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**Gudem et al.**

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(54) **GLOBAL NAVIGATION SATELLITE SYSTEM RECEIVER WITH FILTER BYPASS MODE FOR IMPROVED SENSITIVITY**

6,809,775 B2 10/2004 Yule  
6,987,950 B2 1/2006 Coan  
6,999,027 B1 \* 2/2006 Stockmaster ..... 342/357.29  
7,444,166 B2 \* 10/2008 Sahota ..... H04B 7/0802  
455/140

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(Continued)

**FOREIGN PATENT DOCUMENTS**

CN 1681216 A 10/2005  
CN 101228458 A 7/2008

(Continued)

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**OTHER PUBLICATIONS**

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Myung-Woon Hwang et al., "A High IIP2 Direct-Conversion Receiver Using Even-Harmonic Reduction Technique for Cellular CDMA/PCS/GPS Applications," Circuits and Systems I: Regular Papers, IEEE Transactions on vol. 55 , Issue: 9; Publication Year: 2008 , pp. 2934-2943.

(Continued)

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**H04B 1/525** (2015.01)

(57) **ABSTRACT**

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A global navigation satellite system receiver with filter bypass mode for improved sensitivity is disclosed. In an aspect, an apparatus is provided that includes a non-bypass signal path coupled to a receiver, the non-bypass signal path comprising a filter. The apparatus also includes a bypass signal path coupled to the receiver, the bypass signal path configure to bypass the filter, and a switch to couple an antenna to the non-bypass signal path during time intervals when signals transmitted by an unrelated local transmitter are transmitted with a signal power that exceeds a selected threshold, and to couple the antenna to the bypass signal path during other time intervals.

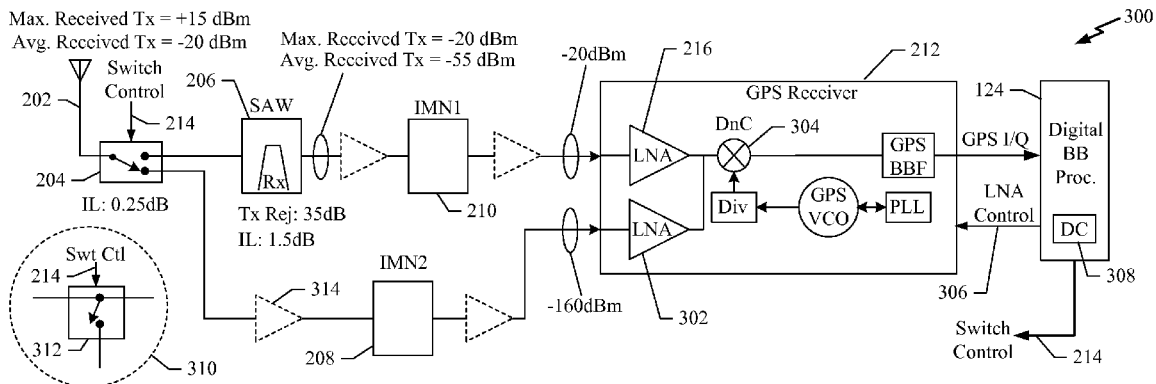
(58) **Field of Classification Search**  
CPC .... H04B 1/1027; H04B 1/1036; H04B 1/109; H04B 1/3805; H04B 1/525; H04B 15/02; H04W 88/06; G01S 19/21; G01S 19/36  
USPC ..... 375/346, 349  
See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

6,442,375 B1 \* 8/2002 Parmentier ..... 455/78  
6,630,862 B1 \* 10/2003 Perthold et al. .... 330/149

**16 Claims, 6 Drawing Sheets**



(56)

References Cited

U.S. PATENT DOCUMENTS

8,270,927 B2 9/2012 Wallace et al.  
 2003/0222709 A1\* 12/2003 Kim ..... H03F 1/0277  
 330/51  
 2004/0005871 A1\* 1/2004 Saito et al. .... 455/287  
 2004/0008094 A1\* 1/2004 Niemi ..... 333/101  
 2004/0018824 A1 1/2004 Fang  
 2005/0215204 A1\* 9/2005 Wallace et al. .... 455/78  
 2006/0055594 A1\* 3/2006 McConnell et al. .... 342/357.1  
 2006/0109939 A1\* 5/2006 Ciccarelli et al. .... 375/350  
 2006/0178122 A1\* 8/2006 Srinivasan et al. .... 455/168.1  
 2007/0008215 A1\* 1/2007 Smith et al. .... 342/357.02  
 2007/0142013 A1 6/2007 Bucknor et al.  
 2008/0175340 A1\* 7/2008 Landmark ..... 375/350  
 2008/0231512 A1\* 9/2008 Yeshayahu ..... 342/417  
 2009/0298455 A1\* 12/2009 Takeuchi ..... H03F 1/22  
 455/296  
 2009/0318087 A1\* 12/2009 Mattila et al. .... 455/63.1  
 2009/0323779 A1 12/2009 Lennen  
 2010/0019970 A1 1/2010 Farrokhi et al.  
 2010/0026547 A1\* 2/2010 Weissman ..... H04B 1/109  
 342/16

2010/0303162 A1\* 12/2010 Wang et al. .... 375/260  
 2012/0195237 A1 8/2012 Chan et al.  
 2013/0003617 A1 1/2013 Gudem et al.  
 2013/0065542 A1\* 3/2013 Proudki ..... H03H 11/1291  
 455/78

FOREIGN PATENT DOCUMENTS

EP 1916767 12/2010  
 JP 2006074313 A 3/2006  
 JP 2006261998 A 9/2006  
 JP 2010177954 A 8/2010  
 WO 0106669 A1 1/2001  
 WO WO-2006055791 A1 5/2006

OTHER PUBLICATIONS

Winternitz, L.M.B. et al; "A GPS Receiver for High-Altitude Satellite Navigation," Selected Topics in Signal Processing, IEEE Journal of; vol. 3 , Issue: 4; Publication Year: 2009 , pp. 541-556.  
 International Search Report and Written Opinion—PCT/US2012/045126—ISA/EPO—dated Oct. 22, 2012.

\* cited by examiner

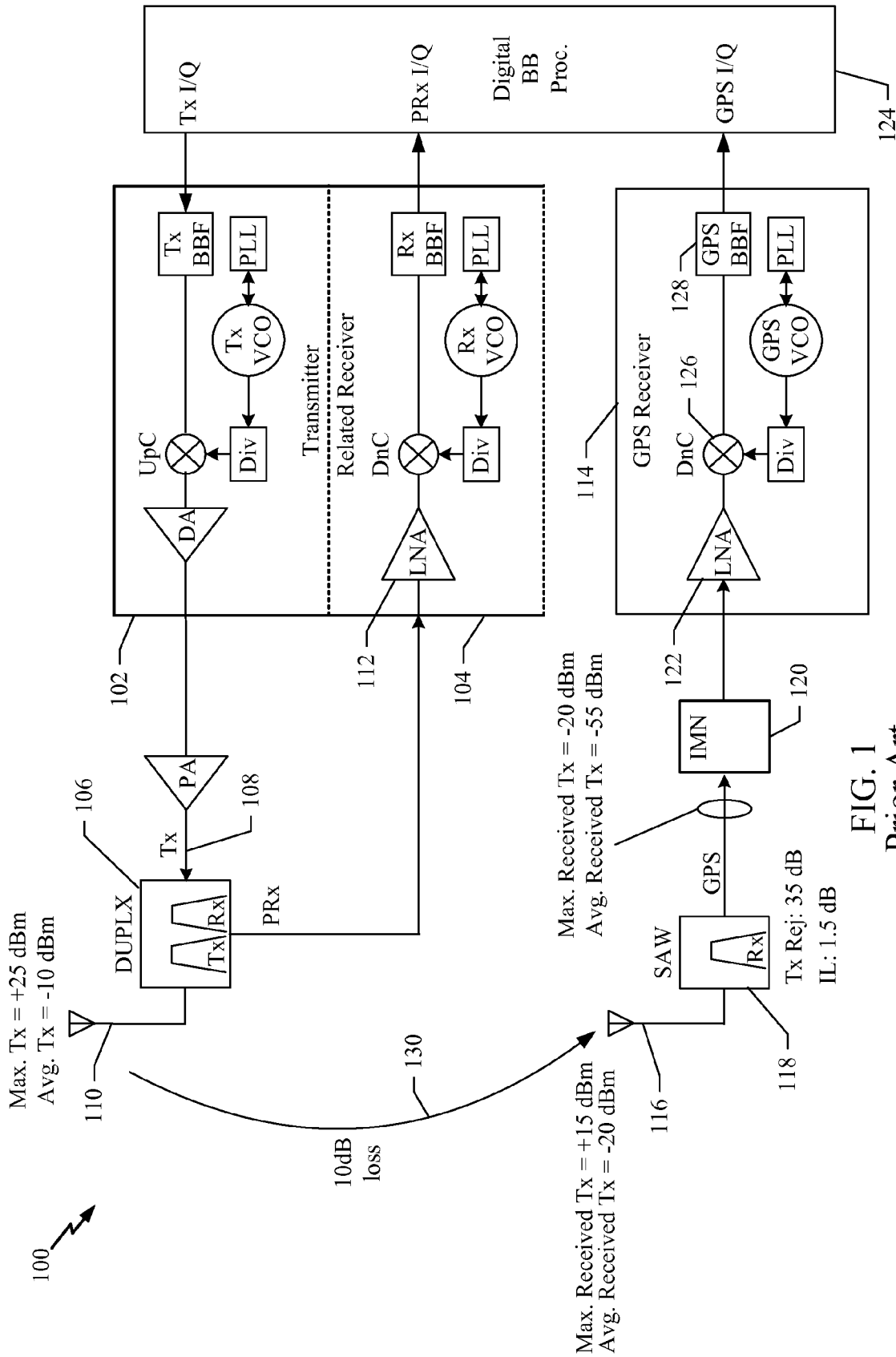


FIG. 1  
Prior Art

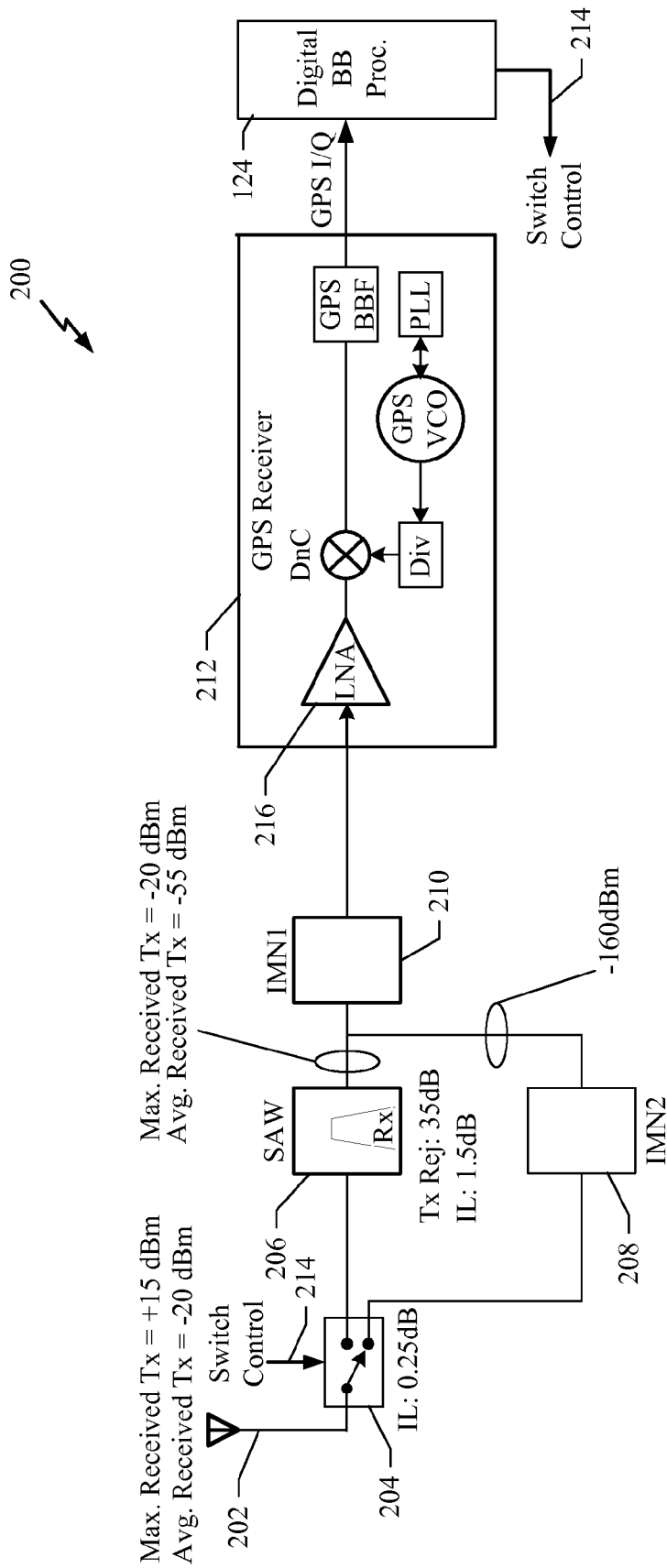


FIG. 2

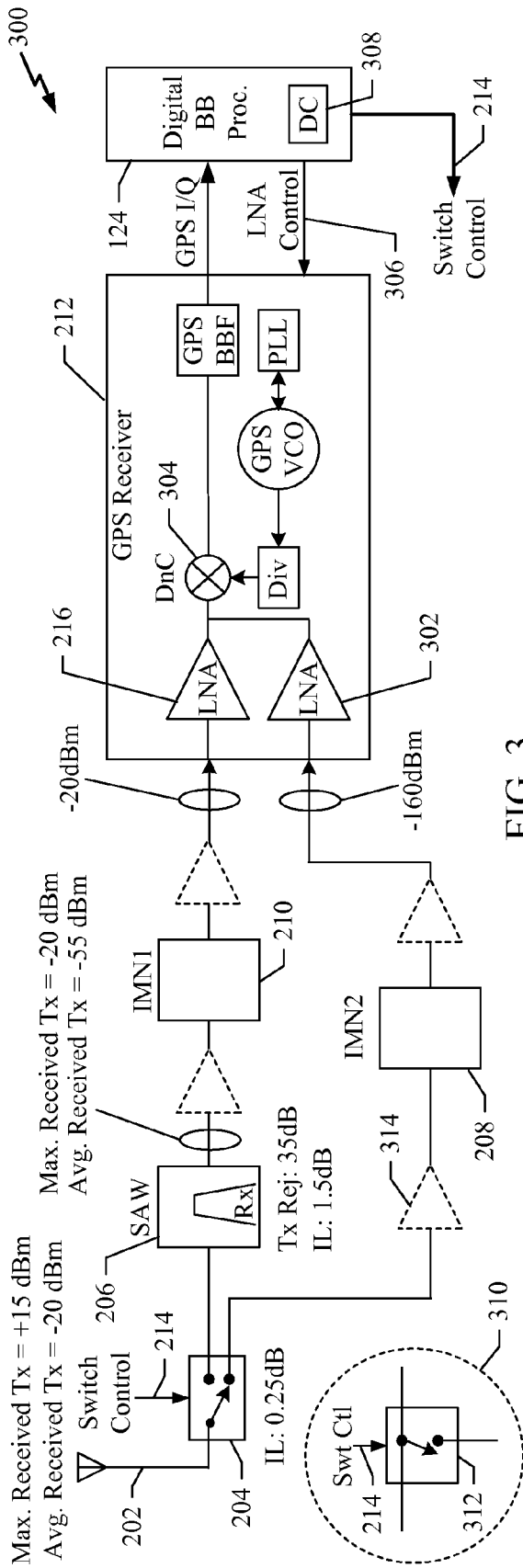


FIG. 3

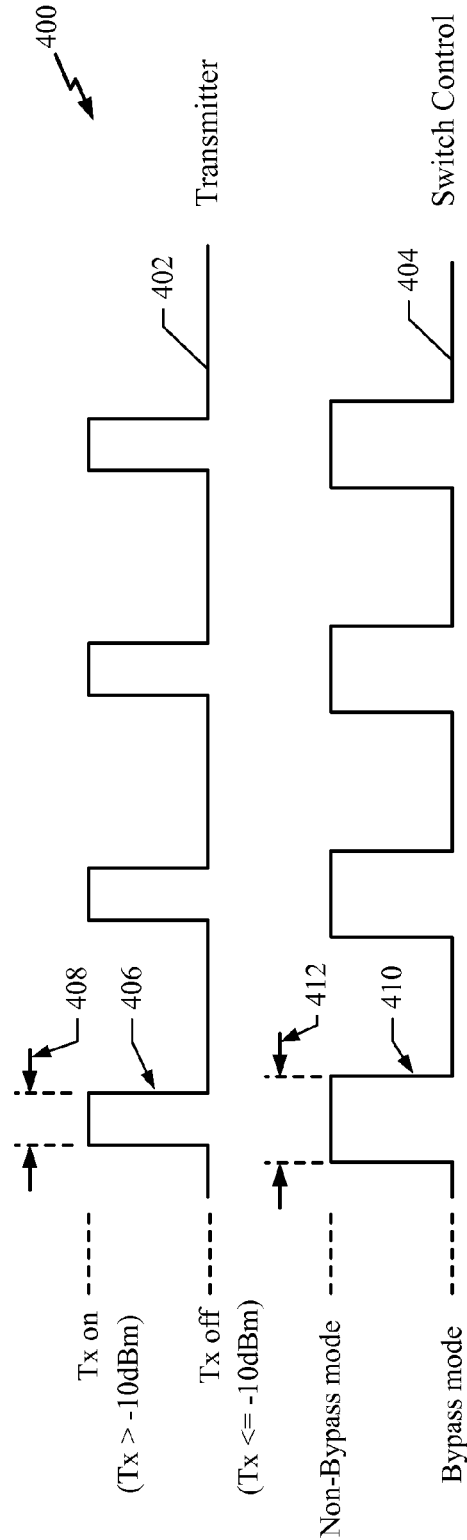


FIG. 4

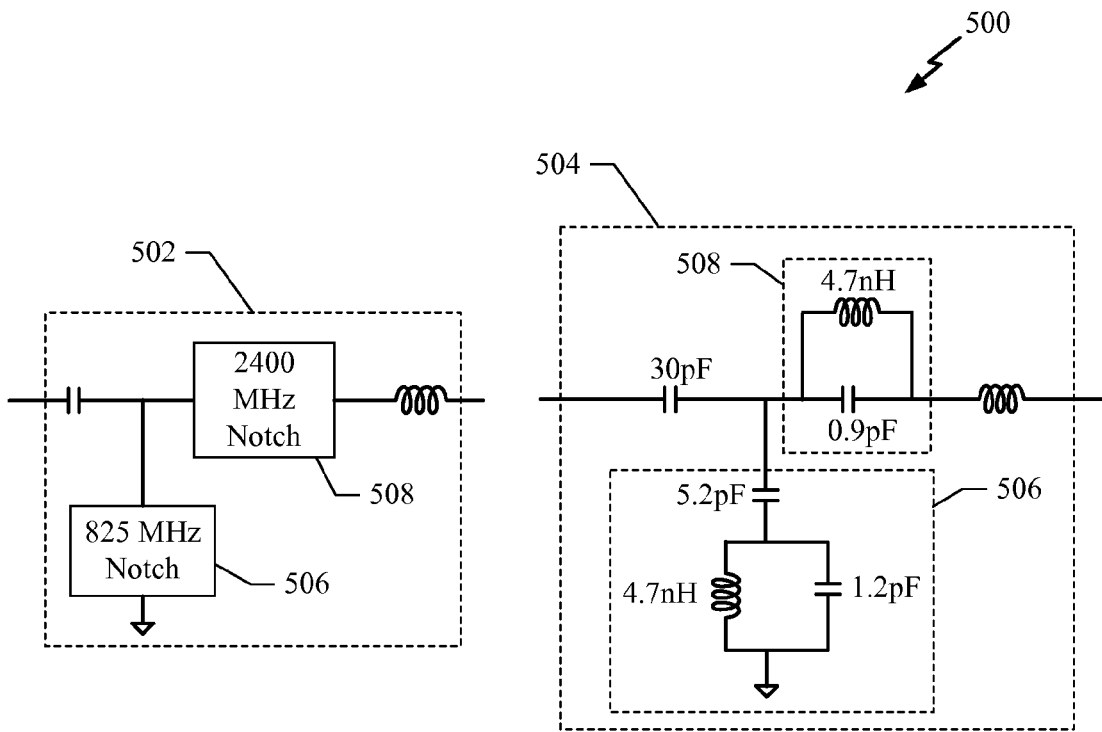


FIG. 5

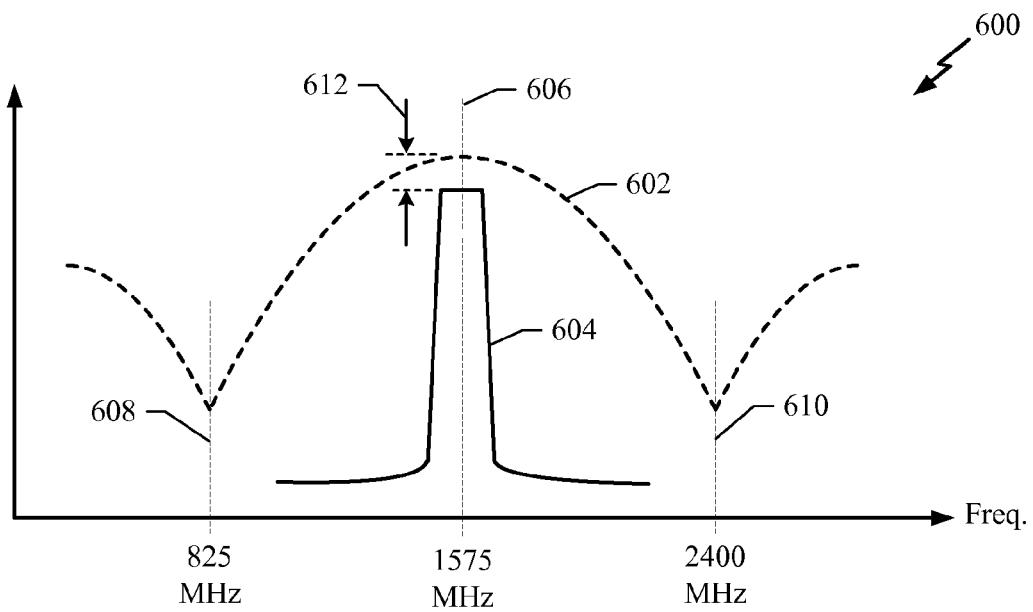


FIG. 6

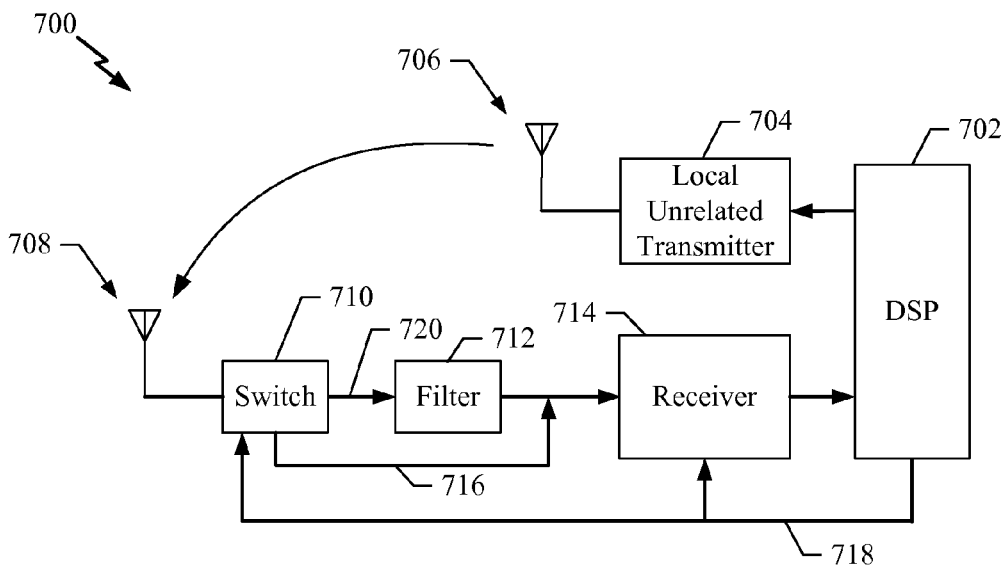


FIG. 7

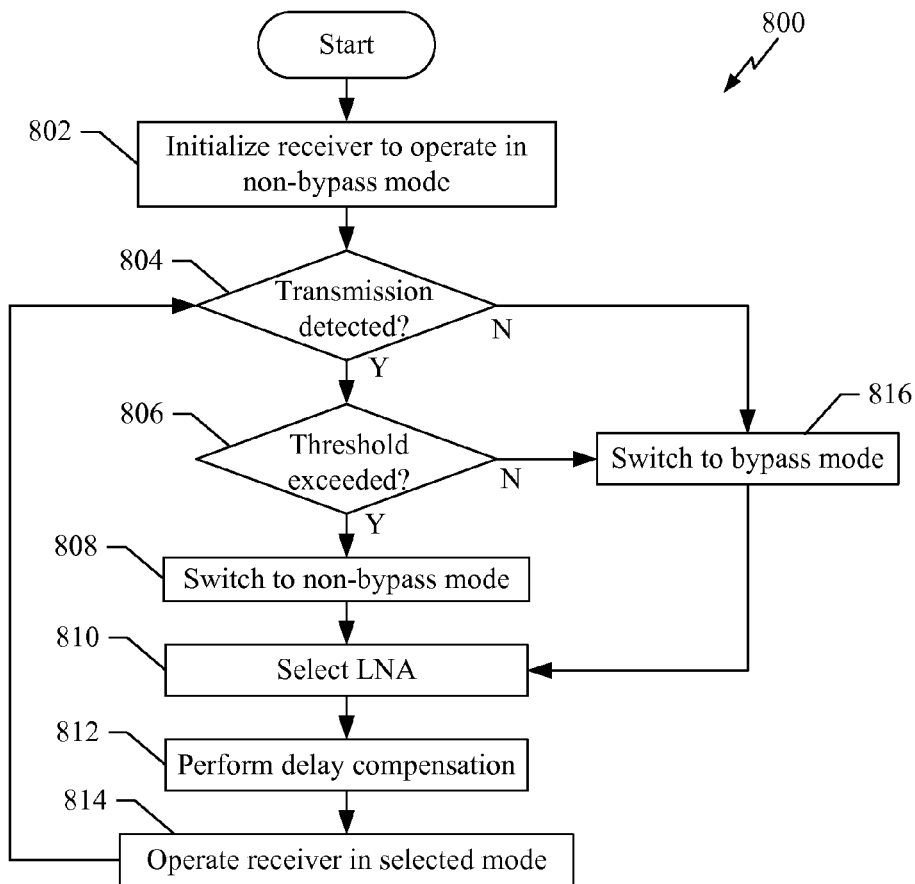


FIG. 8

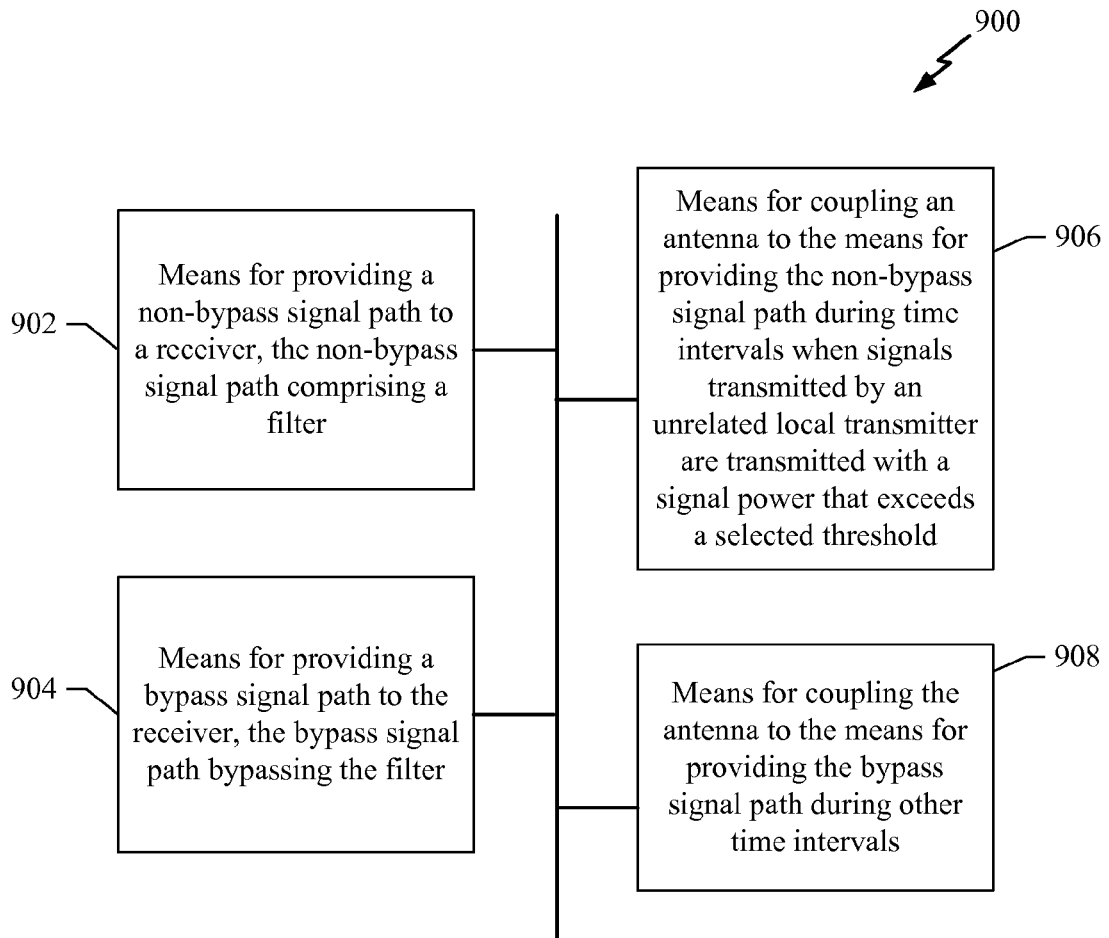


FIG. 9



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## GLOBAL NAVIGATION SATELLITE SYSTEM RECEIVER WITH FILTER BYPASS MODE FOR IMPROVED SENSITIVITY

### BACKGROUND

#### Field

The present application relates generally to the operation and design of Global Navigation Satellite Systems (GNSS), and more particularly, to improving the sensitivity of a GNSS receiver.

#### Background

High quality signal reception is especially important for the current generation of portable devices. Typically, such devices provide multiple services, such as wireless communication services and, for example, position location services that requires the reception of GNSS signals. For example, GNSS comprise a wide range of satellite positioning systems (SPS) that include the Global Positioning System (GPS) used in the United States, the GLObal Navigation Satellite System (GLONASS) used in Russia, the COMPASS navigation system used in China, and other regional positioning systems. Thus, the front end of a wireless receiver needs to be carefully designed to reject interfering signals and receive desired signals with high sensitivity.

To illustrate the problem, consider a GPS coexistence scenario where a portable device includes a GPS receiver and a cellular transmitter. In this GPS coexistence scenario, strong radio frequency signals can appear at the GPS receiver's front-end due to transmission on the cellular channel. Such signals may jam the GPS receiver and thus interfere with GPS signal reception. To address this problem, a band pass filter, such as a surface acoustic wave (SAW) filter, is typically inserted in the receive signal path associate with the GPS receiver. The SAW filter suppresses jamming signals associated with the cellular transmitter but also introduces an insertion loss of approximately 1.5 dB. Thus, at times when there are no jamming signals present, the received GPS signals still experience the insertion loss of the SAW filter thereby reducing receiver sensitivity.

Therefore, it would be desirable to have an efficient way to overcome the insertion loss of filters utilized in a GNSS receiver front end to improve sensitivity.

### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects described herein will become more readily apparent by reference to the following description when taken in conjunction with the accompanying drawings wherein:

FIG. 1 shows a diagram of a conventional front end of a communication device that includes a GPS receiver;

FIG. 2 shows an exemplary front end portion that comprises a GPS receiver configured for improved sensitivity;

FIG. 3 shows an exemplary front end portion that comprises the front end portion shown in FIG. 2 with several modifications;

FIG. 4 shows an exemplary timing diagram illustrating the operation of the front end portion shown in FIG. 3 in a time division transmission environment;

FIG. 5 shows an exemplary input matching network (IMN);

FIG. 6 shows a graph illustrating filtering characteristics of the IMN shown in FIG. 5;

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FIG. 7 shows a diagram of an exemplary front end comprising a receiver that operates with improved sensitivity;

FIG. 8 shows an exemplary method for operating a receiver to achieve improved sensitivity; and

FIG. 9 shows a receiver apparatus configured to achieve improved sensitivity.

### DETAILED DESCRIPTION

The detailed description set forth below in connection with the appended drawings is intended as a description of exemplary embodiments of the invention and is not intended to represent the only embodiments in which the invention can be practiced. The term "exemplary" used throughout this description means "serving as an example, instance, or illustration," and should not necessarily be construed as preferred or advantageous over other exemplary embodiments. The detailed description includes specific details for the purpose of providing a thorough understanding of the exemplary embodiments of the invention. It will be apparent to those skilled in the art that the exemplary embodiments of the invention 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 embodiments presented herein.

FIG. 1 shows a diagram of a conventional front end **100** of a communication device that includes a GPS receiver **114**. For example, the front end **100** is suitable for use in a portable wireless device, such as a smart phone.

The front end **100** comprises a local transmitter **102** and receiver **104** that transmit and receive voice, data, or other information over a communication network. The transmitter **102** and receiver **104** are considered local because they are located within the same communication device as the GPS receiver **114**. The local transmitter **102** and receiver **104** are related in that they operate together to provide bidirectional communications with an external entity using a particular communication protocol. Accordingly, the transmitter **102** is unrelated to the GPS receiver **114** in that they do not operate together to provide bidirectional communications with an external entity using a particular communication protocol.

A duplexer **106** filters and routes a transmit signal **108** from the transmitter **102** to an antenna **110** for transmission. Signals received by the antenna **110** are input to the duplexer **106** where they are filtered and then input to a low noise amplifier (LNA) **112** of the related receiver **104**. Thus, the transmitter **102** and the related receiver **104** operate together to communicate with a wireless network using the appropriate network access technology.

The front end **100** also comprises the GPS receiver **114**. The GPS receiver **114** utilizes a GPS antenna **116** to receive GPS signals that can be used to determine a precise location. The received GPS signals are input to a band pass filter **118**, which comprises a SAW filter, thin film bulk resonator (FBAR) filter, bulk acoustic wave filter (BAW) filter, or any other type of filter. For purpose of this description, it will be assumed that the band pass filter **118** is a SAW filter and is described hereinafter as "SAW filter **118**." The GPS signals are filtered by the SAW filter **118** and then input to an input matching network (IMN) **120** that matches the input impedance of an LNA **122** of the GPS receiver **114**. The received GPS signals are amplified by the LNA **122**, down converted by down-converter **126**, filtered by the BB filter **128** and passed to a digital BB processor **124** where they are used to make accurate position determinations.

The local transmitter **102**, related receiver **104**, and GPS receiver **114** communicate with the digital baseband (BB) processor **124**. The digital BB processor **124** processes information that is transmitted or received over a communication network using the antenna **110**. Thus, the processor **124** knows when and at what power level data or other information will be transmitted by the transmitter **102**. The digital BB processor **124** also processes baseband signals received from the GPS receiver **114** to make position determinations.

During operation, the transmitter **102** transmits a signal from the antenna **110**. The transmitted signal may have a maximum signal power level of approximately +25 dBm and an average signal power level of approximately -10 dBm as indicated. Because the antenna **110** is close to the antenna **116**, a signal transmitted with high power from the antenna **116** may couple to the antenna **110** and jams the GPS receiver **114**. For example, the signal transmitted from the antenna **110** will experience about 10 dB of loss as it travels (as shown at signal path **130**) to the antenna **116** that is utilized by the GPS receiver **114**. The transmitted signal will be received at the GPS antenna **116** and may have a maximum signal power level of about +15 dBm. Without the SAW filter **118**, a signal received at this level would jam the GPS receiver **114** and interfere with the performance of the digital BB processor **124** to make an accurate position determination.

The SAW filter **118** filters out signals that are outside the GPS signal band, which is centered at approximately 1575 MHz. For example, in one exemplary implementation, the SAW filter **118** provides approximately 35 dB of rejection outside the GPS signal band. This level of rejection reduces the maximum signal power of the received transmitted signal (jammer) by approximately 35 dB so that a maximum signal power level of about -20 dBm is received at an input matching network (IMN) **120** and thereafter the LNA **122**. As a result, the LNA **122** receives the transmit signal (jammer) at a power level of about -20 dBm, which is not large enough to jam the GPS receiver **114** or interfere with the operation of the digital BB processor **124** to make accurate position determinations.

Unfortunately, when receiving GPS signals, the SAW filter **118** introduces approximately 1.5 dB of insertion loss (IL). The GPS signals are typically received with a signal power of approximately -160 dBm, and this insertion loss results in lower sensitivity that can affect the performance of the GPS receiver **114** and the operation of the digital BB processor **124** to make accurate position determinations. Accordingly, exemplary embodiments of the disclosed GPS receiver with improved sensitivity operate to reduce or eliminate the signal loss introduced by the SAW filter **118**.

In various exemplary aspects, a GNSS receiver with improved sensitivity is disclosed. For the purpose of this description, the various aspects are described herein with reference to a GPS receiver; however, the various aspects are equally applicable to any type of GNSS receiver.

FIG. 2 shows an exemplary front end portion **200** that comprises a GPS receiver configured for improved sensitivity. For example, the front end portion **200** is suitable for use in the front end **100** shown in FIG. 1. The front end portion **200** comprises GPS antenna **202**, switch **204**, SAW filter **206**, IMN1 **208**, IMN2 **210**, and GPS receiver **212**.

The switch **204** comprises any suitable switching device or circuit and operates to selectively connect the antenna **202** to the SAW filter **206** or the IMN2 **208** based on a switch control signal **214**. The switch **204** inserts about 0.25 dB of insertion loss into the selected signal path.

In one implementation, the digital BB processor **124** outputs the switch control signal **214**. The digital BB processor **124** has knowledge about when and at what power level transmissions are to be performed by the transmitter **102**. During times when the transmitter **102** is to transmit signals at relatively high signal power, the digital BB processor **124** sets the switch control signal **214** to control the switch **204** to connect the antenna **202** to the SAW filter **206** in a non-bypass operating mode. During times when the transmitter **102** is transmitting signals at relatively low power (i.e., -10 dBm or less) or when the transmitter **102** is not transmitting any signals, the digital BB processor **124** sets the switch control signal **214** to control the switch **204** to connect the antenna **202** to the IMN2 **208** in a bypass operating mode. Additional detail about the non-bypass and bypass modes is provided below.

#### Non-Bypass Mode

During the non-bypass operating mode, the switch control signal **214** controls the switch **204** to connect the antenna **202** to the SAW filter **206** on a non-bypass signal path. This mode of operation can be utilized when an unrelated local transmitter, such as the transmitter **102** is actively transmitting a signal that can jam the GPS receiver **212**. For example, assuming that the transmit signal is received at the antenna **202** with a signal level of approximately +15 dBm. The SAW filter **206** provides 35 dB of rejection to attenuate the received maximum transmit signal to about -20 dBm. At this level the received transmit signal (jammer) will not interfere with the operation of the GPS receiver **212**. Thus, in the non-bypass operating mode, the received transmit signal (jammer) is significantly suppressed.

Unfortunately, the SAW filter **206** has an insertion loss of about 1.5 dB, which operates to degrade any GPS signals that are received by the antenna **202** during this operating mode. For example, GPS signals are received at the antenna **202** with a signal power of approximately -160 dBm. The switch **204** routes these signals to the SAW filter **206** where the signal loses 1.5 dB due to the insertion loss of the SAW filter **206**. As a result, the received GPS signals are received at the LNA **216** with a much lower signal level. Thus, in non-bypass mode, the GPS receiver **216** operates with less sensitivity.

#### Bypass Mode

In the bypass operating mode, the switch control signal **214** controls the switch **204** to connect the antenna **202** to the IMN2 **208** on a bypass signal path. For example, the bypass operating mode is used when the transmitter **102** is not transmitting (i.e., no jammer present) or when the transmitter **102** is transmitting with very low signal power such that any received jamming signal does not cause a significant loss of sensitivity at the GPS receiver **212**.

The IMN2 **208** performs impedance matching to match the input impedance of the IMN1 **210**. The output of the IMN1 **210** is input to the LNA **216** of the GPS receiver **212**. Since in this operating mode, the SAW filter **206** is bypassed (i.e., the received GPS signals are routed around the SAW filter **206**), the received GPS signals avoid the insertion loss of the SAW filter **206**, and therefore arrive at the GPS receiver **212** with higher signal levels than can be achieved in non-bypass mode. For example, in bypass mode, GPS signals are received at the GPS receiver **212** with a signal power level that is about 1.5 dB higher than in non-bypass mode. It will be assumed in the various implementations that the IMN2 **208** and IMN1 **210** have very small insertion losses.

FIG. 3 shows an exemplary front end portion **300** that comprises the front end portion **200** shown in FIG. 2 with

several modifications. The antenna **202**, switch **204**, SAW filter **206**, IMN2 **208**, and IMN1 **210** operate as described with reference to FIG. 2. The modifications comprise the addition of LNA **302** to the GPS receiver **212**. The GPS receiver **212** selectively enables the output of the LNA **216** or the output of the LNA **302** to be connected to a down converter (DnC) **304** that converts received GPS signals to baseband. In an exemplary implementation, the digital BB processor **124** outputs an LNA control signal **306** that is used by the receiver **212** to select either the LNA **126** or the LNA **302** to provide an amplified signal for down conversion. For example, in non-bypass mode, the LNA control signal **306** indicates that the LNA **216** is to be selected. In bypass mode, the LNA control signal **306** indicates that the LNA **302** is to be selected.

In an exemplary implementation, the output of the IMN2 **208** is input to the second LNA **302** of the GPS receiver **212**. With this implementation, received signals output from the switch **204** are routed only through IMN2 **208** before being input to the LNA **302**. Thus, the bypass signal path experiences less signal loss than the bypass signal path shown in FIG. 2 since only IMN2 **208** is in the bypath signal path. For example, in FIG. 2, both IMN2 **208** and IMN1 **210** are in the bypass signal path used during bypass mode operation.

In other embodiments, the front end portion **300** comprises additional circuitry to facilitate GPS signal reception in one or both of the bypass and non-bypass signal paths. For example, in an exemplary implementation, one or more external amplifiers (shown using dashed lines) are used to amplify signals prior to input to the GPS receiver **212**. For example, one external amplifier is shown at **314** and is used to amplify a received signal in bypass mode that is then input to the IMN2 **208**.

The external amplifiers are suitable for use in implementations where the GPS antenna **202** is located far away from GPS receiver **212**. In this case, the long conductive traces from the antenna **202** to the receiver **212** may degrade sensitivity. Thus, the external amplifiers amplify the received GPS signal close to the antenna **202** and thereby reduce or eliminate any reduction in sensitivity that might be caused by long signal traces. When using external amplifiers, additional matching networks (not shown) may also be used.

#### Alternate Switch Implementations

In various implementations, the switch **204** is used to route received signals to either the non-bypass or the bypass signal paths. The switch **204** comprises any suitable switching device having a variety of switch configurations. For example, the switch **204** may be replaced with the switch **312** shown at **310**. The switch **312** has little or no insertion loss in the non-bypass signal path and 0.25 dB insertion loss in the bypass signal path. However, such low signal loss does not appreciably affect performance, and therefore virtually any switch configuration may be used to achieve the desired improvements described herein.

#### Phase Adjustment

In various implementations, the switch **204** is used to route received signals to either the non-bypass or the bypass signal paths. When selecting between the non-bypass and bypass signal paths, a slight time delay between the signal paths may be experienced. This time delay may interfere with the digital BB processor **124** in its attempt to determine an accurate position from the received GPS signals.

To prevent interference with the position determination process, the digital BB processor **124** comprises a delay compensator (DC) **308** that stores delay information associated with the non-bypass and bypass signal paths. The

delay compensator **308** comprises a processor, memory, registers or other functional elements (not shown) that operate to compensate for time delays associated with the bypass and non-bypass signal paths. For example, the delay information can be determined at manufacture and loaded into delay compensator **308** at that time. The delay compensator **308** uses the delay information to compensate for any signal time delays that may occur as a result of switching between the non-bypass and bypass signal paths. For example, when the digital BB processor **124** sets the switch control signal **214** to control the switch **204** to route received signals to the bypass signal path, the digital BB processor **124** receives the appropriate delay information provided by the delay compensator **308** to process GPS signals received on the bypass signal path to compensate for a first time delay so that accurate position determinations can be made. A similar process is performed when the digital BB processor **124** switches the received signals to the non-bypass signal path to compensate for a second time delay. As a result, the delay compensator **308** and the digital BB processor **124** can seamlessly compensate or correct for any time delays that may occur each time the receive GPS signals are routed between the non-bypass and bypass signal paths.

FIG. 4 shows an exemplary timing diagram **400** illustrating the operation of the front end portion **300** shown in FIG. 3 in a time division transmission environment. For example, it will be assumed that the transmitter **102** and related receiver **104** are communicating with a communication network utilizing a time division communication protocol, such as GSM, time division long term evolution (TD-LTE), Bluetooth or Wireless LAN. In such a protocol, the transmitter **102** transmits signals during known time intervals.

The diagram **400** comprises a plot **402** of transmission time intervals associated with the transmitter **102**. For example, a first transmission interval **406** is shown during which the transmitter **102** is transmitting signals at a high power level. For example, the high power level is defined to be greater than  $-10$  dBm. The duration of the transmission is indicated at **408**.

The digital BB processor **124** knows about the operation of the transmitter **102** and during the transmission intervals shown in the plot **402**, the digital BB processor **124** outputs the switch control signal **214** to control the switch **204** to select the non-bypass signal path (non-bypass mode) during high power transmission intervals and select the bypass signal path (bypass mode) during low power transmissions intervals or between the transmission intervals when there are no transmissions. For example, a transmission threshold is defined (i.e.,  $-10$  dBm) where transmissions above this threshold are considered high power transmissions, and transmissions below this threshold are considered low power transmissions. Thus, the plot **404** shows the mode selected during each transmission interval and the mode selected between transmission intervals. For example, just before the start of the transmission interval **406**, the non-bypass mode is enabled as indicated at **410**. The non-bypass mode continues (time interval **412**) until the transmission interval **406** is completed, at which time the mode is switched to the bypass mode until the next transmission interval where the transmission power level is greater than  $-10$  dBm. Thus, the digital BB processor **124** operates to control the mode selection based on the transmission power levels.

FIG. 5 shows an exemplary input matching network (IMN) **500**. For example, the IMN **500** is suitable for use as the IMN2 **208** shown in FIG. 3. In an exemplary implementation, the IMN **500** performs both the impedance matching function and operates as a notch filter. For example, during

the bypass mode when no jammer or a low power jammer is present, it is desirable that the IMN **600** have a broad pass band to allow GPS signals to be received with the highest sensitivity. However, during bypass mode it is also possible that other transmissions may be present. For example, typical WAN transmissions occur at approximately 825 MHz and typical WLAN transmissions occur at 2400 MHz. It is possible that such transmissions, if not filtered will saturate the GPS receiver. For example, high energy WLAN transmissions (i.e., about +22 dbm) are received with a signal power of about +12 dbm which will saturate the GPS receiver,

Furthermore, if both WAN and WLAN frequencies are present, they may produce 2<sup>nd</sup> order distortions that would appear at or near the GPS center frequency of 1575 MHz. It is therefore desirable to filter out energy at these frequencies to avoid saturating the GPS receiver and to avoid any 2<sup>nd</sup> order distortions that may appear in the GPS frequency band.

The diagram **502** shows a configuration of the IMN **500** that provides a notch filter **506** at WAN frequencies and a notch filter **508** at WLAN frequencies, which operate to prevent interference with GPS signal processing during operation in bypass mode. The diagram **504** shows exemplary implementations of the notch filter **506** and the notch filter **508** that perform the notch filtering functions.

In an exemplary implementation, the notch filter **506** comprises a 4.7 nH inductor connected in parallel with a 1.2 pF capacitor. This parallel combination is connected to a 5.2 pF capacitor. The notch filter **508** comprises a 4.7 nH inductor connected in parallel with a 0.9 pF capacitor. It should be noted that the implementations of the filters **506** and **508** are exemplary and that other filter implementations are possible. The filtering characteristics of the notch filters **506** and **508** are provided below. It should be noted that the filter **506** is not limited to the filtering characteristics shown in FIG. **6** and may in fact be configured to filter any type of unwanted signals.

FIG. **6** shows a graph **600** illustrating filtering characteristics of the IMN **600** shown in FIG. **6**. For example, the plot **602** illustrates the passband of the IMN **600**. At the GPS center frequency of 1575 MHz, indicated at **606**, the IMN **600** provides very little signal attenuation. At the WAN center frequency of 825 MHz, indicated at **608**, and the WLAN center frequency of 2400 MHz, indicated at **610**, the IMN **600** provide significant signal attenuation (i.e., approximately 20 dB). For comparison, the plot **604** shows the pass band characteristics of the SAW filter **206**. As indicated at **612**, the SAW filter **206** has an insertion loss of about 1.5 dB. Thus, the IMN **600** performs the functions of impedance matching and notch filtering to facilitate the use of bypass mode during which the GPS receivers shown in FIG. **2** and FIG. **3** operate with improved sensitivity.

FIG. **7** shows a diagram of an exemplary front end **700** comprising a receiver **714** that operates with improved sensitivity. For example, the receiver **714** may be a positioning system receiver. The front end **700** is suitable for use in a portable device comprising multiple transceivers to communicate using multiple transmission technologies. For example, the device may comprise cellular, LAN, WLAN or other transceivers and it is desirable that receivers at the device operate with the highest sensitivity.

Typically receivers comprise input filtering that filter unwanted signals from jamming the receiver. However, when such jammers are not present or present at very low power levels, the input filtering may be unnecessary, and

may in fact, insert loss into the signal path that reduces sensitivity. The front end **700** overcomes these and other deficiencies.

The front end **700** comprises digital signal processor (DSP) **702**, antenna **706**, antenna **708**, switch **710**, filter **712**, and local unrelated transmitter **704** that is unrelated to receiver **714**. It will be assumed that the front end **700** operates at a device that comprises multiple transmitters, and for clarity, the unrelated transmitter **704** represents just one of the other transmitters. Accordingly, the operation of the front end **700** with respect to the unrelated transmitter **704** is applicable to the other transmitters that may be present.

DSP **702** outputs signals to be transmitted by the unrelated local transmitter **704** and these signals are transmitted using the antenna **706**. The transmitted signals may be received by the antenna **708**, which is designed to receive signals for processing by the receiver **714**. The switch **710** routes signals received by the antenna **708** on a non-bypass signal path **720** to the filter **712** where undesirable signals are filtered out. For example, the filter **712** may be a SAW filter that has some significant level of insertion loss, for example 1 to 3 dB. The output of the filter **712** is input to the receiver **714** for down conversion. The resulting BB signal is input to the DSP **702** for processing.

Unfortunately, if no jamming signals or only low power jamming signals are present in the signals received by the antenna **708**, the filtering performed by the filter **712** may not be needed but its insertion loss will still reduce the sensitivity of the receiver **714**. In an exemplary implementation, the DSP **702** knows when and at what power levels unrelated transmissions by the unrelated transmitter are to occur. During time intervals when there are no unrelated transmissions or only low power unrelated transmissions, the DSP **702** outputs a control signal **718** to the switch **710** causing the switch **710** to route received signals around the filter **712** on a bypass signal path **716**, thereby bypassing the filter **712** and avoiding its insertion loss. The received signals are received at the receiver **714** with the highest possible signal levels resulting in increased receiver sensitivity.

In various implementations, the DSP **702** can set the control signal **718** based on unrelated transmissions from any unrelated transmitter operating at the device. Not only does the control signal **718** control the operation of the switch **710**, but it may also control the operation of the receiver **714**. For example, the receiver **714** may select a different input configuration based on the control signal **718**. For example, the receiver **714** utilizes one configuration if the filter **712** is not bypassed and another configuration if the filter **712** is bypassed.

The DSP **702** may also perform additional functions based on the status of the control signal **718**. For example, the DSP **702** may comprise one or more parameters that are used to process the signals provided by the receiver **714**. The DSP **702** can adjust or select from the various parameters based on the status of the control signal **718**. For example, if the filter **712** is not bypassed, one set of parameters are used by the DSP **702** to process the received data, for instance to compensate for a first time delay. If the switch **710** is set to bypass the filter **712**, another set of parameters are used by the DSP **702** to process the received data, for instance to compensate for a second time delay.

Therefore, the front end **700** comprises a receiver **714** that operates with improved sensitivity in a device that can include any number of unrelated local transmitters transmitting information using any type of transmission protocol.

FIG. 8 shows an exemplary method **800** for operating a receiver to achieve improved sensitivity. For example, in one implementation, the operations of the method **800** are performed by the front end **300** comprising the GPS receiver **212** shown in FIG. 3.

At block **802**, the receiver is initialized to operate in non-bypass mode. For example, the digital BB processor **124** sets the switch control signal **214** to control the switch **204** to route received signals to the SAW filter **206** on the non-bypass signal path to the receiver **212**.

At block **804**, a determination is made as to whether a transmission (jammer) from a local unrelated transmitter is detected. For example, the digital BB processor **124** knows when transmissions from the transmitter **102** are to occur. If a transmission is to occur, the method proceeds to block **806**. If no transmission is to occur, the method proceeds to block **816**.

At block **806**, a determination is made as to whether the detected transmission is above a power level threshold. For example, the digital BB processor **124** knows the power level of transmissions from the unrelated local transmitter **102**. If the transmitted power level is to exceed a selected threshold (i.e.,  $-10$  dBm), the method proceeds to block **808**. If the power level of the transmission is equal to or below the threshold, the method proceeds to block **816**.

At block **816**, a bypass operating mode is selected. For example, the digital BB processor **124** sets the switch control signal **214** to control the switch **204** to route signals on a bypass signal path that avoids the SAW filter **206**. In this configuration, the signals are received at the receiver **212** with the highest signal level resulting in the improved receiver sensitivity.

At block **808**, a non-bypass mode is selected. For example, the digital BB processor **124** sets the switch control signal **214** to control the switch **204** to route signals on a non-bypass signal path that includes the SAW filter **206**. In this configuration, the signals are filtered to remove jammers but also experience the insertion loss of the filter. The signals are thereafter received at the receiver **212** with lower signal levels resulting in the lower receiver sensitivity.

At block **810**, an LNA at the receiver is selected. For example, in an implementation where the receiver comprises multiple LNAs, the appropriate LNA is selected to receive GPS signals based on the operating mode. For example, referring to FIG. 3, if the non-bypass mode is selected, the receiver **212** enables the LNA **216** to receive the GPS signals based on the LNA control signal **306**. If the bypass mode is selected, the receiver **212** enables the LNA **302** to receive the GPS signals based on the control signal **306**.

At block **812**, delay compensation is performed. For example, the delay compensator **308** and digital BB processor **124** compensate (or correct) for any time delay associated with a particular operating mode. For example, a first time delay associated with the non-bypass operating mode is compensated, or a second time delay associated with the bypass mode is compensated. The compensation (or correction) of the time delays allow the digital BB processor **124** to accurately process the received GPS signals.

At block **814**, the receiver is operated in the selected mode and the method returns to block **804** to determine whether or not additional transmissions are detected.

Thus, the method **800** illustrates a method for operating a receiver, such as the GPS receiver included in the front end **300**, to achieve improved sensitivity. It should be noted that the method **800** is just one implementation and that the operations of the method **800** may be rearranged or otherwise modified such that other implementations are possible.

FIG. 9 shows a receiver apparatus **900** configured to operate with improved sensitivity. The apparatus **900** is suitable for use in the front end **300** shown in FIG. 3 or in the front end **700** shown in FIG. 7. In an aspect, the apparatus **900** is implemented by one or more modules configured to provide the functions as described herein. For example, in an aspect, each module comprises hardware and/or hardware executing software.

The apparatus **900** comprises a first module comprising means **(902)** for providing a non-bypass signal path to a receiver, the non-bypass signal path comprising a filter, which in an aspect comprises the signal path **720**.

The apparatus **900** also comprises a second module comprising means **(904)** for providing a bypass signal path to the receiver, the bypass signal path bypassing the filter, which in an aspect comprises the signal path **716**.

The apparatus **900** also comprises a third module comprising means **(906)** for coupling an antenna to the means for providing the non-bypass signal path during time intervals when signals transmitted by an unrelated local transmitter are transmitted with a signal power that exceeds a selected threshold, which in an aspect comprises the switch **710**.

The apparatus **900** also comprises a fourth module comprising means **(908)** for coupling the antenna to the means for providing the bypass signal path during other time intervals, which in an aspect comprises switch **710**.

Those of skill in the art would understand that information and signals may be represented or processed using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof. It is further noted that transistor types and technologies may be substituted, rearranged or otherwise modified to achieve the same results. For example, circuits shown utilizing PMOS transistors may be modified to use NMOS transistors and vice versa. Thus, the amplifiers disclosed herein may be realized using a variety of transistor types and technologies and are not limited to those transistor types and technologies illustrated in the Drawings. For example, transistor types such as BJT, GaAs, MOSFET or any other transistor technology may be used.

Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the exemplary embodiments of the invention.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hard-

ware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in Random Access Memory (RAM), flash memory, Read Only Memory (ROM), Electrically Programmable ROM (EPROM), Electrically Erasable Programmable ROM (EEPROM), registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

In one or more exemplary embodiments, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

The description of the disclosed exemplary embodiments is provided to enable any person skilled in the art to make or use the invention. Various modifications to these exemplary embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the invention is not intended to be limited to the exemplary embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. An apparatus comprising:

a non-bypass signal path coupled to a receiver configured to receive positioning signals from a Global Navigation Satellite Systems (GNSS), the non-bypass signal path comprising a filter;

a bypass signal path coupled to the receiver, the bypass signal path configured to bypass the filter, the bypass signal path comprising at least one input matching network (IMN) configured to provide impedance matching and filtering, the IMN being configured to provide a broader pass band than the filter of the non-bypass filter path, the IMN comprising a first notch filter configured to attenuate a first range of frequencies used for transmitting signals unrelated to the positioning signals associated with at least one non-local transmitter and a second notch filter configured to attenuate a second range of frequencies used for transmitting signals unrelated to the positioning signals and associated with another at least one non-local transmitter, wherein the presence of signals within both the first range of frequencies and the second range of frequencies produce second order distortions within a third frequency range associated with the positioning signals which the receiver is configured to receive;

a first processor configured to generate a control signal for alternatively routing the received signal through either the non-bypass signal path or the bypass signal path based on whether an expected signal power for transmission signals in the first range of frequencies or the second range of frequencies by an unrelated local transmitter exceeds a selected threshold; and

a delay compensator, the delay compensator comprising a second processor and a memory, the second processor being configured to access time delay information stored in the memory of the delay compensator and being further configured to select first delay information from the memory to compensate for a first time delay associated with the non-bypass signal path responsive to the control signal from the first processor indicating that the non-bypass signal path has been selected and to select second delay information from the memory to compensate for a second time delay associated with the bypass signal path responsive to the control signal from the first processor indicating that the bypass signal path has been selected, wherein the delay compensator is configured to provide the selected first delay information or second delay information to the first processor, and wherein the first processor, during signal processing for signal determination, is configured to use the first delay information to compensate for delays associated with the non-bypass signal path and to use the second delay information to compensate for delays associated with the bypass-signal path;

a switch configured to receive the control signal and in response thereto to select the non-bypass path when the expected signal power exceeds the selected threshold and select the bypass path when the expected signal power does not exceed the selected threshold.

2. The apparatus of claim 1, the filter comprising at least one of a SAW filter, a FBAR filter, and a BAW filter.

3. The apparatus of claim 1, the receiver comprising a positioning system receiver.

4. The apparatus of claim 1, the unrelated local transmitter comprising a wide area network (WAN) transmitter.

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5. The apparatus of claim 1, the first LNA having an output coupled to an output of the second LNA.

6. The apparatus of claim 1, wherein the filter is configured to filter out signals that are outside of a Global Positioning System (GPS) signal band.

7. The apparatus of claim 1, wherein the processor comprises a baseband processor configured to process positioning signals received via the non-bypass signal path and the bypass signal path and to process communication signals received from a local receiver via a communication signal path.

8. The apparatus of claim 1, wherein the receiver is configured to use a first input configuration in response to the received signal being routed through the non-bypass signal path and to use a second input configuration in response to the received signal being routed through the bypass signal path.

9. An apparatus comprising:

means for providing a non-bypass signal path to a receiver configured to receive positioning signals from a Global Navigation Satellite Systems (GNSS), the non-bypass signal path comprising a means for filtering;

means for providing a bypass signal path to the receiver, the bypass signal path configured to bypass the filter, the means for providing the bypass signal path comprising means for providing at least one input matching network (IMN), the means for providing the at least one IMN configured to provide impedance matching and filtering and to provide a broader pass band than the means for filtering of the non-bypass signal path, the means for providing the at least one IMN further comprising a second filtering means and a third filtering means, the second filtering means comprising means for attenuating a first range of frequencies used for transmitting signals unrelated to the positioning signals and associated with at least one non-local transmitter using a first notch filter, the third filtering means comprising means for attenuating a second range of frequencies used for transmitting signals unrelated to the positioning signals and associated with another at least one non-local transmitter using a second notch filter, wherein the presence of signals within both the first range of frequencies and the second range of frequencies produce second order distortions within a third frequency range associated with the positioning signals which the receiver is configured to receive;

first processing means for generating a control signal for alternatively routing the received signal through either the non-bypass signal path or the bypass signal path based on whether an expected signal power for transmission signals in the first range of frequencies or the second range of frequencies by an unrelated local transmitter exceeds a selected threshold;

delay compensation means comprising a second processing means and a data storage means, the second processing means being configured to access time delay information stored in the data storage means and being further configured to select first delay information from the data storage means to compensate for a first time delay associated with the non-bypass signal path responsive to the control signal from the first processing means indicating that the non-bypass signal path has been selected and to select second delay information from the data storage means to compensate for a second time delay associated with the bypass signal path responsive to the control signal from the first processing means indicating that the bypass signal path

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has been selected, wherein the delay compensation means is configured to provide the selected first delay information or second delay information to the first processing means, and wherein first processing means, during signal processing for positioning signal determination, is configured to use the first delay information to compensate for delays associated with the non-bypass signal path and to use the second delay information to compensate for delays associated with the bypass-signal path; and

means for switching configured to receive the control signal and in response thereto to select the non-bypass path when the expected signal power exceeds the selected threshold and select the bypass path when the expected signal power does not exceed the selected threshold.

10. The apparatus of claim 9, the filter comprising at least one of a SAW filter, a FBAR filter, and a BAW filter.

11. The apparatus of claim 9, the receiver comprising a positioning system receiver.

12. The apparatus of claim 9, the unrelated local transmitter comprising a wide area network (WAN) transmitter.

13. A method comprising:

generating, using a first processor, a control signal for alternatively routing a received signal through either a non-bypass signal path or a bypass signal path based on whether the expected signal power for transmission signals by the unrelated local transmitter exceeds a selected threshold, wherein the unrelated local transmitter is unrelated to a local receiver configured to receive positioning signals from a Global Navigation Satellite Systems (GNSS);

switching based on the control signal and in response thereto selecting the non-bypass path when the expected signal power exceeds the selected threshold and selecting the bypass path when the expected signal power does not exceed the selected threshold;

matching an impedance of using an input matching network (IMN) and filtering, the IMN comprising a first notch filter configured to attenuate a first range of frequencies used for transmitting signals unrelated to the positioning signals and associated with at least one non-local transmitter and a second notch filter configured to attenuate a second range of frequencies used for transmitting signals unrelated to the positioning signals and associated with another at least one non-local transmitter, wherein the presence of signals within both the first range of frequencies and the second range of frequencies produce second order distortions within a third frequency range at which the receiver is configured to receive a signal, the IMN providing a broader pass band than a filter of the non-bypass signal path;

obtaining time delay information from a delay compensator comprising a second processor and a memory, wherein obtaining the time delay information further comprises accessing the time delay information stored in the memory with the second processor, and selecting first delay information from the memory to compensate for a first time delay associated with the non-bypass signal path responsive to the control signal indicating that the non-bypass signal path has been selected, and selecting second delay information from the memory to compensate for a second time delay associated with the bypass signal path responsive to the control signal indicating that the bypass signal path has been selected, compensating for the first time delay or the second time delay, during signal processing for positioning signal

determination, using the first delay information to compensate for delays associated with the non-bypass signal path or the second delay information to compensate for delays associated with the bypass-signal path;

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attenuating a range of frequencies associated with at least one non-local transmitter and the another at least one non-local transmitter.

**14.** The method of claim **13**, further comprising filtering out the selected signals on the non-bypass signal path that are transmitted by the unrelated local transmitter with the expected signal power that exceeds the selected threshold.

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**15.** The method of claim **13**, further comprising:

enabling the first LNA to amplify a first received signal carried on the non-bypass signal path; and

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enabling the second LNA of the receiver to amplify a second received signal carried on the bypass signal path.

**16.** The method of claim **13**, further comprising filtering the non-bypass signal path with a notch filter to filter at least one unwanted signal.

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