(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 December 2016 (29.12.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/205952 A1

(51) International Patent Classification:
H04W 88/08 (2009.01) *H04B 1/40* (2015.01)
H01P 1/38 (2006.01)

(21) International Application Number:
PCT/CA2016/050746

(22) International Filing Date:
27 June 2016 (27.06.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/184,661 25 June 2015 (25.06.2015) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

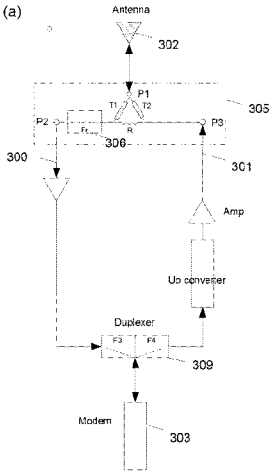
— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

WO 2016/205952 A1

(54) Title: DUPLEXER WITH SIGNAL CANCELLATION

Fig. 3 (a)



(57) Abstract: A wireless communication system has a base station operative to communicate wirelessly with a plurality of customer devices. The base station has a circulator with a first port connected to one or more signal transmission devices, a second port that is connected to one or more antennas, and a third port that is connected to one or more signal reception devices. The circulator communicates transmission signals from the one or more signal transmission devices to the one or more antennas, and communicates received signals from the one or more antennas to the one or more signal reception devices. The plurality of customers devices have cancellation/separation duplexers or circulators.

DUPLEXER WITH SIGNAL CANCELLATION

FIELD

[0001] This relates to a duplexer with signal cancellation for use in two-way wireless communication systems and illustratively in customer premises equipment for full duplex broadband systems operating in the UHF spectrum.

BACKGROUND

[0002] Rural communities around the world are in need of broadband services as is frequently commented on by governments and news media. The efforts to supply such services usually rely on setting up towers and transmitting at low power and at a high frequency range of well over 900 MHz. These systems are expensive and not economically feasible for areas with low population densities.

[0003] Recently, systems employing the 500-900 MHz range and operating in licensed UHF frequencies have been deployed in Canada to service First Nation Communities as well as rural communities. Such systems also require a tower. But the systems permit coverage of 2000 to 3000, or more, square kilometers rather than the 75 – 100 square kilometers covered by the systems using higher frequencies and lower power levels.

[0004] The system at the tower is in communication with a plurality of customers each of which has customer premises equipment (CPE). In a full duplex broadband system where high power signals are transmitted from a base station (the tower) to a plurality of customers premises equipment, these transmit signals, when received by customer premises equipment, have to be isolated from high power customer transmit signals. The isolation is accomplished traditionally by a duplexer. But in a full duplex broadband system, each customer premises equipment is assigned a different pair of transmit and received channel frequencies. Consequently, a duplexer of different specification is required for each customer.

[0005] The duplexer employs two multistage filters and is operative to allow bi-directional communication over a single antenna. For CPE, it operates to separate the receive signal from the transmit signal while permitting them to share a common antenna. The duplexer must be designed for operation in the frequency band (470-860MHz) used by the receiver and

transmitter and must be capable of handling the output power of the transmitter. Also, the duplexer must provide adequate rejection of transmitter noise occurring at the receive frequency and must be designed to operate at, or less than, the frequency separation between the transmitter and receiver. Since duplexers are not available which operate at a separation of less than 24 MHz, the frequencies for each CPE must be 24 MHz apart and each CPE requires a different unique duplexer.

[0006] The system (CPE) of Fig. 1 transmits, illustratively, at 713 MHz and receives at 743 MHz. At the CPE the transmit power of 25 dBm is much greater than the received power of –92 dBm.

[0007] Using the full duplex DOCSIS system for wireless connectivity at a customer location, it was found necessary to be able to transmit a signal that is .5 watts (or 500 mwatts or 76 dBmV into a 75 Ohms antenna and also receive a signal that is 1.000e-12 watts (or 1.000e-9 mwatts or –40 dBmV) on the same antenna. As can be seen the transmit signal is huge compared to the receive signal. To be able to use the same antenna for transmit and receive signals, it was necessary to have a duplexer that can separate the two signals and achieve a reasonable level of signal to noise ratio on the receive signal. The duplexer has to be able to provide greater than 110 dB of separation between the two signals. Making a duplexer that can achieve 110 dB of separation is extremely difficult. Only fixed frequency duplexers can be made with fixed frequency components. If the transmit and receive frequencies are close together (less than 18 MHz), it is next to impossible to make a duplexer that can achieve 110 dB of separation. Ceramic duplexers are the only ones that are of reasonable size and they have been used to-date to provide the separation. Each time a new pair of frequencies is used, a new ceramic duplexer has to be custom built. There is no easy way of creating a frequency agile duplexer or equivalent. Also the ceramic duplexers have not been able to achieve the separation needed and the receive signals are corrupted by the transmit signals. Much higher receive signals are needed to reduce the corruption of the receive signals by the transmit signals.

[0008] The CPE equipment has two limitations, which limit the area over which satisfactory system operation can occur. First, the duplexer has difficulties separating the transmit and receive channels from one another. The second limitation is due to the fact that the gain of the common antenna does not have to be the same for both the transmit and the

receive signals. The problem thus is to eliminate the need for a different duplexer for each CPE or provide a frequency agile duplexer.

SUMMARY

[0009] According to an aspect, the present device relates to a Wilkinson combiner, which is normally operative to combine first and second signals at first and second input ports for output at a third port, that has a characteristic of responding to a single input signal at one of the input ports to cancel that signal at the second input port. That characteristic is turned to account herein by the addition of a filter at the second input port and operating that port as an output port. The resulting device was tested and exhibited over 40 dB of signal cancellation and an additional 80 dB of separation a result which was particularly attractive for use as a duplexer for two way communication systems, where a transmit signal at the first input port (the transmit port) is totally cancelled at the receive port and signals received at the 3rd port arrive uncontaminated by the transmit signal.

[0010] Thus, according to an aspect, a signal combiner (plus a filter circuit) connected between a common antenna and the down link and uplink of a two-way communication system provides a much better result than does a conventional duplexer in preventing contamination of a receive signal in the downlink from high power signals in the uplink. Adapting a Wilkinson (or a hybrid) combiner by adding a filter circuit results in a duplexer with a cancellation portion and a separation portion which provided a surprising useful solution to the specific problem of customer premises equipment or the base station equipment in a way that's useful for all full-duplex communication systems.

[0011] One technique to reduce the corruption by the transmit signal of the receive signal is to utilize two separate antennas. One for transmit and a second for receive. This way there is no electrical connection between the two antennas. The corruption of the receive signals by the transmit signals is reduced since there is no electrical connection between the two signals. This requires mounting two antennas on a pole within close proximity. Plus the two antenna have to be aligned separately, they have to be spaced apart to achieve additional separation to reduce the corruption of the receive signal by the transmit signal. Even with a large separation between the two antennas the best possible separation with the two signals is less than 30 dB. The cost of this solution was high and required having two antennas, a

solution too expensive for CPE. The two antennas system, however, was extremely useful for mounting on a tower as is explained in United States Patent and Trademark Office co-pending application no. 13/750,987, filed 01/25/2013 for the present applicant.

[0012] Utilizing a Wilkinson combiner with a filter circuit a signal cancellation was achieved that provided over 40 dB between the two signals and 80 dB of separation due to the filter circuit. The signal cancellation filter circuit combination permits the use of the same antenna for transmit and receive signals.

[0013] In addition, the receive filter circuit no longer needs to have the same rating as the transmit band-pass filter. The transmit signal received on the receive port is over 40 dB less than the actual transmit signal and thus there is no need for a transmit filter at all.

[0014] When the Wilkinson is tuned correctly, over 50 dB of separation is achieved. The 80 dB of separation provided by the filter circuit and the addition of the cancellation portion provides an effective separation of over 120 dB, something that could not be achieved with ceramic duplexer or any other kinds of integratable duplexers. With this additional cancellation, even smaller signals can be received and much higher signal to noise ratio on the receive signal can be achieved. A much lower power rated receive filter circuit can also be used. Furthermore, the cancellation portion circuit can be made to work over a broad frequency spectrum by using a multistage Wilkinson. With the additional 40 dB of cancellation, transmit and receive signals could also be much closer in frequency than is possible with conventional duplexers, almost vanishingly close.

[0015] One of the drawbacks of the Wilkinson combiner is that 3 dB of power is lost on the transmit signal and also 3 dB of power is lost on the receive signal. But in view of the additional over 40 dB of isolation this is a small price to pay. It may also be possible to use an uneven power rating on the Wilkinson combiner to reduce the power loss on the receive signal or the transmit signal.

[0016] The same cancellation filter circuit combination (cancellation/separation duplexer) can be used in any full duplex communication system where a duplexer is utilized today be it Tower, Customer Premise Equipment or Mobile communication system. Currently, most mobile communication system are half-duplex since there is a problem separating the transmit and receive frequencies since high quality duplexers are not easily made and high separation between the two signals is extremely difficult to achieve. With the Wilkinson combiner and

filter circuit combination there is provided an extremely large separation between the two isolated signals.

[0017] With the initial cancellation, between the two signals, the addition of a heterodyne circuit creates a frequency agile transceiver, see Fig. 4.

[0018] Accordingly, there is provided a duplexer having first, second and third ports and adapted for connection between an antenna and uplink and downlink, respectively, in a full duplex communication system.

[0019] According to an aspect, the duplexer comprises first and second quarter wave transformers connected between said first and third and between said first and second ports, respectively, a balancing resistor connected between said third port and the output of said second transformer, and a filter circuit connected between said output of said second transformer and said second port.

[0020] In some aspects, the filter circuit of the duplexer may comprise a bandpass filter or a heterodyne receiver.

[0021] In some aspects the duplexer may be in combination with an antenna connected to said first port and an uplink and a downlink of a two-way communication system connected to said third port and said second port respectively. The antenna may be located exterior to a customer premises in a wireless full duplex communication system between equipment in each of a plurality of customers premises and a tower in the base station of said system, said combination in each of the customer premises equipment comprising a heterodyne circuit for providing a frequency agile circuit for passing each frequency of each different pair of spaced apart frequencies assigned to each of said customers.

[0022] In some aspects, there may be a mobile device comprising a duplexer having some or all of the aspects described above, and there may be a plurality of mobile devices in communication with a base station.

[0023] According to an aspect, there is provided a duplexer operative to provide a signal cancellation and separation for connection between an antenna and a downlink and an uplink of a full duplex communication system.

[0024] In some aspects, the duplexer of the communication system comprises first, second, and third ports; first and second like quarter wave transformers connected between said first port and said second port and between said first port and said third port, respectively;

a filter circuit connected between said first quarter wave transformer and said second port; and a balancing resistor connected at one end to said first output port and to a point between said first quarter wave transformer and said filter at the other end.

[0025] In some aspects, there may be a duplexer with one or more features described herein that are attributed to duplexers in combination with an antenna connected to the first port. There may be a down link and an uplink connected to said second port and said third port respectively.

[0026] According to an aspect, there is provided a method of making a duplexer with cancellation and separation. The method may comprise the steps of modifying a Wilkinson combiner having a first port with first and second quarter wave transformers connected between a second port and said first port and between a third port and said first port respectively and a balancing resistor connected between said second and third ports. The Wilkinson combiner may be modified by connecting a bandpass filter circuit to said second quarter wave transformer and said balancing resistor at one end and the third port at the other end.

[0027] The modified Wilkinson combiner may have one or more features attributable to duplexers as described herein.

[0028] According to an aspect, there is provided a duplexer comprising first, second and third ports adapted for connection to an uplink and a downlink of a full duplex wireless communication system. The duplexer may comprise first and second quarter wave transformers connected between said first port and said second port and between said first port and said third ports respectively; a filter circuit connected between said second quarter wave transformer and said third port; and a balancing resistor connected between said second quarter wave transformer and said filter circuit at one end and said second port at the other end.

[0029] According to an aspect, there is provided a duplexer operative to provide signal cancellation and separation. The duplexer may comprise a cancellation portion and a separation portion, said cancellation portion being operative to cancel all but a selected signal from multiple signals applied thereto, said separation portion being operative to filter out selected signal from non-selected signals.

[0030] According to some aspects, the cancellation portion may comprise a Wilkinson

combiner as described herein in a cancellation configuration and the separation portion may comprise a filter connected at an outlet of the cancellation portion.

[0031] According to an aspect, there is provided a full duplex, two-way communication system comprising a duplexer as described herein, said duplexer being connected between an antenna and a transmit port and a receive port, said duplexer being operative to prevent transmit signals at said transmit port from appearing at said receive port.

[0032] According to some aspects, the system may comprise a heterodyne receiver connected to said receive port.

[0033] According to some aspects, first and second quarter wave transformers may be located between said transmit port and said receive port and operative to shift the phase of transmit signals 180 degrees in a manner to effectively cancel said transmit signals at said receive port.

[0034] According to some aspects, said duplexer transmit and receive ports may be connected such that the phase of any signal transmitted at said transmit port is shifted 180 degrees in a manner to effectively cancel the transmit signal at said receive port.

[0035] According to an aspect, there is provided a full duplex wireless communication system in which transmit and receive signals are transmitted between a base station and a plurality of subscriber equipment at first and second frequencies which are vanishingly close, each of said base station and subscriber equipment comprising a cancellation/separation duplexer having a transmit port and a receive port and being operative to shift the phase of any transmit signal at one of said transmit ports 180 degrees at the corresponding receive port.

[0036] According to some aspects, the system may comprise cancellation/separation duplexers with first and second quarter wave transformers operative to shift the phase of any transmit signal 180 degrees.

[0037] According to some aspects, the subscriber equipment may comprise customer premises equipment mobile devices, or combinations thereof.

[0038] According to an aspect, there is provided a full duplex wireless communication system comprising a base station and a plurality of subscriber equipment, each of said base station and subscriber equipment comprising a cancellation/separation duplexer where transmit signals from subscriber equipment and receive signals from said base station are at the same frequency and encoded in first and second encoding techniques, respectively.

[0039] According to some aspects, the encoding techniques in the system may be frequency modulation and/or amplitude modulation.

[0040] According to some aspects, the subscriber equipment may comprise mobile devices, customer premises equipment, or combinations thereof.

[0041] According to some aspects, the system may comprise an antenna and a cancellation/separation duplexer having a transmit and a receive port wherein the impedance of said antenna and said transmit and receive ports are matched.

[0042] According to some aspects, the transmit and receive signals may be encoded in CMDA.

[0043] According to an aspect, in a full duplex wireless communication system in which transmit and receive signals are transmitted between a base station and individual subscriber equipment at the same frequency, the transmission of transmit and receive signals are encoded in first and second encoding techniques, respectively. The base station and the individual subscriber equipment may each comprise a cancellation/separation duplexer.

[0044] According to an aspect, there is provided the transmission of transmit and receive signals at the same frequency encoded in first and second encoding techniques, respectively, in a full duplex wireless communication system.

[0045] According to some aspects, the transmission of transmit and receive signals may be in a full duplex wireless communication system that comprises cancellation/separation duplexers.

[0046] According to some aspects, the first and second encoding techniques comprised frequency and amplitude modulation.

[0047] According to some aspects, the transmit and receive signals may be encoded in CDMA.

[0048] According to an aspect, there is provided a full duplex wireless communication system in which signals are transmitted between a base station and a plurality of subscriber equipment at the same frequency, each of said base station and subscriber equipment comprising a cancellation/separation duplexer having a transmit port and a receive port and being operative to shift the phase of any transmit signal at one of said transmit ports 180 degrees at the corresponding receive port.

[0049] According to some aspects, the transmit and receive signals may be encoded in

first and second different encoding techniques. The transmit and receive signals may be encoded in frequency modulation and amplitude modulation, respectively or in CMDA.

[0050] According to some aspects, each of said duplexers may be connected to an antenna and the impedances of the antenna and the receive and transmit ports of the duplexer are the same.

[0051] According to another aspect, there is provided a wireless communication system comprising a tower operative to communicate wirelessly with a plurality of customers wherein said tower comprises a circulator and said plurality of customers having cancellation/separation duplexers and communications therebetween are encoded with a first and second different encoding schemes for transmit and receive signals.

[0052] According to another aspect, there is provided a method of sending transmit signals between a circulator in a base station and a service subscriber having a cancellation/separation duplexer, said method using the same frequency for transmit and receive signals, and the use of first and second encoding schemes for said transmit and receive signals respectively.

[0053] According to another aspect, there is provided a full duplex wireless communication system comprising a base station operative to communicate wirelessly with a plurality of subscriber equipment using the same frequency for transmit and receive signals therebetween, each of said subscriber equipment comprising a circulator connected between an antenna and an uplink and a downlink, each of said subscriber equipment comprising a modem operative to encode transmit signals in a first encoding scheme and decoding receive signal a second encoding scheme respectively.

[0054] According to an aspect, said base station may comprises a modem operative to encode transmit signals in said second encoding scheme and decoding receive signals in said first encoding scheme. Said subscriber equipment may comprise customer premises equipment and said base station comprises a tower. Said subscriber equipment may comprises a mobile device.

[0055] According to an aspect, transmit and receive signals may be encoded in CDMA.

[0056] According to another aspect, there is provided a method for operating a full duplexer wireless system comprising a base station and a plurality of subscriber equipment in which transmit and receive signals therebetween utilize the same frequency, said method comprising transmitting and receiving signals at said subscriber equipment encoded in first

and second encoding schemes respectively and transmitting and receiving signals at said base station encoded in said second and first encoding schemes respectively.

[0057] It will be understood that the features described with respect to the duplexers, communication systems, transmissions may be combined in various combinations to be applicable in various situations, as will be recognized by those skilled in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

[0058] These and other features will become more apparent from the following description in which reference is made to the appended drawings, the drawings are for the purpose of illustration only and are not intended to be in any way limiting, wherein:

Fig. 1 is a generic block diagram of prior art two way communication system;

Fig. 2 is a block diagram of a prior art two way communication system for customer premises equipment (CPE);

Fig. 3a and 3b are block diagrams of a generic wireless two way communication system including a cancellation/separation circuit combination and a single stage Wilkinson adapted to that use respectively;

Fig. 4 is a block diagram of the customer premises equipment of Fig. 2 adapted to include a cancellation/separation circuit;

Fig. 5a, 5b, and 5c are block diagrams of the Wilkinson in various modes of operation;

Fig. 6 shows op amp circulator circuit;

Fig. 7 shows circulator with filters; and

Fig. 8 is a block diagram of the customer premises equipment of Fig. 4 where the cancellation/separation circuit is replaced with a circulator.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0059] Fig. 1 is a block diagram of a generic, prior art, two-way communication system. The system comprises a down link 10 and an uplink 11 connected to an antenna 13 via duplexer 14. The uplink and down link are connected to modem 16 via a second duplexer 17, the signals travelling as indicated by down pointing arrow 18 and up pointing arrow 19 in the down link and up link respectively.

[0060] Fig. 2 is a block diagram of prior art customer premises equipment for an illustrative, prior art, two-way communication system for wireless rural broadband service. The equipment comprises an antenna 110. Transceiver 140 is connected between the antenna and a modem 150. Connection to modem 150 is via duplexer 151.

[0061] The transceiver comprises an uplink 160 and a down link 170. Down link 170 and uplink 160 are connected to antenna 110 via duplexer 180. Uplink 160 comprises amplifier 190, up converter (UPC) 200, amplifier 210, and low pass filter 220. Down link 170 comprises amplifier 230. Customer premises equipment herein operates at 743 MHz downstream and 713 MHz up stream and requires a sharp duplexer.

[0062] Fig. 3a is a block diagram of the generic two-way communication system of Fig. 1 utilizing a cancellation/separation duplexer instead of a conventional duplexer. The system comprises a down link 300 and an uplink 301 connected between an antenna 302 and a modem 303 (through duplexer 309) as is the case in the prior art system of Fig. 1. But down link 300 and uplink 301 are connected to antenna 302 via a cancellation/separation duplexer 305.

[0063] Fig. 3b is a diagram of a Wilkinson combiner adapted by the addition of a filter circuit to form the cancellation/separation duplexer herein. The Wilkinson combiner is used to combine two signals into a single output. The Wilkinson combiner has three ports designated P1, P2 and P3. As shown in the Fig. 3b, quarter wave transformers T1 and T2 are connected between ports P1 and P2 and between ports P1 and P3 respectively. A balancing resistor R is connected between port P2 and port P3.

[0064] The Wilkinson combiner with a filter circuit constitutes a “cancellation/separation duplexer”.

[0065] The cancellation/separation duplexer is connected into any two-way communication system by connecting port P2, in Fig. 3a, to the input to down link 300 and connecting port P3 to uplink 301. As shown in Fig. 3a, downlink 300 and uplink 301 are connected to modem 303, as shown via block 309 in Fig. 3a. Block 309 represents a conventional duplexer.

[0066] Fig. 4 is a block diagram of customer premises equipment (CPE) for an illustrative rural broadband system using the cancellation/separation duplexer 305 of Fig. 3a. The CPE is operative to receive (downstream) signals at 743 MHz and (upstream) transmit signals at

713 MHz. The down link 401 comprises amplifier 402 high pass filter 403 and filter 417 of the duplexer. The uplink comprises low pass filter 410, amplifier 411, up converter 413, sharp filter 414, up converter (UPC) 415 and amplifier 416.

[0067] The uplink includes signal detector 421 connected to amplifier 416 operative to turn amplifier 416 on when a transmit signal is present.

[0068] Sharp filter 414 in the CPE illustratively operates at Intermediate Frequency of about 170 MHz suitable for UHF band (470– 860 MHz). The filter can be used for each CPE in communication with a base station. The cost of a different duplexer for each CPE is thus eliminated and the use of identical fixed filters instead permits low cost manufacturing to bring the cost down dramatically.

[0069] As shown in Fig. 4, filter 414 is sandwiched between first and second up converters 413 and 415. These up converters are programmable, are voltage controlled and inexpensive. They are operative to change the frequency supplied by the modem (5 – 60 MHz) first to some Intermediate Frequency (170 MHz) and then to the 713 MHz transmit frequency as is explained more fully hereinafter.

[0070] Up converter 413 is connected to modem 420 via amplifier 411 and low pass filter 410. Up converter 415 is connected to the antenna via amplifier 416. Signal detector 421 is connected between amplifier 411 and low pass filter 410, and is connected to amplifier 416 via on/off switch (not shown).

[0071] The system of Fig. 4 operates to process transmit and receive signals as follows: The receive signal is received at the antenna 113. The signal goes through quarter wave transformer T1 into filter 417. Filter 417 passes the desired receive signal and attenuates all the other signals. The output of filter 417 is then fed into amp 402 that amplifies the signal. The output is fed into high pass filter 403. The output of the high pass filter 403 is connected to modem 420. Modem 420 receives the receive signal and processes the signal internally. The transmit signal is generated by modem 420 and fed into the input of the low pass filter 410. This filter blocks all the receive signal from entering the signal detector 421. The output of the Signal detector is fed into amp 411. The programmable upconverter 413 takes the input signal from amp 411 and translates it to an Intermediate Frequency (170 MHz). The Intermediate Frequency signal is fed into a fixed sharp filter 414. This filter is the same filter used in all the Transceivers regardless of location. The signal is cleaned up by the sharp filter

and the output is fed into the programmable upconverter 415 that takes the signal to 713 MHz. This upconverter can be programmed to convert the 170 MHz to any one of the 470-860 MHz UHF band frequencies. The output of the programmable upconverter 415 is fed into amplifier 416. The output of amplifier 416 is only turned on when the signal detector 421 senses an input signal. The output of the amp 416 is fed into port P3 of the Wilkinson combiner 305. The transmit signal fed into port P3 sees 3 dB less at the antenna input. The same transmit signal is seen as being at least 40 dB less at port P21 on the cancellation/separation duplexer. The benefit of this is that even though the transmit signal is large it is seen to be over 40 dB less at port P21 on the Wilkinson combiner that is input port for the receive signal. Effectively using the cancellation/separation duplexer, to connect the antenna cost 3dB in signal loss for transmit purposes. The Transceiver would have to produce 3 dB additional power to compensate for the loss in the duplexer. The 3 dB loss is easily compensated by outputting additional power on the amp 416 and thereby having the same power input to the antenna. The real benefit is that transmit power seen at input Filter 417 is over 40 dB lower.

[0072] The Intermediate Frequency described herein is conveniently chosen to be intermediate the system transmit frequency (470–860 MHz) and 5–60 MHz supplied by the modem at the customer premises. The Intermediate Frequency, on the other hand, may be any convenient frequency, even above the system transmit frequency. In this case, instead of two up-converters, an up converter converts the modem transmit frequency to the Intermediate Frequency and a down converter converts the frequency to the CPE transmit frequency.

[0073] Fig's 5a, 5b, and 5c show, schematically, the Wilkinson organized as a splitter, a combiner, and as a cancellation/separation device respectively. The arrows in each case represent the direction of data flow. The signals are designated #1, #2, and #3 corresponding to the port designations. It is to be noticed that only Fig. 5c includes a filter which adapts the Wilkinson for use as a duplexer.

[0074] Using the cancellation/separation duplexer as disclosed herein, enables mobile devices to become full duplex systems thereby allowing a doubling of data rates due to fact that they can transmit and receive at the same time.

[0075] The heterodyne receiver is also well know (i.e. a radio tuner) and is used with the

duplexer, disclosed herein, to provide a frequency agile transceiver which is programmable and thus obviates the need for different duplexers in CPE systems as noted above.

[0076] The single and multistage Wilkinson combiner also are well known, the latter permitting the frequency band to be made much wider thereby allow the duplexer to operate over a much wider frequency band than is possible with existing duplexers.

[0077] The cancellation/separation duplexer allows the use of the same carrier frequency for both transmit and receive.

[0078] Normally a receive signal is considerably less in power than the transmit signal. Preferably, the power of the transmit signal at the receive port is 50 dB less due to the 180 degree phase shift (signal cancellation) provided by the cancellation/separator duplexer. Consequently, the power of the transmit and receive signals at the receive port is relatively the same.

[0079] To separate the two signals at the receive port, two different modulation techniques are used. Amplitude modulation carrier and frequency modulation carrier were implemented experimentally and provided an additional 20 dB of signal separation, a total effective separation of 70 dB between the signals. It is clear that the same carrier frequency can be used for both transmit and receive by using a Wilkinson combiner/splitter plus a filter to produce the cancellation/separation duplexer. By interfacing to the transmit/receive antenna and by using two different modulation techniques over 70 dB of separation is obtained.

[0080] The 70 dB of separation has also been achieved by tuning the impedance of the transmit and receive ports to exactly match that of the antenna. With exact matched impedance plus the use of two different modulation techniques an extremely robust wireless system using the same carrier frequency is provided.

[0081] CDMA is an example of multiple access where several transmitters can send information simultaneously over a single communication channel. This allows several users to share a band of frequencies. To permit the band sharing without undue interference between the users, CDMA employs spread spectrum technology and a special coding scheme where each transmitter is assigned a code. Using CDMA with different coding for the transmit and receive channels the receive code can be separated from the transmit code using a Wilkinson combiner/splitter plus a filter to produce the cancellation/separation duplexer. With exact impedance matching CDMA can be used to provide an extremely robust wireless

system using the same carrier frequency for both transmit and receive channels.

Alternative embodiment

[0082] Circulators are 3-port ferro-magnetic devices that allows energy to be coupled only from port A to port B, from port B to port C, and from Port C to Port A, where no energy can flow in the reverse direction. Referring to FIG. 8, circulator 310 has ports P1, P2 and P3.

[0083] Circulators can be distinguished from duplexers or diplexers. Duplexers are passive frequency-selective three-port devices designed specifically to allow simultaneous transmission and reception on adjacent frequencies on the same antenna and have separate transmitter and receiver ports (connectors) and a common (shared) antenna port. Duplexers are generally carefully tuned to the specific transmit and receive frequencies being used. Typical duplexer specifications might be insertion loss of less than 1 dB and isolation greater than 75 dB. Diplexers are similar in function to the duplexer in that it combines two (or more) ports into a single port. Like the duplexer, the diplexer is frequency selective, but typically broadband. A typical application for a diplexer is to allow two transceivers on two different bands to share a common transmission line. For example, a 2-meter transceiver and a 70-cm transceiver might each be connected a single diplexer which is connected to a single coax. On the other end of the coax might be a dual-band antenna, or another diplexer that separates the signals for connection to two separate antennas.

[0084] By connecting a circulator to an antenna and between a down link and an uplink as shown for the Wilkinson device of Fig. 3(a), or in other words, by replacing the Wilkinson device in duplexer 305 with a circulator 310 as shown in Fig. 8, a duplex operation can be realized.

[0085] Fig. 1 shows a prior art wireless circuit with a downlink 10 and an uplink 11 connected to an antenna 13 via duplexer 14. Duplexer 14 comprises two multistage filters F1 and F2. A circulator may be thought of as being used along with duplexer 14 in an arrangement as shown in Fig. 7. The advantage of thinking about the combination of a circulator 310 and a duplexer 309 is that we see that the filter F1 no longer needs to handle the power of the energy in the transmit uplink. The immediate benefit is a significant drip in the cost of the filter F1. For example, the cost may drop from between $400-$500 to under five dollars. Another benefit is that we gain over 20 dB in isolation, which permits us to operate

in a full duplex mode using the same frequency for transmit and receive. As in the case with the Wilkinson cancellation/separation embodiments, the transmit filter F2 is unnecessary. Thus, the circulator plus the downlink filter F1 becomes a complete replacement for a duplexer.

[0086] It was found that, by using a circulator with a significantly higher power rating compared to the maximum power in the uplink, the intermodal noise generated in the circulator became negligible and obviated the additional noise added to the low level downlink signals. For example, it was found that a circulator with a power rating that is at least ten times greater than the power of the uplink gave favorable results and reduced the intermodal noise to negligible levels.

[0087] Unfortunately, such circulators are expensive and bulky. Although it avoids the 3 dB loss, characteristic of the Wilkinson device noted hereinbefore, its use is practical, because of size and cost, only in tower locations or base stations. Nevertheless, active circulators are available which weigh only a few grams and such circulators are usable in subscriber equipment herein. Such active circulators are described by Charles Wenzel of Wenzel Associates Inc., published in RF design awards in 1991 titled "Low Frequency Circulator/Isolator Uses No Ferrite or Magnet". While not suggested in this publication, these devices would be more practical in hand held devices. Charles Wenzel's Low Frequency Circulator/Isolator circuit is shown in Fig. 6. In order to use a circulator where the same frequency is used for both transmit and receive, two different encoding schemes need to be used. The following table contains illustrative encoding scheme pairs for transmit and receive signals. CDMA coding also can be used.

Transmit Signal	**Receive Signal**
AM Modulated	FM Modulated
CDMA signal with first code	CDMA signal with second code
FM Modulation	AM Modulation

[0088] In a first system embodiment a circulator is used in a tower and (Wilkinson type) cancellation/separation duplexers are used in mobile devices and customer premise equipment. In a second embodiment, an active circulator duplexer is used in both tower and subscriber equipment. Other combinations and modifications may be achieved by those

skilled in the art.

[0089] The circulator described above may also be used with a heterodyne receiver, which allows the device, either the base station or the CPE, to be provide a frequency agile transceiver that is programmable, and thus obviates the need for different duplexers in order to handle different frequencies. Referring to FIG. 8, the heterodyne receiver (not shown) may be connected up stream of filter 306.

[0090] What has been described is considered merely illustrative of the principles of this invention. Thus, it should be understood that those skilled in the art are capable of producing modifications thereof within the scope of the claims.

WHAT IS CLAIMED IS:

1. A wireless communication system comprising:

a base station operative to communicate wirelessly with a plurality of customer devices;

the base station comprising a circulator having a first port connected to one or more signal transmission devices, a second port that is connected to one or more antennas, and a third port that is connected to one or more signal reception devices, wherein the circulator communicates transmission signals from the one or more signal transmission devices to the one or more antennas, and communicates received signals from the one or more antennas to the one or more signal reception devices; and

the plurality of customers devices comprising cancellation/separation duplexers.

2. The wireless communication system of claim 1, wherein the circulator has a power rating sufficiently higher than the maximum uplink power to minimize the affect of the intermodal noise on the low level downlink signals.

3. The wireless communication system of claim 1, wherein the signals using the same frequency for transmit and receive signals.

4. The wireless communication system as in claim 2 wherein the base station communications are encoded with a first and second different encoding schemes for transmit and receive signals.

5. The wireless communication system as in claim 4 wherein the customers equipment comprises a modem operative to encode transmit signals in the second encoding scheme and decoding receive signals in the first encoding scheme.

6. The wireless communication system as in claim 1 wherein the transmit and receive signals are encoded in CDMA.

7. The wireless communication system as in claim 1 wherein one of the ports on the cancellation/separation duplexer is connected to a heterodyne receiver.

8. The wireless communication system as in claim 1, wherein the third port of the circulator is connected to a heterodyne receiver.

9. A method of operating a full duplexer wireless system, the system comprising a base station and a plurality of customer devices in which signals are transmitted and received therebetween using the same frequency, the method comprising the steps of:

transmitting signals by the customer devices in a first encoding schemes and receiving signals by the customer devices in a second encoding scheme; and

transmitting signals by the base station in a second encoding schemes and receiving signals by the base station in a first encoding scheme.

10. In combination:

a circulator having a first port connected to an antenna that receives and transmits wireless signals, a second port, and a third port;

a low power capacity filter connected to the second port; and

a high power capacity filter connected to the third port.

11. The combination of claim 10, wherein the low power capacity filter is connected to a heterodyne receiver.

12. The combination of claim 10, wherein the circulator has a power rating sufficiently higher than the maximum uplink power transmitted through the high power capacity filter to minimize the effect of the intermodal noise on the low power level signals transmitted through the second port and the low power capacity filter.

13. A circulator comprising:

first, second, and third ports connected in a circular arrangement and operative to unidirectionally direct energy received at one of the ports to the next sequential port, wherein

the first port is connected to an antenna that receives and transmits wireless signals, the second port is connected to a low power filter and the third port is connected to a high power filter.

14. A wireless communication system comprising:

a base station operative to communicate wirelessly with a plurality of customer devices, wherein the base station comprises of high power circulator and the customer devices comprises op amp circulator circuits.

15. The wireless communication system of claim 14, wherein the op amp circulator circuits comprise at least one downlink connected to a heterodyne receiver.

16. Customer devices of a wireless communication system, each customer device comprising an op amp circulator circuit having an uplink connection, an antenna, and a downlink connection, the downlink connection being connected to a heterodyne receiver.

17. The customer devices of claim 16, wherein the uplink connection is connected to a high power filter, and the downlink connection is connected to a lower power filter.

18. The customer devices of claim 16, wherein the circulator has a sufficiently higher power rating compared to the maximum power in the uplink connection to reduce the intermodal noise in the circulator to a negligible level on the downlink signals.

Fig 1 Prior Art

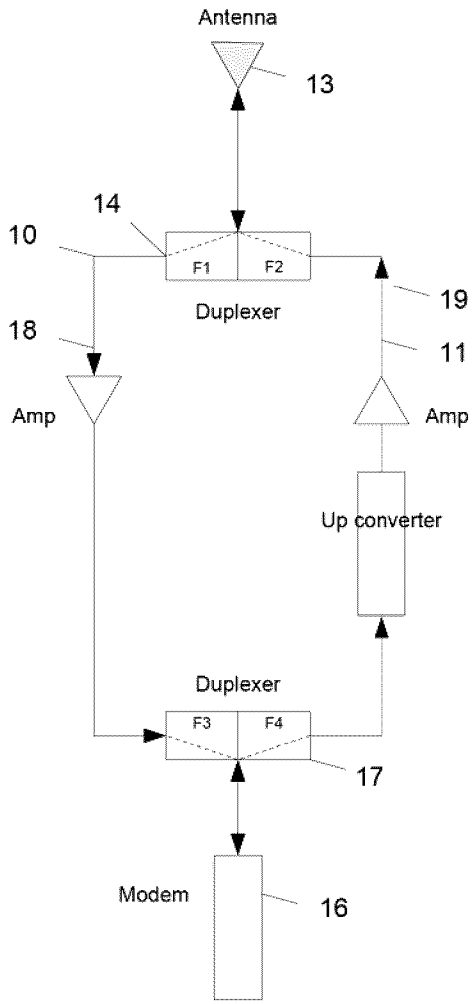


Fig 2 Prior Art

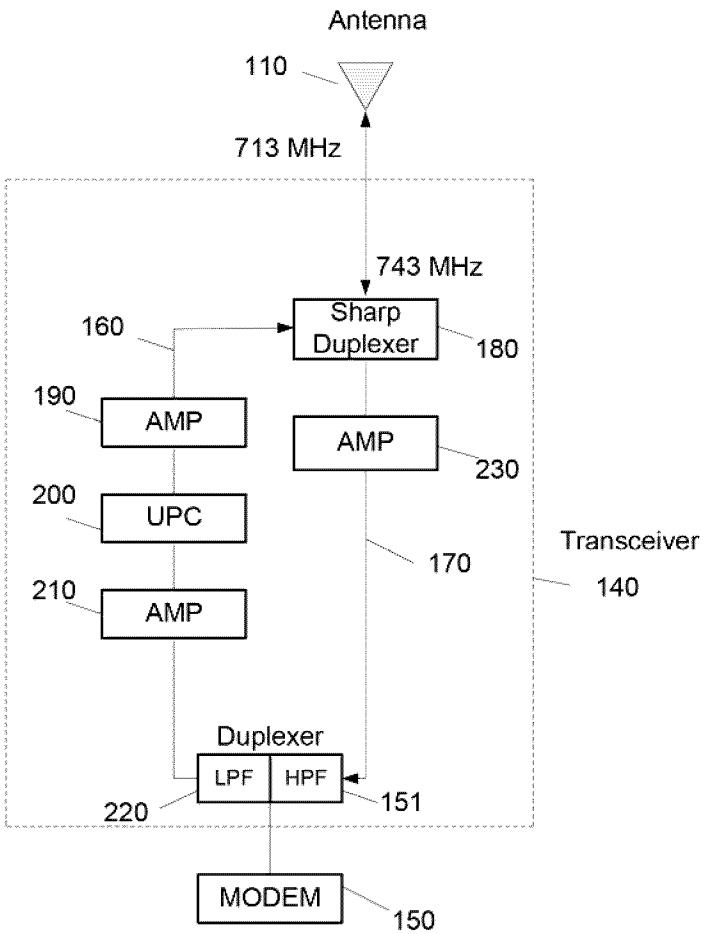


Fig. 3 (a)

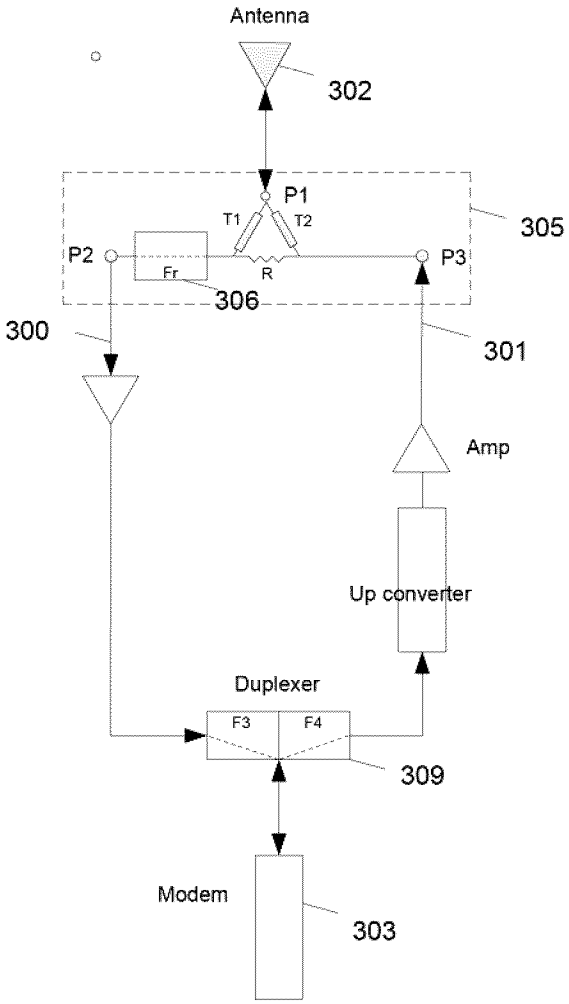

Antenna
302
P1
T1
T2
305
P2
Fr
R
P3
306
300
301
Amp
Up converter
Duplexer
F3
F4
309
Modem
303

Fig. 3 (b)

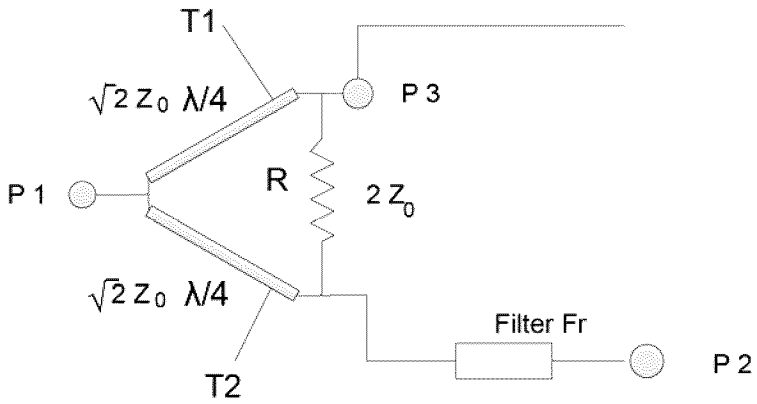


Fig 4

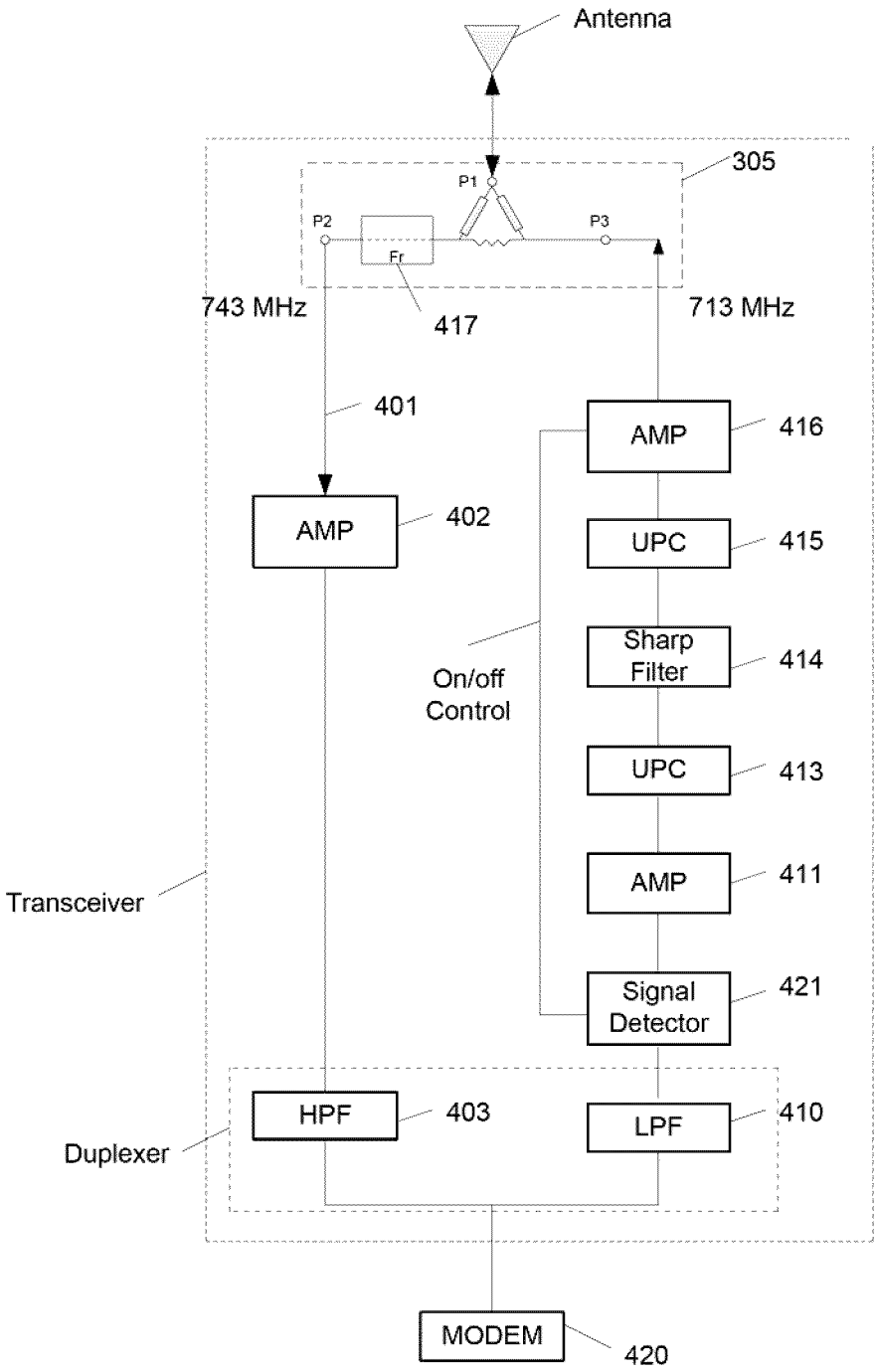

Antenna
305
P1
P2
P3
Fr
743 MHz
417
713 MHz
401
AMP
402
AMP
416
UPC
415
Sharp Filter
414
On/off Control
UPC
413
AMP
411
Signal Detector
421
Transceiver
HPF
403
LPF
410
Duplexer
MODEM
420

Fig. 5a

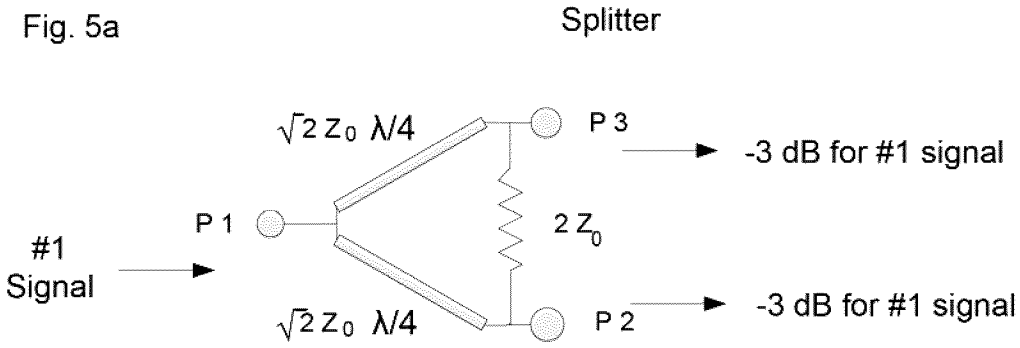


Fig. 5b

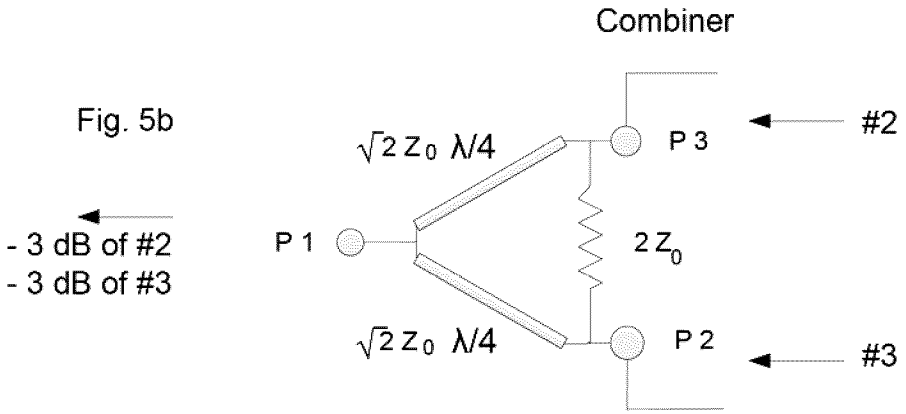
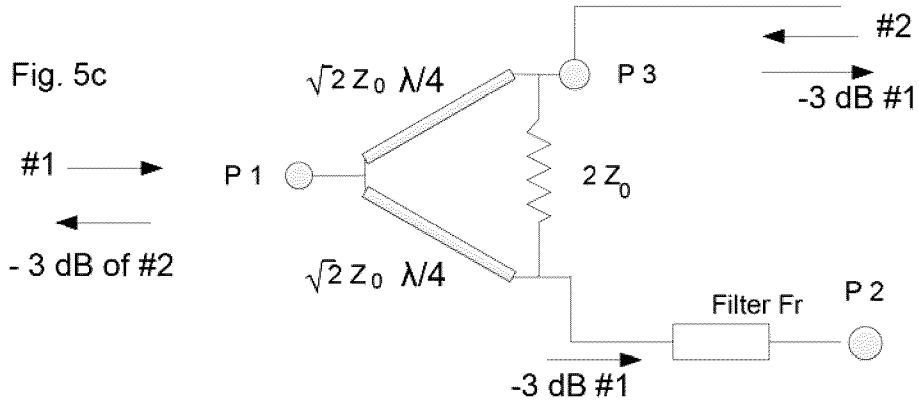


Fig. 5c



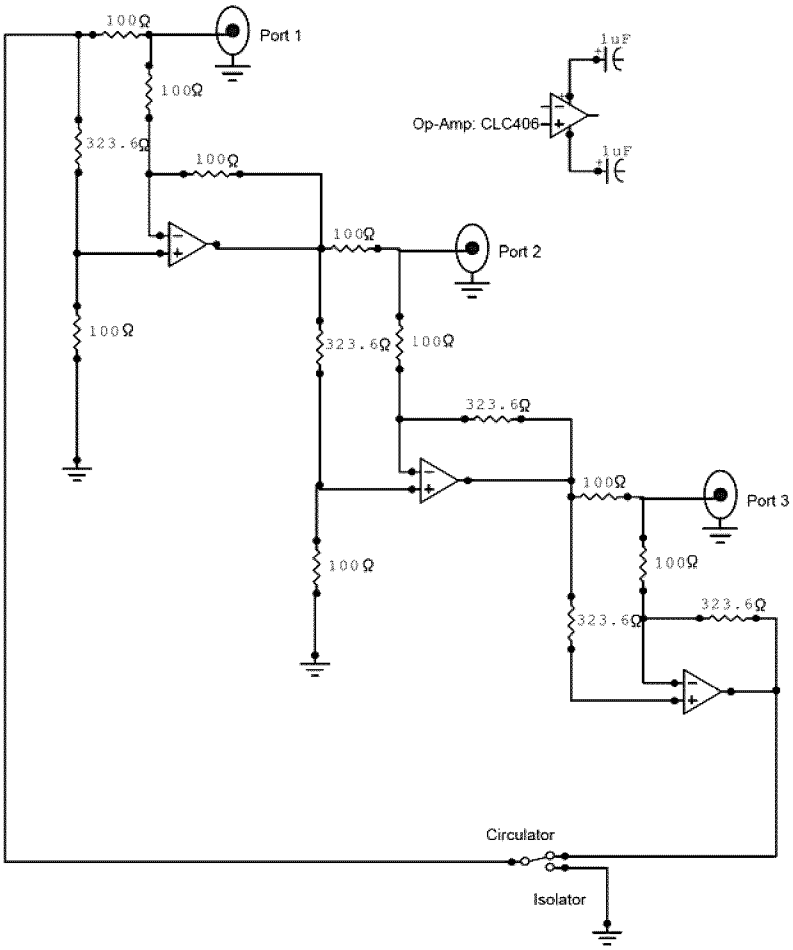

100Ω
Port 1
100Ω
323.6Ω
100Ω
1uF
Op-Amp: CLC406
1uF
100Ω
Port 2
100Ω
323.6Ω
100Ω
323.6Ω
100Ω
Port 3
100Ω
100Ω
323.6Ω
323.6Ω
Circulator
Isolator

Figure.6

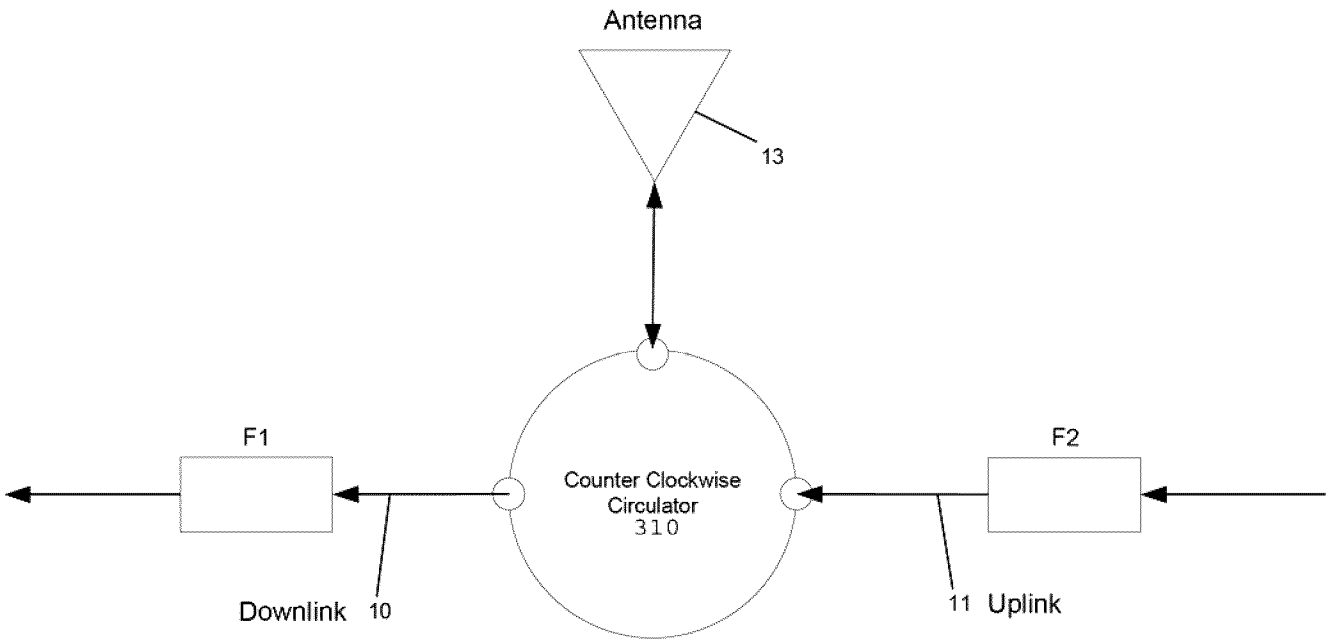
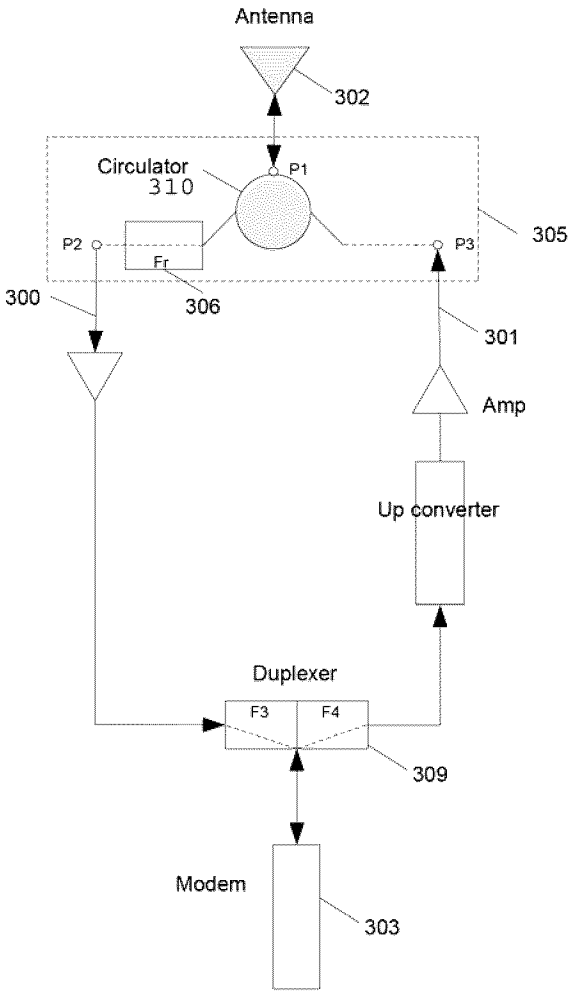

Antenna
13
F1
F2
Counter Clockwise
Circulator
310
Downlink
10
11
Uplink

Figure. 7

Fig. 8


Antenna
302
Circulator
310
P1
P2
P3
Fr
305
306
300
301
Amp
Up converter
Duplexer
F3
F4
309
Modem
303

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2016/050746

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***H04W 88/08*** (2009.01) , ***H01P 1/38*** (2006.01) , ***H04B 1/40*** (2015.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: H04W 88/08 (2009.01) , H01P 1/38 (2006.01) , H04B 1/40 (2015.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Questel Orbit
Keywords: circulator/isolator, filter, ports, duplexer, modulation, amplitude/16QAM/64QAM, encoding scheme, ultra-high frequency (UHF), cancellation/separation, radio turner/superhet/heterodyne receiver, high power filter, low power filter/surface acoustic wave/saw

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2015/048678 (Bharadis et al.) 2 April 2015 (02-04-2015) *Abstract; paragraphs 0004-0007, 0035, 0036, 0039, 0040, 0056-0061; Fig. 3*	1, 6 2, 5, 7, 8
Y	CA 2,834,725 (Lakhani et al.) 26 May 2015 (26-05-2015) *0010, 0014, 0015, 0019, 0020, 0038 0043, 0063-0066; claims 3, 24, 32, 34, and 37; Fig. 4*	2, 5, 7, 8
A	US 2013/0295860 (Roussel et al.) 07 November 2013 (07.11.2013) *whole document*	1-8
A	CN 102,664,684 (Zhang et al.) 12 September 2012 (12-09-2012) *whole document*	1-8 1-8
A	JP 5,036,394 (Takei) 26-09-2012 (26 September 2012) *whole document*	

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 10 November 2016 (10-11-2016)	Date of mailing of the international search report 07 December 2016 (07-12-2016)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer Mei Li (819) 635-3698

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2016/050746

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Group A - Claims 1-8 are directed to a wireless communication system comprising a base station operative to communicate wirelessly with a plurality of customer devices;

Group B – Claim 9 is directed to a method of operating a full duplexer wireless system wherein the downlink using a second encoding scheme and uplink using a first encoding scheme;

Group C – Claims 10-13 are directed to a circulator having a first port, a second port and a third port which connected to an antenna, a lower power capacity filer and a high power filer respectively ;

Group D – Claims 14-18 are directed to customer devices of a wireless communication system, wherein each customer deice comprising an op amp circulator circuit.

There is no common inventive concept between Groups A, B, C, and D. Therefore, the claims are found lack of unity. The claims must be limited to one inventive concept as set out in Rule 13 of the PCT.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos.:

4. ☑ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos.:

1-8

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2016/050746

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
WO2015048678A1	02 April 2015	WO2015048678A1	02 April 2015 (02-04-2015)
		CN104521148A	15 April 2015 (15-04-2015)
		CN104521148B	24 August 2016 (24-08-2016)
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		EP2859659A4	09 March 2016 (09-03-2016)
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		WO2015073905A2	21 May 2015 (21-05-2015)
		WO2015073905A3	12 November 2015 (12-11-2015)
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		AU2014357310A1	14 July 2016 (14-07-2016)
		WO2015077876A1	04 June 2015 (04-06-2015)
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		US8655301B2	18 February 2014 (18-02-2014)
		US7702295B1	20 April 2010 (20-04-2010)
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		US8213877B1	03 July 2012 (03-07-2012)
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		US2013017795A1	17 January 2013 (17-01-2013)
		US8498584B2	30 July 2013 (30-07-2013)
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		CN102664684B	08 April 2015 (08-04-2015)
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		JP2008278169	13 November 2008 (12-11-2008)