METHODS FOR INCREASING RF THROUGHPUT VIA USAGE OF TUNABLE FILTERS

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ABSTRACT
Methods and devices are described for increasing RF throughput in a multiple RF paths RF transmit/receive system with a plurality RF transmit/receive systems. In one case a tunable notch filter is used to reduce channel interference between the plurality of RF transmit/receive systems.
FIG. 2B
FIG. 2C
FIG. 2D
FIG. 3
FIG. 7
FIG. 9
METHODS FOR INCREASING RF THROUGHPUT VIA USAGE OF TUNABLE FILTERS

CROSS REFERENCE TO RELATED APPLICATIONS


[0002] The present application may be related to U.S. Pat. No. 6,804,502, issued on Oct. 12, 2004 and entitled “Switch Circuit and Method of Switching Radio Frequency Signals”, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. Pat. No. 7,910,993, issued on Mar. 22, 2011 and entitled “Method and Apparatus for use in improving Linearity of MOSFET’s using an Accumulated Charge Sink”, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 13/797,779 entitled “Scalable Periphery Tunable Matching Power Amplifier”, filed on Mar. 3, 2013, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to International Application No. PCT/US2009/001358, entitled “Method and Apparatus for use in digitally tuning a capacitor in an integrated circuit device”, filed on Mar. 2, 2009, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 13/595,893, entitled “Method and Apparatus for Use in Tuning Resistance in a Circuit Device”, filed on Aug. 27, 2012, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 14/042,312, filed on Sep. 30, 2013, entitled “Methods and Devices for Impedance Matching in Power Amplifier Circuits”, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. Pat. No. 7,248,120, issued on Jul. 24, 2007, entitled “Stacked Transistor Method and Apparatus”, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 13/828,121, filed on Mar. 14, 2013, entitled “Autonomous Power Amplifier Optimization”, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 13/967,866 entitled “Tunable Impedance Matching Network”, filed on Aug. 15, 2013, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 13/797,686 entitled “Variable Impedance Match and Variable Harmonic Terminations for Different Modes and Frequency Bands”, filed on Mar. 12, 2013, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 14/042,331 entitled “Methods and Devices for Thermal Control in Power Amplifier Circuits”, filed on Sep. 30, 2013, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 13/829,946 entitled “Amplifier Dynamic Bias Adjustment for Envelope Tracking”, filed on Mar. 14, 2013, the disclosure of which is incorporated herein by reference in its entirety. The present application may also be related to U.S. patent application Ser. No. 13/830,555 entitled “Control Systems and Methods for Power Amplifiers Operating in Envelope Tracking Mode”, filed on Mar. 14, 2013, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

[0003] 1. Field

[0004] The present teachings relate to RF (radio frequency) circuits. More particularly, the present teachings relate to methods for increasing data throughput in an RF transmit/receive system.

[0005] 2. Description of Related Art

[0006] Radio frequency (RF) devices, such as cell phone transmitters, are becoming increasingly complex due to additional frequency bands, more complex modulation schemes, higher modulation bandwidths, and the introduction of data throughput improvement schemes such as simultaneous RF transmission and/or reception within a same or different, but closely spaced, bands or channels within a band (e.g., voice, data), and aggregate transmission wherein information is multiplexed over parallel RF transmissions. Due to the high integration and closely spaced transmit/receive paths of a front-end stage used in such RF devices, RF signal interference from neighboring paths, either receive or transmit, can influence RF signal of a transmit/receive path (e.g., via intermodulation) and therefore affect (e.g., reduce) a corresponding throughput by increasing spectrum usage within a frequency band and therefore limiting the number of simultaneous RF transmission and/or reception (e.g., number of usable channels) within a frequency band.

SUMMARY

[0007] According to a first aspect of the present disclosure, a radio frequency (RF) circuitual arrangement is presented, the arrangement comprising: a first transmit/receive system comprising a first transmit path configured to transmit a first transmit RF signal at a first transmit/receive port, and a first receive path configured to receive a first receive RF signal at the first transmit/receive port; a second transmit/receive system comprising a second transmit path configured to transmit a second transmit RF signal at a second transmit/receive port, and a second receive path configured to receive a second receive RF signal at the second transmit/receive port, and one or more tunable notch filters configured to reduce a radio frequency interference of a transmit/receive system of the first and second transmit/receive systems over the other transmit/receive system.

[0008] According to a second aspect of the present disclosure, a radio frequency (RF) integrated circuit is presented, the integrated circuit comprising: an RF switch comprising a first switch terminal and a second switch terminal; a RF tunable notch filter comprising a first port and a second port, wherein in a first configuration of the RF integrated circuit the first port is connected to the first switch terminal and the second port is connected to the second switch terminal, and in a second configuration of the RF integrated circuit the first port is connected to the second switch terminal; a first input/
output terminal connected to the first switch terminal; a second input/output terminal connected to the second port, and a control terminal, wherein during operation, a control signal at the control terminal of the RF integrated circuit is configured to tune the RF tunable notch filter and/or control the RF switch to enable/disable a current flow through the RF tunable notch filter.

[0009] According to a third aspect of the present disclosure, a method for reducing radio frequency (RF) interference in an RF circuit arrangement is presented, the method comprising: providing a plurality of RF transmit/receive systems coupled to a plurality RF antennas; connecting in a path of a first RF transmit/receive system of the plurality of RF transmit/receive systems one or more RF tunable notch filters; adjusting an RF tunable notch filter of the one or more RF tunable notch filters based on a characteristic of a transmit/receive RF signal of an RF transmit/receive system of the plurality of RF transmit/receive systems other than the first RF transmit/receive system, and based on the adjusting, reducing an RF interference of the transmit/receive RF signal over the first RF transmit/receive system.

[0010] According to a fourth aspect of the present disclosure, a radio frequency (RF) circuit arrangement is presented, the arrangement comprising: a transmit path configured to transmit, during a transmit mode of operation of the RF circuit arrangement, a transmit RF signal at a transmit/receive port of the RF circuit arrangement; a receive path configured to receive, during a receive mode of operation of the RF circuit arrangement, a receive RF signal at the transmit/receive port, and a tunable notch filter configured to reduce a radio frequency interference of the transmit RF signal over the receive RF signal, wherein during operation, the RF circuit arrangement is configured to simultaneously operate in the transmit and receive modes of operation.

[0011] According to a fifth aspect of the present disclosure, a method for reducing radio frequency (RF) interference in an RF circuit arrangement is presented, the method comprising: providing an RF transmit path to transmit a transmit RF signal over an antenna; providing an RF receive path to receive a receive RF signal over the antenna; coupling a tunable notch filter to the RF transmit or the RF receive path; adjusting the tunable notch filter based on a frequency of operation of the transmit RF signal, and based on the adjusting, reducing an RF interference of the transmit RF signal over the receive RF signal.

BRIEF DESCRIPTION OF DRAWINGS

[0012] The accompanying drawings, which are incorporated into and constitute a part of this specification, illustrate one or more embodiments of the present disclosure and, together with the description of example embodiments, serve to explain the principles and implementations of the disclosure.

[0013] FIG. 1 shows an exemplary block diagram of a transmit/receive system comprising a transmit path and a receive path used in a multi-band and multi-channel RF front-end stage of an RF device, as used, for example, in a cellular phone.

[0014] FIG. 2A shows an exemplary graph of frequency spectra of an RF transmit signal and an RF receive signal of the transmit/receive system of FIG. 1.

[0015] FIG. 2B and FIG. 2C show exemplary graphs of frequency bands and associated frequency channels which can be used in the transmit/receive system of FIG. 1.

[0016] FIG. 2D shows an exemplary embodiment according to the present disclosure of a transmit/receive system comprising a tunable notch filter in a receive path.

[0017] FIG. 3 shows an exemplary block diagram of a multiple RF paths transmit/receive system comprising two parallel transmit/receive systems which can be used to increase throughput of an RF front-end stage.

[0018] FIG. 4A shows a frequency plan which can be used by the multiple RF paths transmit/receive system of FIG. 3.

[0019] FIG. 4B shows a frequency plan comprising intermodulation products of two RF signals.

[0020] FIG. 4C shows a frequency plan comprising intermodulation products of two RF transmit signals of the multiple RF paths transmit/receive system of FIG. 3, wherein an intermodulation product can occupy one or more receive channels of a receive band used by the multiple RF paths transmit/receive system.

[0021] FIG. 4D shows the frequency plan of FIG. 4C for a case where additional to the two RF transmissions, an RF reception is also taking place. As depicted in FIG. 4D, a spectrum of an intermodulation product between the two RF transmit signals can occupy a portion of the spectrum used for an RF receive signal.

[0022] FIGS. 5A-SB show embodiments according to the present disclosure of the multiple RF paths transmit/receive system of FIG. 3, wherein a tunable notch filter is used to reduce interference of one transmit/receive system over the other.

[0023] FIG. 6 shows an embodiment according to the present disclosure of the multiple RF paths transmit/receive system of FIG. 3, wherein series and shunt connected tunable notch filters within both the transmit/receive systems are used to immune either transmit/receive system with respect to the other.

[0024] FIG. 7 shows an embodiment according to the present disclosure wherein switches are used to bypass the series and shunt connected tunable notch filters used in FIG. 6.

[0025] FIG. 8A shows an embodiment according to the present disclosure of a monolithically integrated tunable notch filter in parallel connection with an RF switch.

[0026] FIG. 8B shows an embodiment according to the present disclosure of a monolithically integrated tunable notch filter in series connection with an RF switch.

[0027] FIG. 9 shows an exemplary embodiment of a switch with stacked transistors.

DETAILED DESCRIPTION

[0028] Throughout this description, embodiments and variations are described for the purpose of illustrating uses and implementations of the inventive concept. The illustrative description should be understood as presenting examples of the inventive concept, rather than as limiting the scope of the concept as disclosed herein.

[0029] As used in the present disclosure, the terms "switch ON" and "activate" may be used interchangeably and can refer to making a particular circuit element electronically operational. As used in the present disclosure, the terms "switch OFF" and "deactivate" may be used interchangeably and can refer to making a particular circuit element electronically non-operational. As used in the present disclosure, the terms "amplifier" and "power amplifier" may be used interchangeably and can refer to a device that is configured to
amplify a signal input to the device to produce an output signal of greater magnitude than the magnitude of the input signal.

[0030] The present disclosure describes electrical circuits in electronics devices (e.g., cell phones, radios) having a plurality of devices, such as for example, transistors (e.g., MOSFETs). Persons skilled in the art will appreciate that such electrical circuits comprising transistors can be arranged as amplifiers. As described in a previous disclosure (U.S. patent application Ser. No. 13/797,779), incorporated herein by reference in its entirety), a plurality of such amplifiers can be arranged in a so-called “scalable periphery” (SP) architecture of amplifiers where a total number (e.g., 64) of amplifier segments are provided. Depending on the specific requirements of an application, the number of active devices (e.g., 64, 32, etc.), or a portion of the total number of amplifiers (e.g. 1/64, 2/64, 40% of 64, etc. . . .), can be changed for each application. For example, in some instances, the electronic device may desire to output a certain amount of power, which in turn, may require 32 of 64 SP amplifier segments to be used. In yet another application of the electronic device, a lower amount of output power may be desired, in which case, for example, only 16 of 64 SP amplifier segments are used. According to some embodiments, the number of amplifier segments used can be inferred by a nominal desired output power as a function of the maximum output power (e.g. when all the segments are activated). For example, if 30% of the maximum output power is desired, then a portion of the total amplifier segments corresponding to 30% of the total number of segments can be enabled. The scalable periphery amplifier devices can be connected to corresponding impedance matching circuits. The number of amplifier segments of the scalable periphery amplifier device that are turned on or turned off at a given moment can be according to a modulation applied to an input RF signal, a desired output power, a desired linearity requirement of the amplifier or any number of other requirements.

[0031] The term “amplifier” as used in the present disclosure is intended to refer to amplifiers comprising single or stacked transistors configured as amplifiers, and can be used interchangeably with the term “power amplifier (PA)”. Such terms can refer to a device that is configured to amplify a signal input to the device to produce an output signal of greater magnitude than the magnitude of the input signal. Stacked transistor amplifiers are described for example in U.S. Pat. No. 7,248,120, issued on Jul. 24, 2007, entitled “Stacked Transistor Method and Apparatus”, the disclosure of which is incorporated herein by reference in its entirety. Such amplifier and power amplifiers can be applicable to amplifiers and power amplifiers of any stages (e.g., pre-driver, driver, final), known to those skilled in the art.

[0032] As used in the present disclosure, the term “mode” can refer to a wireless standard and its attendant modulation and coding scheme or schemes. As different modes may require different modulation schemes, these may affect required channel bandwidth as well as affect the peak-to-average ratio (PAR), also referred to as peak-to-average power ratio (PAPR), as well as other parameters known to the skilled person. Examples of wireless standards include Global System for Mobile Communications (GSM), code division multiple access (CDMA), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE), as well as other wireless standards identifiable to a person skilled in the art. Examples of modulation and coding schemes include binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), quadrature amplitude modulation (QAM), 8-QAM, 64-QAM, as well as other modulation and coding schemes identifiable to a person skilled in the art.

[0033] As used in the present disclosure, the term “band” can refer to a frequency range. More in particular, the term “band” as used herein refers to a frequency range that can be defined by a wireless standard such as, but not limited to, wideband code division multiple access (WCDMA) and long term evolution (LTE).

[0034] As used in the present disclosure, the term “channel” can refer to a frequency range. More in particular, the term “channel” as used herein refers to a frequency range within a band. As such, several channels used to transmit/receive a same wireless standard.

[0035] FIG. 1 shows a block diagram of a transmit/receive system (100) comprising a transmit path and a receive path which can be used in a multi-band and multi-channel RF front-end stage of an RF device, such as, for example, a cellular phone. The transmit/receive system (100) of FIG. 1 comprises a transceiver unit (140) adapted to generate an RF signal to be transmitted via a antenna (110) of the system. An RF transmit path of the transmit/receive system (100) can comprise an RF amplifier module (120) and a duplexer unit (130). The RF amplifier module (120) can amplify the RF signal provided by the transceiver unit (140) and further shape the RF signal in a way more suitable for transmission, such as described in, for example, U.S. patent application Ser. No. 13/829,946 and U.S. patent application Ser. No. 13/830,555, both of which are herein incorporated by reference in their entirety. Furthermore, as known to the person skilled in the art, the amplifier module (140) can comprise a plurality of series connected amplifiers, such as a driver and a final, wherein each of the series connected amplifiers may further comprise stacked transistors such as described in, for example, U.S. Pat. No. 7,248,120, incorporated herein by reference in its entirety, and/or parallel amplifiers such as scalable periphery amplifiers, as described in, for example, U.S. patent application Ser. No. 13/797,779, incorporated herein by reference in its entirety, and/or efficiency improvement amplifiers such as envelope tracking amplifiers, as described in U.S. patent application Ser. No. 13/967,866 and U.S. patent application Ser. No. 13/797,686, both incorporated herein by reference in their entirety. The amplifier module (130) thus feeds an amplified RF signal of the amplifier module (120) to the duplexer unit (130), which duplexer unit further filters the RF signal to be transmitted through a band-pass filter centered at a frequency of operation of the band within which the RF signal is transmitted. The duplexer unit (130) can allow simultaneous transmit and receive via a same transmit/receive port, such as the antenna (110), by filtering the transmit RF signal such as not to affect (e.g. overload) a receive RF signal to the receive path and filtering a receive RF signal according to a receive frequency band and channel. A received RF signal, subsequent to filtering by the duplexer (130), can be fed to the transceiver unit (140) via an internal amplifier (e.g. low noise amplifier) which is tuned for the frequency of the received RF signal and has an input stage.
closely matched to the receive path electrical characteristics (e.g. impedance) at the tuned frequency. Once the received RF signal is amplified, the transceiver unit (140) can further down convert the received amplified signal to an intermediate frequency (IF) signal used for decoding of the information (e.g. voice, data) in the received RF signal.

[0035] FIG. 2A shows an exemplary graph of frequency spectra of an RF transmit signal (210) and an RF receive signal (220) of the transmit/receive system (100) of FIG. 1. The transmit RF signal has an RF spectrum (210) centered at a transmit center frequency \( f_T \) and of peak power \( P_T \) at the transmit center frequency. Similarly, the receive RF signal has an RF spectrum (220) centered at a receive center frequency \( f_R \) and of peak power \( P_R \) at the receive center frequency. As depicted in the exemplary graph of FIG. 2A, the transmit RF signal can have an energy several order of magnitude higher than the energy of the receive RF signal, such as, for example, \( P_T/P_R > 100 \). The separation between the receive and the transmit channels in correspondence of the receive and transmit signals, as measured for example by the difference between \( f_T \) and \( f_R \), and in combination with the filters of the duplexer unit (130) of FIG. 1, allow for a detection of the RF receive signal. Therefore, design of the duplexer (130) can be according to a desired transmit/receive channel separation, latter channel separation taking into consideration spread in frequency required for the specific modulation scheme used in the RF transmit/receive signal.

[0037] As previously mentioned, a transmit/receive RF signal can be in correspondence of a frequency band associated to a wireless standard (e.g. mode), and in turn, the frequency band can comprise a plurality of channels which can be used to transmit/receive an RF signal according the defined modulation scheme of the wireless standard. FIG. 2B shows two adjacent bands (230) and (240), each band comprising a plurality (e.g. 3) of adjacent channels with center frequencies \( \{ f_{x1}, f_{x2}, f_{x3} \} \) for the channels of band (230) and center frequencies \( \{ f_{y1}, f_{y2}, f_{y3} \} \) for the channels of band (240). Separation of the various channels (e.g. distance between two adjacent center frequencies) can be such as to allow a frequency spread defined by the attenuating modulation scheme. The bands (230, 240) shown in FIG. 21 can be used for the transmit/receive system (100) of FIG. 1, such as for example, band (230) for receiving and band (240) for transmitting. Accordingly, the transmit/receive system can use any of the three channels of band (230) for transmitting and any of the three channels of band (240) for receiving. The duplexer unit (130) of the transmit/receive system (100) can be designed such as to have a center frequency for its receive filter according to the center frequency of the receive band (230) and a center frequency for its transmit filter according to the center frequency of the transmit band (240). As shown in the exemplary graph of FIG. 2B, at a given time of operation of the transmit receive system (100), a transmit channel defined by the center frequency \( f_{x1} \) can be used simultaneously with a receive channel defined by the center frequency \( f_{y1} \), and at another time of operation as depicted by FIG. 2C, a transmit channel defined by the center frequency \( f_{x2} \) can be used simultaneously with a receive channel defined by the center frequency \( f_{y2} \). In some cases the spacing (e.g. frequency spread) between the transmit and receive channels can be kept constant, such as, for example, exclusively using the pairs \( (f_{x1}, f_{y1}), (f_{x2}, f_{y2}), \) or \( (f_{x3}, f_{y3}) \) as transmit/receive frequency centers. As depicted by the two FIGS. 2B and 2C, the further apart the two channels used for transmit and receive, the least the interference between the transmit and receive signals can be. As the RF transmit signal can have far more energy than that of an RF receive signal, interference of the transmit RF signal into the receive path can have a noticeable effect on reception of the receive RF signal (e.g. overload of the receive path). Therefore, one can minimize such interference effect by increasing the receive/transmit channel spacing, or by not using all possible combinations transmit/receive channels (e.g. constant spacing as per above), both at the cost of reduced number of channels for a given frequency band of operation. Alternatively and according to the various embodiments of the present disclosure, filtering can be used to further reduce the amount of transmit RF signal reaching the receiver.

[0038] According to an embodiment of the present disclosure, a method for reducing such interference effect while maintaining a higher number of transmit/receive channels is provided. Such method uses a tunable filter in the receive and/or transmit path to further isolate the two paths with respect to each other. For example, a tunable band-reject filter tuned at a center frequency of an RF transmit signal (e.g. \( f_{x1}, f_{x2}, f_{x3} \)) can be placed in the receive path to reject a transmit RF frequency in the receive path such as depicted in FIG. 2D. Such tunable band-reject filter (235) of FIG. 2D can be placed after the duplexer unit (130) (e.g. between duplexer and input amplifier of transceiver 140) and can be designed to provide band-reject filters centered at any one of the frequencies \( f_{x1}, f_{x2}, f_{x3} \) of the channels used in the transmission of the RF signal. Although not shown in the exemplary embodiment of FIG. 21, the tunable band reject filter can comprise one or more stages (e.g. resistor-inductor-capacitor RLC) interconnected in a series and/or a shunt configuration and coupled and/or connected to the receive path in a series and/or shunt configuration (shunt configuration not shown in FIG. 2D). Some examples of such filters are provided in the above mentioned U.S. application Ser. No. entitiled “Integreted Tunable Filter Architecture” (Attorney Docket No. PER-115-PAP) filed on even date herewith and incorporated herein by reference in its entirety. A controller unit aware of the operation of the transmit/receive system of FIG. 2D, such as, for example, the transceiver unit (140), can control the configuration of the tunable band-reject filter (235) according to the channel (e.g. a corresponding frequency of operation) being used for transmission and/or reception at a given time of operation of the system. A band-reject filter configuration of the tunable band-reject filter (235) of FIG. 2D can reject a frequency within a transmission channel while pass frequencies outside the transmission channel. This tunable notch filter (e.g. band-reject) can be used to reduce the attenuation requirements of the duplexer. Since the controller knows the frequency assignments (e.g. channels used) at that moment, it can place the center of the notch at the appropriate frequency. The design requirements for such notch filter may be easier than design requirements of a bandpass filter or the duplexer filter. Fewer resonators may be required because the filter doesn’t have to cover the entire band (e.g. consisting of various channels) and the shape of the filter response can be less important than the shape of a bandpass and/or duplexer filter. The reduced number of resonators (e.g. filter stages) typically results in lower insertion loss (e.g. less than 1.5 dB versus larger than 2.0 dB) and smaller physical implementations of such tunable notch filter.

[0039] The person skilled in the art readily knows that the system block diagram depicted in FIG. 1 is a simplistic rep-
presentation of a single path transmit/receive system used in an RF front-end stage, as such front-end stage can include a plurality of similar transmit/receive paths sharing the same antenna (110), and the same transceiver unit (140). In other exemplary configurations, the plurality of the transmit/receive paths can use different antennas, such as to further increase data throughput via simultaneous RF transmit/receive on a same or different bands and/or channels, as depicted in FIG. 3. Some examples of such system implementations using a plurality of transmit/receive paths and antennas are carrier aggregation, multiple-input multiple-output (MIMO), or simply multiple radios in one end product such as a mobile cell phone.

[0040] With further reference to FIG. 3, a block diagram of a multiple paths (e.g. two paths) transmit/receive system (300) is shown, wherein each transmit/receive path uses a separate antenna. Principle of operation of each of the two transmit/receive paths is the same as described in relation to the block diagram depicted in the FIG. 1. A first transmit/receive path of the system (300) of FIG. 2 is defined by the transceiver unit (140), the amplifier module (120), the duplexer unit (130) and the antenna (110), whereas a second transmit/receive path of the system (300) is defined by the transceiver unit (140), the amplifier module (320), the duplexer unit (330) and the antenna (310). It should be noted that the antenna (110, 310) can be considered as a common transmit/receive port for the corresponding transmit/receive path as other types of ports can be envisioned such as to allow simultaneous outflow and inflow of signals to the transmit/receive system 300, such as, for example, a coupler and/or other devices known to the skilled person. It should further be noted that although the exemplary multiple RF paths transmit/receive system (300) of FIG. 3 uses a single transceiver unit (140) for all transmit/receive paths, according to some embodiments, different transceiver units can be used for each of the plurality of transmit/receive paths or for groups of the plurality of transmit/receive paths.

[0041] The duplexer units (130) and (330) of FIG. 3 can be designed for certain transmit/receive frequency bands of operation. As previously mentioned, transmit/receive system (140, 120, 130, 110) can transmit at a first transmit band and receive at a first receive band, whereas transmit/receive system (140, 320, 330, 310) can transmit at a second transmit band and receive at a second receive band. In some cases, the first and second transmit/receive bands can be a same band (e.g. same frequency span) and in other cases they can be different, as the configuration depicted in FIG. 3 can allow increased in data throughput by using the multiple (e.g. two) transmit/receive paths for an aggregate transmit/receive scheme (e.g. of a same mode) or by using the transmit/receive paths for transmit/receive different modes.

[0042] FIG. 4A shows a frequency plan that can be used by the multiple RF paths transmit/receive system (300) of FIG. 3 to increase data throughput. In the frequency plan depicted in FIG. 4A, a first frequency band (410) can range from a frequency $f_1$ to a frequency $f_2$, while a second frequency band (420), adjacent to the frequency band (410), can range from the frequency $f_3$ to a frequency $f_4$. Similarly, at a far end side of the frequency plan of FIG. 4A, a frequency band (430) can range from a frequency $f_5$ to a frequency $f_6$, while an adjacent frequency band (440), can range from the frequency $f_7$ to a frequency $f_8$. Within the frequency band (410, 420, 430, 440), a first channel (410a, 420a, 430a, 440a) may be adjacent to a second channel (410b, 420b, 430b, 440b), while a third channel (410c, 420c, 430c, 440c) may be separated from the first and the second channels.

[0043] In a first mode of operation of the multiple RF paths transmit/receive system (300) of FIG. 3 and with reference to the frequency plan of FIG. 4A, a mode being defined by, for example, a wireless system standard, separate frequency bands can be used by the multiple transmit/receive paths of the multiple RF paths transmit/receive system (300) for each signal transmission and signal reception. For example, any channel (410a, 410b, ..., 410f) of frequency band (410f) can be used for reception of an RF signal via the transmit/receive system (140, 120, 130, 110) while any channel (430a, 430b, ..., 430f) of frequency band (430f) can be used for transmission of an RF signal via the transmit/receive system (140, 120, 130, 110). Similarly, within the frequency band (420a, 420b, ..., 420f) of frequency band (420f) can be used for transmission of an RF signal via the transmit/receive system (140, 120, 130, 110) while any channel (440a, 440b, ..., 440f) of frequency band (440f) can be used for reception of an RF signal via the transmit/receive system (140, 120, 130, 110). In such mode of operation of the multiple RF paths transmit/receive system (300) of FIG. 3, transmission over the band (420) by one of the transmit/receive systems of the multiple RF paths system (300) can coincide with transmission and/or reception over the bands (430, 440) by the other transmit/receive system, and similarly, transmission over the band (440) by one transmit/receive system of the multiple RF paths system (300) can also coincide with transmission and/or reception over the bands (410, 420) by the other transmit/receive system. Therefore, during operation of the multiple RF paths transmit/receive system (300) of FIG. 3, an exemplary spectrum occupied by each of the transmit/receive systems of the multiple RF paths system (300) can be represented by the graphs depicted in FIGS. 2B and 2C, wherein the frequency bands (230, 240) can be (410, 420) for the transmit/receive system (140, 120, 130, 110) or (430, 440) for the transmit/receive system (140, 320, 330, 310).

[0044] According to a second mode of operation of the multiple RF paths transmit/receive system (300) of FIG. 3 and with reference to the frequency plan of FIG. 4A, a mode being defined by, for example, a wireless system standard, a same frequency band can be used by the multiple transmit/receive paths of the multiple RF paths transmit/receive system (300) for each signal transmission and signal reception. For example, any channel (410a, 410b, ..., 410f) of frequency band (410f) can be used for reception of an RF signal via the transmit/receive system (140, 120, 130, 110) while any channel (430a, 430b, ..., 430f) of frequency band (430f) can be used for transmission of an RF signal via the transmit/receive system (140, 120, 130, 110) while any channel (440a, 440b, ..., 440f) of frequency band (440f) can be used for reception of an RF signal via the transmit/receive system (140, 120, 130, 110). Similarly and simultaneously to the reception, any channel (420a, 420b, ..., 420f) of frequency band (420f) can be used for transmission of an RF signal via the transmit/receive system (140, 120, 130, 110) while any channel (440a, 440b, ..., 440f) of frequency band (440f) can be used for reception of an RF signal via the transmit/receive system (140, 120, 130, 110). In such mode of operation of the multiple RF paths transmit/receive system (300) of FIG. 3, transmission by one of the transmit/receive systems of system (300) over the band (420) can coincide with transmission and/or reception over the bands (410, 420) by the other transmit/receive system, and similarly, transmission over the band (440) by one transmit/receive system of the multiple RF paths system (300) can also
coincide with transmission and/or reception over the bands (430, 440) by the other transmit/receive system of the multiple RF paths system (300). Therefore, during operation of the multiple RF paths transmit/receive system (300) of FIG. 3, a spectrum occupied by each of the transmit/receive systems of the multiple RF paths system (300) can be represented by the graphs depicted in FIGS. 2B and 2C, wherein the frequency bands (230, 240) can be either (410, 420) for both transmit/receive systems (140, 120, 130, 110) and (140, 320, 330, 310), or (430, 440) for both the transmit/receive systems (140, 120, 130, 110) and (140, 320, 330, 310).

[0045] According to an embodiment of the present disclosure, a tunable notch filter, such as a narrow tunable band-reject filter, can be placed (e.g., via a series and/or a shunt connection/coupling, such as depicted in FIG. 6 later described) in either or both transmit/receive systems (140, 120, 130, 110) and (140, 320, 330, 310) in order to immune the two systems from interfering with each other (as depicted for example in FIG. 5A and FIG. 5B later described). As it is known to the person skilled in the art, RF signals at different frequencies used within a same system, such as in the multiple RF paths transceiver/receive system (300) of FIG. 3 operating in either first or second mode of operation as described in the prior sections, can influence each other via, for example, coupling (e.g., via radiation and/or crosstalk) and/or intermodulation (e.g., intermodulation distortion).

[0046] As it is well known to the person skilled in the art, intermodulation between two signals at differing frequencies \(f_1, f_2\) can engender sideband signals centered around each of the frequencies and distant from each frequency by the difference of the frequencies \(f_1, f_2\), as depicted in FIG. 4B. As shown in FIG. 4B, two signals (e.g. RF signals) centered at frequencies \(f_1, f_2\) with frequency spectra (401) and (402) respectively, can engender intermodulation components (403, 404) centered at frequencies \(2f_1-f_2\) and \(2f_2-f_1\). Let's consider the multiple RF paths transmit/receive system (300) of FIG. 3 operating in the second mode as described above, wherein both transceiver/receive systems transmit and receive using the same band. FIG. 4C depicts the transmit spectrum (401,402) of the first/second transmit/receive system operating within a transmit band (420) (e.g. referring to FIG. 4A) and using a corresponding transmit channel of center frequency \(f_1/3\) (e.g. channels 420a, 420b of FIG. 4A). Such operation of the multiple RF paths transmit/receive system (300) can engender intermodulation components (403,404). In particular and as depicted by FIG. 4C and with further reference to FIG. 4A, such intermodulation components can occur within an adjacent reception band (410) and therefore can affect reception over one or more reception channels of the reception band (410) used by the multiple RF paths transmit/receive system (300) as depicted by the receive spectrum (408) of the receive band (410) in FIG. 4D. Presence (or not) of intermodulation and location within a frequency spectrum can be predicted based on the operation mode of the multiple RF paths transmit/receive system (300). According to the various embodiments of the present disclosure, a tunable notch filter can be used to decrease the signal level at the frequency \(f_1\) and/or at the frequency \(f_2\), thus reducing the amplitude of the intermodulation product (e.g. filter 553 of FIG. 6 later described), or the notch can be used to attenuate the intermodulation product (e.g. filter 545s of FIG. 6 later described) that is generated (e.g. \(2f_1-f_2\)). Such decrease of intermodulation distortion can effectively counter the limiting effect of the intermodulation on the performance of a radio system (e.g. system 300 of FIG. 3).

[0047] The teachings according to the present disclosure provide methods and apparatus to reduce such interference in a multiple RF paths transmit/receive system, such as the exemplary system depicted in FIG. 3. It follows that, according to an exemplary embodiment of the present disclosure, a tunable notch filter, such as for example a tunable narrow band-reject filter tuned at a center frequency of an RF transmit signal, can be used in a transmit/receive system to immune such system from a second transmit/receive system operating at a different RF transmit frequency. This is depicted in FIG. 5A, wherein a tunable notch filter (535) is used in a multiple RF paths transmit/receive system (500), similar to the system (300) of FIG. 3, such as to immune a transmit/receive system (140, 320, 330, 310) from the transmit/receive system (140, 120, 130, 110). In the embodiment according to the present disclosure as depicted in FIG. 5A, the tunable notch filter (535) placed (e.g. in series connection) between the antenna (310) and the duplexer (330) of the transmit/receive system (140, 320, 330, 310) can be tuned to a frequency of operation of the transmit/receive system (140, 120, 130, 110), such as for example, an RF transmit frequency. According to other embodiments of the present disclosure, the tunable notch filter (535) can be placed at any point of the transmit/receive path between the transceiver unit (140) and the antenna (310), and can be connected in either a series or a shunted configuration to the transmit/receive path, the connection type being dependent on the design of the tunable notch filter used. According to yet further embodiments of the present disclosure, one or more tunable notch filters similar to the tunable notch filter (535) can be placed at any point of the transmit/receive system (140, 320, 330, 310) between the transceiver unit (140) and the antenna (310). According to yet another embodiment of the present disclosure, a filter of the tunable notch filter (535) of FIG. 5A can be a narrow band-reject filter which rejects a frequency within a first transmission channel used by the transmit/receive system (140, 120, 130, 110) while passes frequencies outside the first transmission channel and therefore can allow the transmit/receive system (140, 320, 330, 310) to use a transmission channel or reception channel adjacent to the first transmission channel, and thereby increase a total data (RF) throughput of system (500).

[0048] It should be noted that when the exact same bands (e.g. transmit band) are being used in both transmit/receive systems (e.g. as per system 500 of FIG. 5A), a duplexer of one transmit/receive system can protect its receiver from its transmitter as well as the second transmitter. FIG. 5A shows where the second transmitter operates at other bands (e.g. different from one used by the first transmitter), the duplexer may not have sufficient attenuation at those bands and therefore cannot protect its receiver from the second transmitter. Furthermore transmitter nonlinearity can generate increased modulated spectral bandwidth and harmonics not sufficiently attenuated by the corresponding duplexer filter and which can be detrimental to the other receiver. It follows that according to the various embodiments of the present disclosure, the notch filter (e.g. 535) may be in the portion of the transmit path preceding the duplexer (e.g. 330) as depicted in FIG. 5B, or in the common transmit/receive path between the duplexer and antenna as depicted in FIG. 5A. The person skilled in the art readily knows that such problems as related to isolation of transmit signals are more pronounced when the two radio paths (e.g. 140, 120, 130, 110) and (140, 320, 330, 310) are
in one small area such as a mobile phone, where isolation between the antennas (110, 310) may be quite limited (e.g. 15 dB of isolation) and therefore a transmitted signal from one antenna can influence quality of reception over the other antenna. In the embodiment depicted by FIG. 511, the notch filter (535) can be tuned at a center frequency corresponding to a harmonic of the operating frequency of the RF signal amplified by (320).

[0049] Although the exemplary configuration depicted by FIGS. 5A-5B show one tunable notch filter in the bottom transmit/receive system, according to an embodiment of the present disclosure, one or more tunable notch filters (e.g. 545a, 545b) similar to the tunable notch filter (535) can be placed (e.g. via a series and/or a shunt connection) at any point of the transmit/receive system (140, 120, 130, 110) as depicted, for example, in FIG. 6. In the exemplary embodiment according to the present disclosure depicted in FIG. 6, the tunable notch filter (545a) is shunted to the receive path of the transmit/receive system (140, 120, 130, 110), whereas the tunable notch filter (545b) is in series connection between the antenna (110) and the duplexer unit (130). The exemplary embodiment according to the present disclosure as depicted in FIG. 6 can immune from interference either transmit/receive system from the other. Tunable notch filters (545a, 545b) can be tuned to reduce effect of the frequency spectrum used in the transmit/receive system (140, 320, 330, 310) on the frequency spectrum used in the transmit/receive system (140, 120, 130, 110) similar to the way that tunable notch filter (535) can reduce effect of the frequency spectrum used in the transmit/receive system (140, 120, 130, 110) on the frequency spectrum used in the transmit/receive system (140, 320, 330, 310).

[0050] In the embodiment according to the present disclosure as depicted in FIG. 6, the various tunable notch filters (535, 545a, 545b) can be controlled via a controller unit aware of the operation of each transmit/receive system (140, 120, 130, 110) and (140, 320, 330, 310), such as the controller unit (140). Depending on a mode of operation (e.g. modulation, frequency) of each of the transmit/receive systems, the controller unit can know how to tune a tunable notch filter in order to immune each of the transmit/receive systems from interference of the other. In some cases, it is possible that no tunable notch filter is necessary, and therefore, according to some embodiments of the present disclosure, the tunable notch filters can be switched in or out of a corresponding path, such as depicted in FIG. 7, wherein RF switches (725a, 725b, 725c) can be used to switch in or out tunable notch filters (545a, 545b, 535).

[0051] According to a further embodiment of the present disclosure, the combination of tunable notch filter (e.g. 545a, 545b, 535) and switch (e.g. 725a-c) can be monolithically integrated within a same integrated circuit as depicted in FIG. 8A and FIG. 8B. The integrated circuit of FIG. 8A/8B comprises a control terminal (CNTRL) which can be used to control the configuration of the internal switch (725c-725a) and the tuning of the tunable notch filter (535/545a) via a control signal, generated, for example, by a transceiver unit or a signal-aware controller module. The person skilled in the art will know that such control signal can comprise one or more digital and/or analog signal lines and a corresponding interface can be implemented in a variety of methods which are outside the scope of the present disclosure. As noted in the previous sections of the present disclosure, the integrated circuit of FIG. 8A can be used in a series connection with a signal path connected to ports S1 and S2 of the integrated circuit, whereas the integrated circuit of FIG. 8B can be used in a shunt connection with a signal path connected to port S (or port N) of the integrated circuit and a common reference potential connected to the port N (or port S) of the integrated circuit. In both configurations of the integrated circuit depicted by FIG. 8A and FIG. 8B, the turning ON/OFF of the switch can cause a current to flow not through the tunable notch filter and therefore affect or not a characteristic of a signal coupled to the integrated circuit. Furthermore, such integrated circuit as depicted in FIG. 8A and FIG. 8B can be made to operate in a single-ended or differential signal mode, as required by a receive/transmit path wherein such integrated circuit is used. As known by the person skilled in the art, a receive path of a multiple RF paths transmit/receive system such as one depicted in the various figures of the present disclosure can comprise a differential signal path (e.g. input to a transceiver unit).

[0052] The tunable notch filters described in the various embodiments according to the present disclosure can be constructed using one or more variable reactive elements, such as variable capacitors and variable inductors. Digitally tunable capacitors (DTC) and/or digitally tunable inductors, as described in, for example, International Application No. PCT/US2009/001358 and U.S. patent application Ser. No. 13/595,893, can also be used in constructing such tunable notch filter. The person skilled in the art readily knows how to realize such tunable filters and how to select components with values (e.g. ranges of values) consistent with a desired filter bandwidth and attenuation. As known by the person skilled in the art, such components can be partitioned into various filter stages via series and/or shunt connections, and in turn, the various filter stages can be interconnected (e.g. cascaded) via series and/or shunt connections. Some exemplary embodiments of tunable notch filters are described in the above mentioned U.S. application Ser. No. 15/039,893 entitled “Integrated Tunable Filter Architecture” (Attorney Docket No. PER-115-PAP) filed on even date herewith and incorporated herein by reference in its entirety.

[0053] Although the various exemplary embodiments of the present disclosure are based on a multi-path transmit/receive system showing two separate transmit/receive systems (e.g. (140, 120, 130, 110) and (140, 320, 330, 310)), each with a dedicated transmit/receive antenna (e.g. (110, 310), such limitation of two transmit/receive systems is mainly exemplary in nature and not intended to limit the scope of the invention which can certainly be extended to more than two such transmit/receive systems, each with a dedicated transmit/receive antenna. In such configuration, a controller unit can tune the various tunable notch filters according to the known signal spectra used in the various transmit/receive systems. Such spectra can comprise not only known operating frequencies (e.g. channel frequencies) associated to the various transmitted and received signals within the various transmit/receive systems, but also can comprise various harmonics and intermodulation products thereof which alone or in combination can affect operation of one or more of the various transmit/receive systems. Additionally, each transmit/receive system can comprise more than one transmit/receive path, as a plurality of parallel transmit/receive paths can be connected to an antenna via a dedicated antenna switch, as typically done in current RF front-end stages used in current cellular devices.
By way of further example and not limitation, any switch or switching circuitry of the present disclosure, such as switches (725a-c) of FIG. 7 can be implemented using transistors, stacked transistors (FETs), diodes, or any other devices or techniques known to or which can be envisioned by a person skilled in the art. In particular, such switching circuitry can be constructed using CMOS technology and various architectures known to the skilled person, such as, for example, architecture presented in U.S. Pat. No. 7,910,993, issued on Mar. 22, 2011 and entitled “Method and Apparatus for use in Improving Linearity of MOSFET’s using an Accumulated Charge Sink”, and in U.S. Pat. No. 6,804,502, issued on Oct. 12, 2004 and entitled “Switch Circuit and Method of Switching Radio Frequency Signals”, both incorporated herein by reference in their entirety. FIG. 9 shows an exemplary embodiment of a single-pole single-throw switch with stacked transistors, which the skilled person can use as an elementary component of the various switches used in the various embodiments according to the present disclosure.

Although FETs (e.g. MOSFETs) can be used to describe transistor and stacked transistor switches used in the various embodiments of the present disclosure, a person skilled in the art would recognize that either P-type or N-type MOSFETs may be used. The skilled person would also recognize that other types of transistors such as, for example, bipolar junction transistors (BJTs) can be used instead or in combination with the N-type or P-type MOSFETs. Furthermore, a person skilled in the art will also appreciate the advantage of stacking more than two transistors, such as three, four, five or more, provide on the voltage handling performance of the switch. This can for example be achieved when using non bulk-Silicon technology, such as insulated Silicon on Sapphire (SOS) technology and silicon on insulator (SOI) technology. In general, the various switches used in the various embodiments of the present disclosure, including when monolithically integrated with a tunable notch filter, such as depicted in FIG. 8, can be constructed using CMOS, silicon germanium (SiGe), gallium arsenide (GaAs), gallium nitride (GaN), bipolar transistors, or any other viable semiconductor technology and architecture known, including micro-electro-mechanical (MEM) systems. Additionally, different device sizes and types can be used within a stacked transistor switch such as to accommodate various current handling capabilities of the switch.

The examples set forth above are provided to give those of ordinary skill in the art a complete disclosure and description of how to make and use the embodiments of the present disclosure, and are not intended to limit the scope of what the inventors regard as their disclosure. Modifications of the above described modes for carrying out the disclosure may be used by persons of skill in the art, and are intended to be within the scope of the following claims. All patents and publications mentioned in the specification may be indicative of the levels of skill of those skilled in the art to which the disclosure pertains. All references cited in this disclosure are incorporated by reference to the same extent as if each reference had been incorporated by reference in its entirety individually.

It is to be understood that the disclosure is not limited to particular methods or systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting. As used in this specification and the appended claims, the singular forms “a”, “an”, and “the” include plural referents unless the context clearly dictates otherwise. The term “plurality” includes two or more referents unless the context clearly dictates otherwise. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the disclosure pertains.

A number of embodiments of the disclosure have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the present disclosure. Accordingly, other embodiments are within the scope of the following claims.

1. A radio frequency (RF) circuit arrangement comprising:
   a first transmit/receive system comprising a first transmit path configured to transmit a first transmit RF signal at a first transmit/receive port, and a first receive path configured to receive a first receive RF signal at the first transmit/receive port;
   a second transmit/receive system comprising a second transmit path configured to transmit a second transmit RF signal at a second transmit/receive port, and a second receive path configured to receive a second receive RF signal at the second transmit/receive port, and
   one or more tunable notch filters configured to reduce a radio frequency interference from a transmit/receive system of the first and second transmit/receive systems over the other transmit/receive system.

2. The RF circuit arrangement of claim 1, wherein a tunable notch filter of the one or more tunable notch filters is connected between a transmit/receive port of the first and the second transmit/receive ports and a duplexer unit in correspondence of the transmit/receive port.

3. The RF circuit arrangement of claim 1, wherein a tunable notch filter of the one or more tunable notch filters is connected between a duplexer unit of a transmit/receive system of the first and the second transmit/receive systems and an input RF amplifier of the transmit/receive system.

4. The RF circuit arrangement of claim 1, wherein the tunable notch filter of the one or more tunable notch filters is connected between a transmit amplifier of a transmit/receive system of the first and the second transmit/receive systems and a duplexer unit in correspondence of the transmit/receive system.

5. The RF circuit arrangement of any one of claims 2-4, wherein the tunable notch filter is connected in series and/or a shunt configuration.

6. The RF circuit arrangement of claim 1, further comprising one or more RF switches, wherein the one or more RF switches are configured to enable or disable an effect of the one or more tunable notch filters over a transmit/receive system of the first and second transmit/receive systems.

7. The RF circuit arrangement of claim 6, wherein a switch of the one or more RF switches is connected in parallel to a tunable notch filter of the one or more tunable notch filters.

8. The RF circuit arrangement of claim 7, wherein the switch is connected between a first and a second input/output terminal of the tunable notch filter.

9. The RF circuit arrangement of claim 6, wherein a switch of the one or more switches is connected in series to a tunable notch filter of the one or more tunable notch filters.
10. The RF circuital arrangement of claim 7 or claim 9, wherein a switch of the one or more switches comprises stacked transistors.

11. The RF circuital arrangement of claim 1, wherein a tunable notch filter of the one or more tunable notch filters is a band-reject filter configured to reject a frequency band in correspondence of a first transmit/receive channel and to pass a frequency band in correspondence of a second transmit/receive channel adjacent to the first transmit/receive channel.

12. The RF circuital arrangement of claim 11, wherein the frequency band is in correspondence of one of: a) a frequency of operation of a transmit RF signal of the first and the second transmit RF signals, b) a harmonic of a), and c) an intermodulation product of any combination of a) and b).

13. The RF circuital arrangement of claim 1, wherein a tunable notch filter of the one or more tunable notch filters comprises one or more variable reactive elements.

14. The RF circuital arrangement of claim 13, wherein the one or more variable reactive elements are partitioned in one or more stages interconnected via series and/or shunt connections.

15. The RF circuital arrangement of claim 13, wherein a reactive element of the one or more reactive elements comprises one of: a) a digitally tunable capacitor, and b) a digitally tunable inductor.

16. The RF circuital arrangement of claim 1, wherein during operation of the circuital arrangement, the first and the second transmit/receive systems are adapted to simultaneously transmit and/or receive an RF signal over a channel of a plurality of channels of a frequency band.

17. The RF circuital arrangement of claim 1, wherein the first transmit/receive port comprises a first transmit/receive antenna and the second transmit/receive port comprises a second transmit/receive antenna.

18. The RF circuital arrangement of claim 1, further comprising one or more transmit/receive systems similar to the first/second transmit/receive systems, wherein one or more of the one or more tunable notch filters are configured to reduce a radio frequency interference of a transmit/receive system of the RF circuital arrangement over the other transmit/receive systems of the RF circuital arrangement.

19. A radio frequency (RF) integrated circuit comprising: an RF switch comprising a first switch terminal and a second switch terminal; a RF tunable notch filter comprising a first port and a second port, wherein in a first configuration of the RF integrated circuit the first port is connected to the first switch terminal and the second port is connected to the second switch terminal, and in a second configuration of the RF integrated circuit the first port is connected to the second switch terminal; a first input/output terminal connected to the first switch terminal; a second input/output terminal connected to the second port; and a control terminal, wherein during operation, a control signal at the control terminal of the RF integrated circuit is configured to tune the RF tunable notch filter and/or control the RF switch to enable/disable a current flow through the RF tunable notch filter.

20. The RF integrated circuit of claim 19, wherein the RF tunable notch filter comprises one or more variable reactive elements.

21. The RF integrated circuit of claim 20, wherein a reactive element of the one or more variable reactive elements comprises one of: a) a digitally tunable capacitor, and b) a digitally tunable inductor.

22. The RF integrated circuit of claim 19 monolithically integrated on a same integrated circuit.

23. The RF integrated circuit of claim 22 fabricated using a technology comprising one of: a) Silicon on Sapphire, b) Silicon on Insulator, c) bulk-Silicon, and d) micro-electro-mechanical systems.

24. The RF circuital arrangement of claim 19 configured for operation in one of: a) a differential mode, and b) a single-ended mode.

25. A communication device for transmitting and receiving RF signals via one or more antennas, the communication device comprising the RF circuital arrangement of claim 1 or claim 18, wherein the one or more antennas of the communication device are coupled to a plurality of transmit/receive ports of a plurality of transmit/receive systems of the RF circuital arrangement.

26. The communication device of claim 25 further comprising a transceiver unit, wherein during operation of the communication device, the transceiver unit is adapted to send/receive a plurality of transmit/receive RF signals to/from the plurality of transmit/receive systems of the RF circuital arrangement.

27. The communication device of claim 26, wherein, during operation of the communication device, the transceiver unit is adapted to control the one or more tunable notch filters based on a characteristic of one or more RF signals of the plurality of transmit/receive RF signals.

28. The communication device of claim 27, wherein the characteristic comprises a frequency spectra of the one or more RF signals.

29. The communication device of claim 28, wherein the frequency spectra comprises at least one of: a) spectra of a frequency of operation of an RF signal of the one or more RF signals, b) spectra of a harmonic of a) and c) spectra of an intermodulation product of the one or more RF signals.

30. A method for reducing radio frequency (RF) interference in an RF circuital arrangement, the method comprising: providing a plurality of RF transmit/receive systems coupled to a plurality of RF antennas; connecting in a path of a first RF transmit/receive system of the plurality of RF transmit/receive systems one or more RF tunable notch filters; adjusting an RF tunable notch filter of the one or more RF tunable notch filters based on a characteristic of a transmit/receive RF signal of an RF transmit/receive system of the plurality of RF transmit/receive systems other than the first RF transmit/receive system; and based on the adjusting, reducing an RF interference of the transmit/receive RF signal over the first RF transmit/receive system.

31. The method of claim 30, further comprising: monitoring the characteristic of the transmit/receive RF signal; based on the monitoring, detecting a change of the characteristic; based on the detecting, further adjusting the RF tunable notch filter; and based on the further adjusting, maintaining a reduced RF interference of the transmit/receive RF signal over the first RF transmit/receive system.
32. The method of claim 31, further comprising: based on the maintaining, providing a larger operating frequency spectrum to the first transmit/receive RF system; based on the providing, increasing a number of transmit/receive channels available to the first transmit/receive RF system; and based on the increasing, increasing data throughput of the RF circuitual arrangement.

33. The method of claim 30, wherein the characteristic of the transmit/receive RF signal comprises a known operating frequency of the transmit/receive RF signal.

34. The method of claim 33, wherein the known operating characteristic is in correspondence of a selected transmit/receive channel.

35. The method of claim 34, wherein selection of the selected transmit/receive channel is performed by a transceiver unit.

36. A radio frequency (RF) circuitual arrangement comprising:
   a transmit path configured to transmit, during a transmit mode of operation of the RF circuitual arrangement, a transmit RF signal at a transmit/receive port of the RF circuitual arrangement;
   a receive path configured to receive, during a receive mode of operation of the RF circuitual arrangement, a receive RF signal at the transmit/receive port; and
   a tunable notch filter configured to reduce a radio frequency interference of the transmit RF signal over the receive RF signal, wherein during operation, the RF circuitual arrangement is configured to simultaneously operate in the transmit and receive modes of operation.

37. The RF circuitual arrangement of claim 36, wherein the transmit path and the receive path are coupled to the transmit/receive port via a duplexer unit and wherein the tunable notch filter is connected between the duplexer unit and one of: a) an input RF amplifier of the receive path, b) a transmit RF amplifier of the transmit path, and c) the transmit/receive port.

38. The RF circuitual arrangement of claim 36 or claim 37, wherein the tunable notch filter is connected in a series or shunt configuration.

39. The RF circuitual arrangement of claim 38, further comprising an RF switch coupled to the tunable notch filter, wherein during operation of the RF circuitual arrangement, the RF switch is configured to enable and/or disable an effect of the tunable notch filter over the receive RF signal.

40. The RF circuitual arrangement of claim 39, wherein the switch comprises stacked transistors.

41. The RF circuitual arrangement of claim 39, wherein the switch is connected in one of: a) parallel configuration and b) serial configuration to the tunable notch filter.

42. The RF circuitual arrangement of claim 36, wherein the tunable notch filter is a band-reject filter configured, during operation of the RF circuitual arrangement, to reject a frequency of operation of the transmit RF signal and to pass a frequency of operation of the receive RF signal.

43. The RF circuitual arrangement of claim 42, wherein: the frequency of operation of the transmit RF signal is in correspondence of a transmit channel of a plurality of transmit channels; and
   the frequency of operation of the receive RF signal is in correspondence of a receive channel of a plurality of receive channels; and
   the RF circuitual arrangement is configured to operate in one or more transmit and receive channels.

44. The RF circuitual arrangement of claim 36, wherein the tunable notch filter comprises one or more variable reactive elements.

45. The RF circuitual arrangement of claim 44, wherein a reactive element of the one or more variable reactive elements comprises one of: a) a digitally tunable capacitor, and b) a digitally tunable inductor.

46. The RF circuitual arrangement of claim 36, wherein the transmit/receive port comprises a transmit/receive antenna.

47. A communication device for transmitting and receiving radio frequency (RF) signals via an antenna, the communication device comprising the RF circuitual arrangement of claim 43, wherein the antenna of the communication device is coupled to the transmit/receive port of the RF circuitual arrangement.

48. The communication device of claim 47 further comprising a transceiver unit, wherein during operation of the communication device, the transceiver unit is configured to send the transmit RF signal and to receive the receive RF signal respectively to/from the transmit path and receive path of the RF circuitual arrangement.

49. The communication device of claim 48, wherein, during operation of the communication device, the transceiver unit is adapted to control the tunable notch filter based on a transmit channel frequency and/or a receive channel frequency in correspondence of the transmit RF signal and the receive RF signal respectively.

50. A method for reducing radio frequency (RF) interference in an RF circuitual arrangement, the method comprising: providing an RF transmit path to transmit a transmit RF signal over an antenna; providing an RF receive path to receive a receive RF signal over the antenna; coupling a tunable notch filter to the RF transmit or the RF receive path; adjusting the tunable notch filter based on a frequency of operation of the transmit RF signal; and based on the adjusting, reducing an RF interference of the transmit RF signal over the receive RF signal.

51. The method of claim 50, wherein the adjusting further comprises:
   further adjusting the tunable notch filter based on a frequency of operation of the receive RF signal.

52. The method of claim 50, wherein the frequency of operation is in correspondence of a frequency of a selected transmit channel and wherein the adjusting is performed under control of a controller unit aware of the selected transmit channel.

53. The method of claim 52, wherein the controller unit is a transceiver unit.

54. The method of claim 51, wherein the adjusting is based on an intermodulation product of the frequency of operation of the transmit RF signal and the frequency of operation of the receive RF signal.