+ \\ &\quad Q_{ref}\cos(\omega t)]+n(t), \end{aligned}$$

where $e_1=a\cos(\omega)-\hat{a}^k\cos(\hat{\phi}^k)$, $e_2=a\sin(\phi)-\hat{a}^k\sin(\hat{\phi}^k)$.

The radio-frequency residual signal ϵ^k and the radio-frequency reference signal X^k are mixed, it can be noticed that, besides the baseband signal, the product does not contain any terms at fundamental frequency ω, but only contains second harmonic terms at frequency 2ω. Therefore a signal corresponding to the product item is low-pass filtered to obtain the baseband signal.

$$\{\epsilon^kX^k\}_{LPF}=[P_{ref}e_1/2,\ P_{ref}e_2/2]^T \tag{4}$$

where $P_{ref}=I_{ref}^2Q_{ref}^2$. Based on the LMS adaptive filtering algorithm, the coefficient of the (k+1)-th iteration, can be obtained via the coefficient of the k-th iteration and the baseband signal $\{\epsilon^kX^k\}$: $W^{k+1}=W^k+\mu\{\epsilon^kX^k\}_{LPF}$, where μ is a step size parameter of the LMS adaptive filtering algorithm. Substituting into formula (4), it is finally obtained that

$$W^{k+1}=W^k+\mu P_{ref}[e_1,\ e_2]^T/2.$$

It can be seen that, W^{k+1} is linear iteration of W^k. With $\hat{a}^k$ and $\hat{\phi}^k$ of W^k approaching a and ϕ, the vector $[e_1, e_2]^T$ in the iteration expression of W^{k+1} will decreases gradually, and W^{k+1} will converge to W^k. So, through selecting a proper μ, the amplitude adjustment a and the phase adjustment ϕ of the self-interference signal relative to the reference signal can be estimated, and the filtering coefficient for the least mean squares adaptive filtering processing module can be adjusted accordingly, so as to achieve the objective of adjusting the reference signal to minimize ϵ^k.

In order to see an advantage of the LMS adaptive filtering algorithm relative to the amplitude phase search algorithm based on RSSI detection, refer to FIG. **5** which shows MSE (Mean Squared Error) performance comparison of the two algorithms. In this figure, a noise-to-signal ratio SNR=85 db, μ is selected as 0.6, and 12-bit quantization is performed to the filtering coefficient of the least mean squares adaptive filtering processing module. It can be seen from FIG. **5** that, relative to the amplitude phase search algorithm based on RSSI detection, the LMS adaptive filtering algorithm adopted by the least mean squares adaptive filtering processing module of this embodiment has a faster convergence speed and provides a more accurate estimation result.

Compared with the first embodiment, this embodiment provides a specific baseband extracting manner. Although the baseband signal is known at the transmitter side, considering that a non-linear factor of a power amplifier of the transmitter will influence an effect of self-interference elimination, therefore in simulating interference elimination, an amplified radio-frequency signal is usually used as a reference signal, i.e. the radio-frequency reference signal in this embodiment. Usually, in order to obtain a baseband signal, down conversion needs to be performed to the radio-frequency residual signal and the radio-frequency reference signal respectively, but in such method a local oscillator signal needs to be generated, which is complicated to implement, and moreover, may introduce non-linear factors, such as I/Q imbalance, and affect the converge speed of the algorithm and the accuracy of estimation. However, in this embodiment, down conversion needs not to be performed, the radio-frequency reference signal is directly split into two signals, one of which is phase-shifted by 90 degrees, and then the two split radio-frequency reference signals are mixed with the radio-frequency residual signal and then low-pass filtered to filter out all harmonic components, so as to obtain the baseband signals. Therefore, during iteration, the least mean squares adaptive filtering processing module can operate in the baseband, which facilitates digital computation and control and realizes a purpose of controlling convergence of the radio-frequency reference signal. Since down conversion needs not to be performed in this embodiment, implementation complexity is reduced, and an influence of the non-linear factors, such as I/Q imbalance, to the algorithm is avoided.

Third Embodiment

FIG. **6** shows a flow of an adaptive radio-frequency interference cancelling method according to a third embodiment of the present invention. Only parts related to the embodiment of the present invention are shown for convenience of explanation.

The adaptive radio-frequency interference cancelling method provided by the present embodiment includes:

Step **S601**: Adjust an amplitude and a phase of a radio-frequency reference signal and output a radio-frequency adjustment signal, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal.

Step **S602**: Obtain a radio-frequency residual signal, where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal.

Step **S603**: Receive the radio-frequency residual signal and the radio-frequency reference signal, and extract baseband signals, perform least mean squares adaptive filtering processing on the baseband signals to obtain an amplitude phase control signal, where the amplitude phase control signal is used to control adjustment of the amplitude and the phase of the radio-frequency reference signal.

Steps **S601-S603** of this embodiment are correspondingly implemented by the amplitude phase adjusting module **1**, the subtractor **2**, and the baseband extracting and filtering module **3**. In the method of this embodiment, a feedback loop is formed; in step **S603**, the baseband signals are extracted from the radio-frequency residual signal and the radio-frequency reference signal, and the amplitude phase control signal is obtained according to the LMS adaptive filtering algorithm to control and adjust the amplitude and the phase of the radio-frequency reference signal described in step **S601**, and then the next iteration is performed until the radio-frequency reference signal converges to the self-interference signal of the radio-frequency received signal. Compared to the existing algorithm based on RSSI detection, the LMS adaptive filtering algorithm of this embodiment has a faster convergence speed and provides a more accurate estimation result.

Fourth Embodiment

FIG. **7** shows a flow of an adaptive radio-frequency interference cancelling method according to a fourth embodiment of the present invention. Only parts related to the embodiment of the invention are shown for convenience of explanation.

The adaptive radio-frequency interference cancelling method provided by this embodiment includes:

Step **S701**: Adjust an amplitude and a phase of a radio-frequency reference signal and output a radio-frequency adjustment signal, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal.

Step **S702**: Obtain a radio-frequency residual signal, where the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal.

Step **S703**: Split the radio-frequency reference signal into two signals, mix one of the two split signals with the radio-frequency residual signal and perform low-pass filtering to obtain a first baseband product signal.

Step **S704**: Phase-shift the other split radio-frequency reference signal by 90 degrees, mix with the radio-frequency residual signal and perform low-pass filtering to obtain a second baseband product signal.

Step **S705**: Perform least mean squares adaptive filtering processing on the first baseband product signal and the second baseband product signal to generate an amplitude phase control signal, where the amplitude phase control signal is used to control adjustment of the amplitude and the phase of the radio-frequency reference signal.

The steps **S703-S705** above are detailed and preferred steps of step **S603** in the third embodiment. In this embodiment, adjustment of the amplitude and the phase is based on the products of the radio-frequency reference signal X and the radio-frequency residual signal ϵ. In detail, the radio-frequency reference signal is split into two signals, one of which is phase-shifted by 90 degrees, the two split radio-frequency reference signals are then mixed with the radio-frequency residual signal and pass through low-pass filters to obtain the baseband products of the two signals. Then, the amplitude and the phase of the self-interference signal relative to the reference signal, i.e. adjustment coefficient of the amplitude and the phase, are estimated using the LMS adaptive filtering algorithm to complete corresponding adjustment of the amplitude and the phase of the radio-frequency reference signal X. The adjusted radio-frequency signal is cancelled from the radio-frequency received signal again and a new radio-frequency residual signal is obtained to perform the next iteration.

Usually, in order to obtain a baseband signal, down conversion needs to be performed on the radio-frequency residual signal and the radio-frequency reference signal respectively, but in such method a local oscillator signal needs to be generated, which is complicated to implement and moreover, may introduce non-linear factors, such as I/Q imbalance, and affect the convergence speed of the algorithm and accuracy of estimation. However, in this embodiment, down conversion needs not to be performed, the radio-frequency reference signal is directly split into two signals, one of which is phase-shifted by 90 degrees, and then the two split radio-frequency reference signals are mixed with the radio-frequency residual signal and then low-pass filtered to filter out all harmonic components, to obtain the baseband signals. Therefore, during iteration, the least mean squares adaptive filtering processing module can operate in the baseband, which facilitates digital computation and control and realizes a purpose of controlling convergence of the radio-frequency reference signal. Since down conversion needs not to be performed in this embodiment, implementation complexity is reduced, and an influence of the non-linear factors, such as I/Q imbalance, to the algorithm is avoided.

Fifth Embodiment

FIG. **8** shows a structure of a receiver according to a fifth embodiment of the invention. Only parts related to the embodiment of the present invention are shown for convenience of explanation.

The receiver according to this embodiment includes a receiving antenna **41**, a low noise amplifier **43**, a down-converter **44**, an analog-to-digital converter **45**, a digital interference cancelling device **46**, a reception digital signal processor **47**, and an adaptive radio-frequency interference cancelling device **42** according to the first embodiment or the second embodiment. The receiving antenna **41**, the adaptive radio-frequency interference cancelling device **42**, the low noise amplifier **43**, the down-converter **44**, the analog-to-digital converter **45**, the digital interference cancelling device **46**, and the reception digital signal processor **47** are connected sequentially. The adaptive radio-frequency interference cancelling device **42** is further input with a radio-frequency reference signal from a transmitter, and the digital interference cancelling device **46** is further input with a digital reference signal from the transmitter.

The radio-frequency received signal received by the receiver of the embodiment includes a self-interference signal and a useful signal. The adaptive radio-frequency interference cancelling device **42** of the embodiment achieves adjustment of an amplitude and a phase of the radio-frequency reference signal using an LMS adaptive filtering algorithm to enable the radio-frequency reference signal to converge to the self-interference signal in the radio-frequency received signal. Therefore, after converging, the signal output by the adaptive radio-frequency interference cancelling device **42** is the useful signal, thus self-interference elimination is achieved. Compared to an existing receiver, the adaptive radio-frequency interference cancelling device **42** in this embodiment adopts the LMS adaptive filtering algorithm, which has a faster convergence speed and provides a more accurate estimation result compared to the amplitude phase search algorithm based on RSSI detection adopted by an existing radio-frequency interference cancelling device.

Sixth Embodiment

FIG. **9** shows a structure of a wireless full duplex communication system according to a sixth embodiment of the invention. Only parts related to the present embodiment of the present invention are shown for convenience of explanation.

The wireless full duplex communication system according to the present embodiment includes a transmitter **50** and a receiver **40** according to the fifth embodiment. The transmitter includes a transmission digital signal processor **51**, a digital-to-analog converter **52**, an up-converter **53**, a power amplifier **54** and a transmitting antenna **55** which are connected sequentially. A radio-frequency reference signal output by the power amplifier **54** is input to the adaptive radio-frequency interference cancelling device **42** of the receiver, and a digital reference signal output by the transmission digital signal processor **51** is input to the digital interference cancelling device **46** of the receiver.

The wireless full duplex communication system of this embodiment is composed of the transmitter **50** and the receiver **40**. The adaptive radio-frequency interference cancelling device **42** in the receiver **40** adopts the LMS adaptive filtering algorithm, while a radio-frequency interference cancelling module in an existing receiver adopts the amplitude phase search algorithm based on RSSI detection. The receiver of this embodiment has a faster convergence speed and provides a more accurate estimation result.

Persons of ordinary skill in the art may understand that, all or a part of the steps of the method in the foregoing embodiments may be implemented by a program instructing relevant hardware. The foregoing program may be stored in a computer readable storage medium, such as a ROM/RAM, a magnetic disk, an optical disc etc.

The foregoing embodiments are merely some preferable embodiments of the present invention, but not intended to limit the present invention. Any modifications, equivalent replacements, and improvements made according to the spirit and scope of the present invention should fall within the protection scope of the present invention.

What is claimed is:

1. An adaptive radio-frequency interference cancelling device, comprising:

an amplitude phase adjusting module, configured to adjust an amplitude and a phase of a radio-frequency reference signal, output a radio-frequency adjustment signal to a subtractor, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal;

the subtractor, configured to receive the radio-frequency received signal and the radio-frequency adjustment signal output by the amplitude phase adjusting module, and output a radio-frequency residual signal, wherein the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal; and

a baseband extracting and filtering module, configured to receive the radio-frequency reference signal and the radio-frequency residual signal output by the subtractor, extract baseband signals and perform least mean squares adaptive filtering processing on the baseband signals to obtain an amplitude phase control signal and output to the amplitude phase adjusting module, wherein the amplitude phase control signal is used to control the amplitude phase adjusting module to adjust the amplitude and the phase of the radio-frequency reference signal.

2. The device according to claim **1**, wherein the baseband extracting and filtering module comprises a first multiplier, a first low-pass filter, a phase shifter, a second multiplier, a second low-pass filter, and a least mean squares adaptive filtering processing module, the radio-frequency reference signal is split into two signals, of which one is mixed with the radio-frequency residual signal by the first multiplier and passes through the first low-pass filter to obtain a first baseband product signal, and the other split radio-frequency reference signal is phase-shifted by 90 degrees via the phase shifter, then mixed with the radio-frequency residual signal by the second multiplier and filtered by the second low-pass filter to obtain a second baseband product signal, and the first baseband product signal and the second baseband product signal are input to the least mean squares adaptive filtering processing module to generate the amplitude phase control signal used to control the amplitude phase adjusting module.

3. The device according to claim **2**, wherein the amplitude phase control signal is an adjustment coefficient signal, and the amplitude phase adjusting module adjusts the amplitude and the phase of the radio-frequency reference signal according to the received adjustment coefficient signal.

4. A receiver, comprising a receiving antenna, a low noise amplifier, a down-converter, an analog-to-digital converter, a digital interference cancelling device, and a reception digital signal processor, wherein the receiver further comprises an adaptive radio-frequency interference cancelling device according to claim **1**, the receiving antenna, the adaptive radio-frequency interference cancelling device, the low noise amplifier, the down-converter, the analog-to-digital converter, the digital interference cancelling device, and the reception digital signal processor are connected sequentially, and the adaptive radio-frequency interference cancelling device is further input with a radio-frequency reference signal from a transmitter and the digital interference cancelling device is further input with a digital reference signal from the transmitter.

5. A wireless full duplex communication system, comprising a transmitter, wherein the transmitter comprises a transmission digital signal processor, a digital-to-analog converter, an up-converter, a power amplifier and a transmitting antenna that are connected sequentially, wherein the system further comprises a receiver according to claim **4**, a radio-frequency reference signal output by the power amplifier is input to an adaptive radio-frequency interference cancelling device of the receiver, a digital reference signal output by the transmission digital signal processor is input to a digital interference cancelling device of the receiver.

6. An adaptive radio-frequency interference cancelling method, comprising:

adjusting an amplitude and a phase of a radio-frequency reference signal and outputting a radio-frequency adjustment signal, to enable the radio-frequency adjustment signal to converge to a self-interference signal in a radio-frequency received signal;

obtaining a radio-frequency residual signal, wherein the radio-frequency residual signal is a difference signal between the radio-frequency received signal and the radio-frequency adjustment signal; and receiving the radio-frequency residual signal and the radio-frequency reference signal, extracting baseband signals, and performing least mean squares adaptive filtering processing on the baseband signals to obtain an amplitude phase control signal, wherein the amplitude phase control signal is used to control adjustment of the amplitude and the phase of the radio-frequency reference signal.

7. The method according to claim **6**, wherein the receiving the radio-frequency residual signal and the radio-frequency reference signal, extracting baseband signals, and performing least mean squares adaptive filtering processing on the baseband signals to obtain an amplitude phase control signal, specifically comprises:

splitting the radio-frequency reference signal into two signals, mixing one of the two split signals with the radio-frequency residual signal and performing low-pass filtering to obtain a first baseband product signal;

phase-shifting the other split radio-frequency reference signal by 90 degrees, mixing with the radio-frequency residual signal and performing low-pass filtering to obtain a second baseband product signal; and

performing least mean squares adaptive filtering processing on the first baseband product signal and the second baseband product signal to generate the amplitude phase control signal, wherein the amplitude phase control signal is used to control the adjustment of the amplitude and the phase of the radio-frequency reference signal.

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