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(54) WIFI RF FRONT END AND ANTENNA MULTIPLEXING

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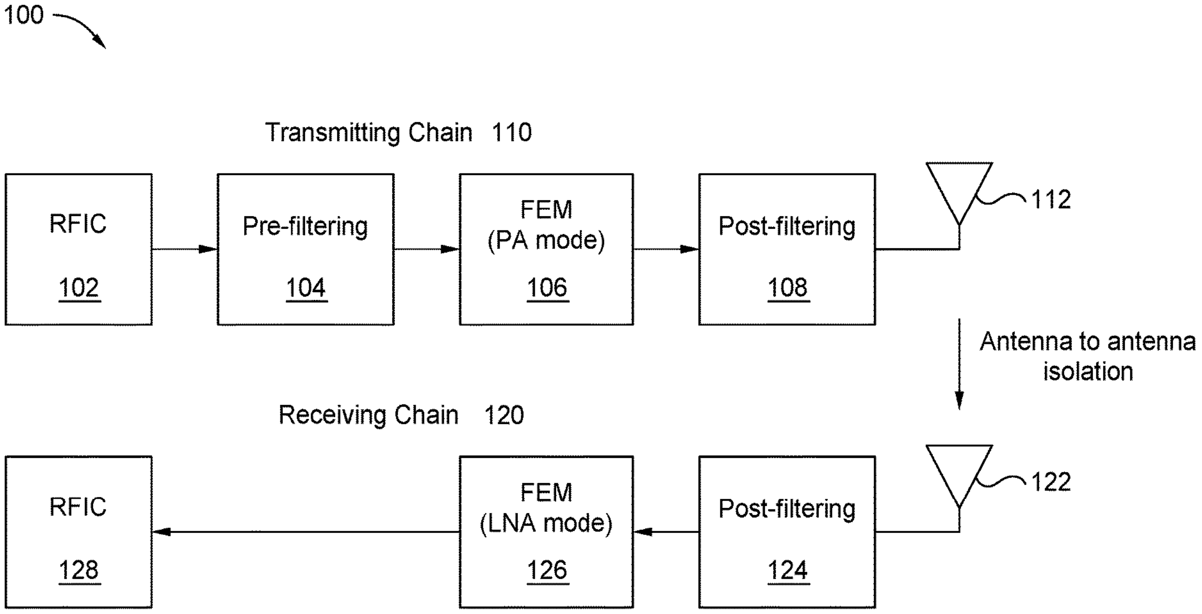
(57) ABSTRACT

Techniques for wireless antenna multiplexing are disclosed. An antenna system for wireless communication includes a plurality of diplexers and first and second antenna arrays. The first antenna array is coupled to a first radio-frequency integrated circuit (RFIC) configured to operate at a first frequency band including a first plurality of sub-bands, and a second RFIC configured to operate at a second frequency band including a second plurality of sub-bands. The second antenna array is coupled to both the first RFIC and the second RFIC. Adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands are assigned to different antenna arrays of the first and second antenna arrays using the plurality of diplexers.



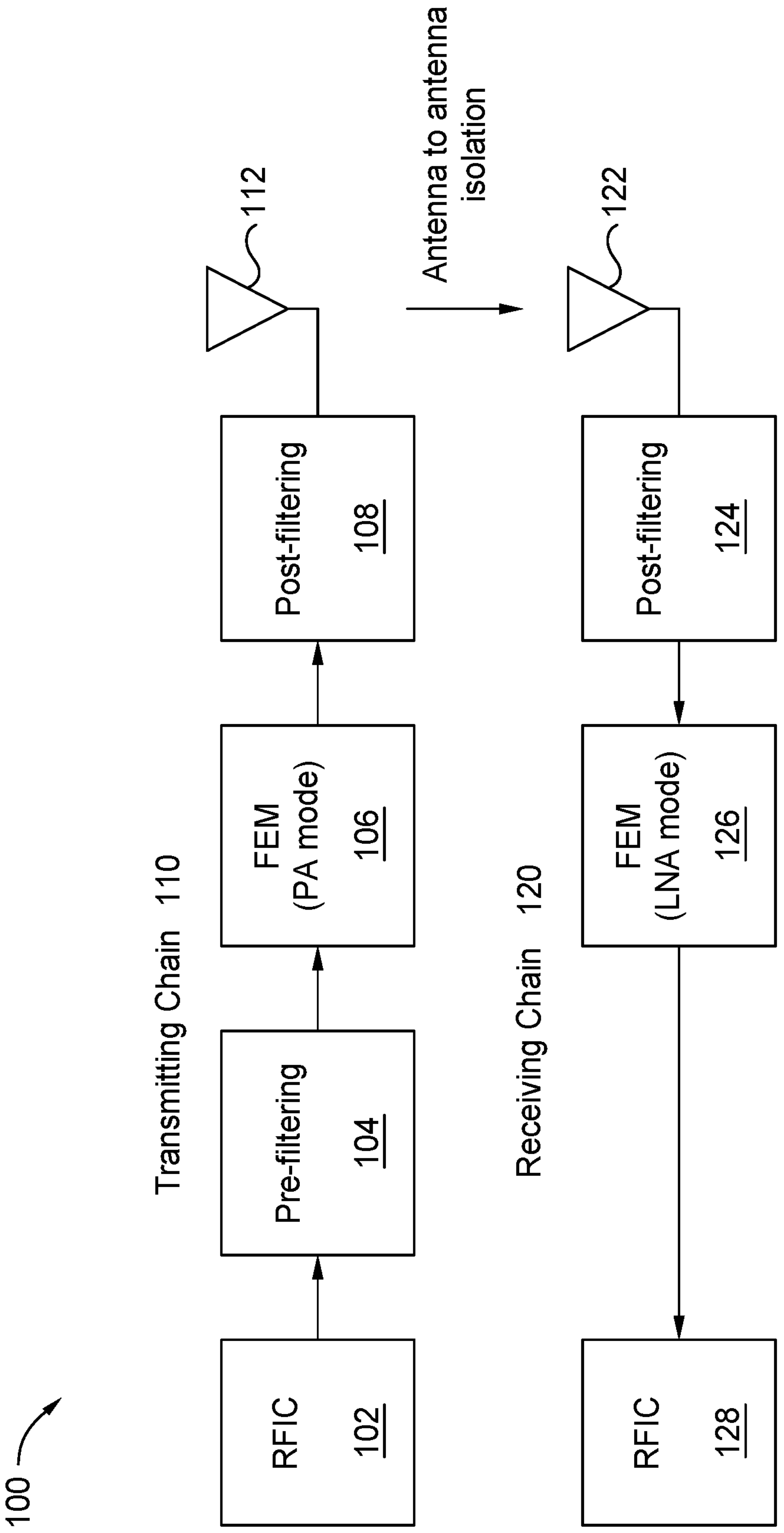

100
Transmitting Chain 110
RFIC
102
Pre-filtering
104
FEM
(PA mode)
106
Post-filtering
108
112
Antenna to antenna
isolation
122
Receiving Chain 120
RFIC
128
FEM
(LNA mode)
126
Post-filtering
124

FIG. 1A

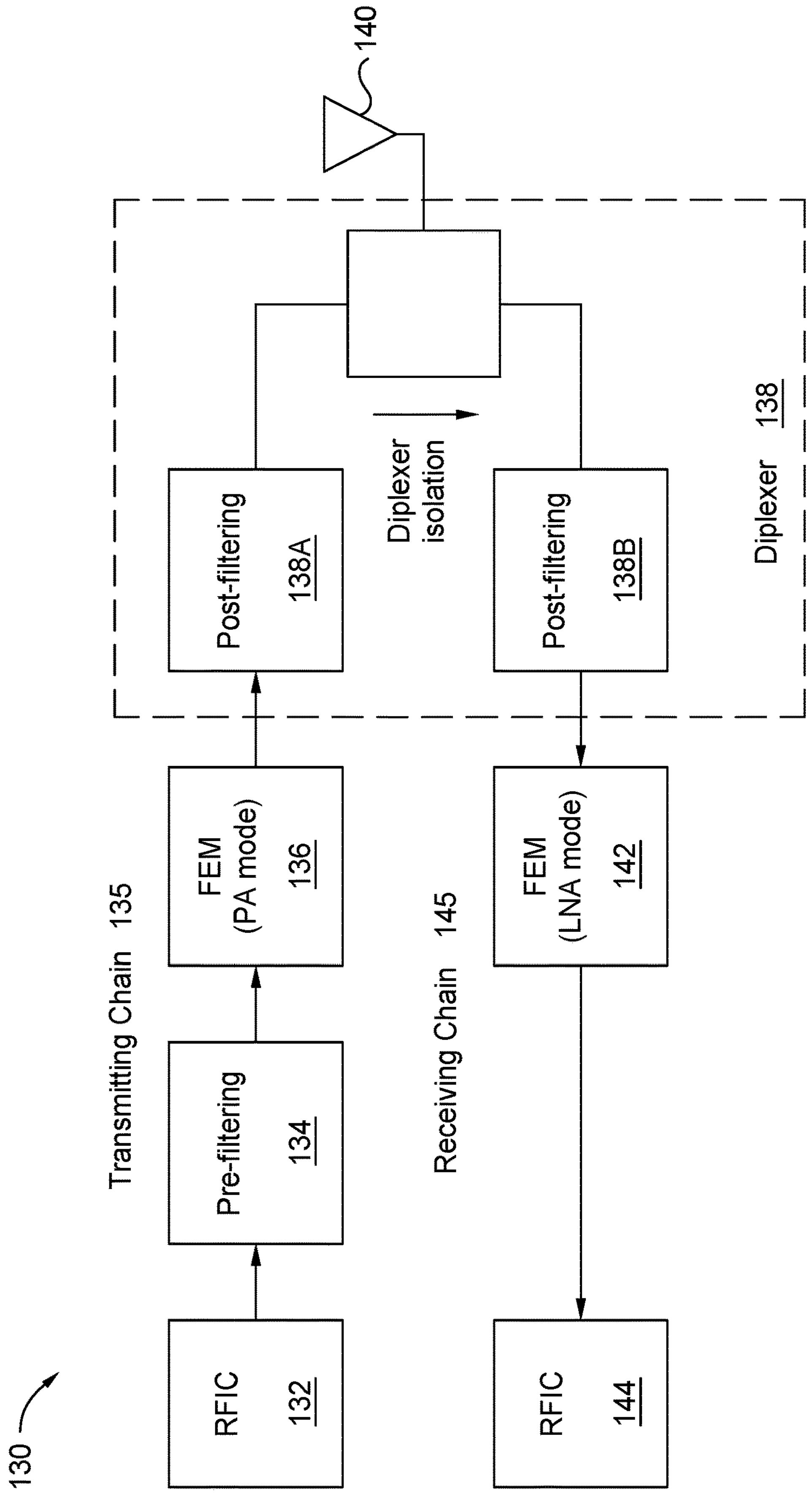

130
Transmitting Chain 135
RFIC 132
Pre-filtering 134
FEM (PA mode) 136
Post-filtering 138A
Diplexer isolation
140
Post-filtering 138B
Diplexer 138
Receiving Chain 145
RFIC 144
FEM (LNA mode) 142

FIG. 1B

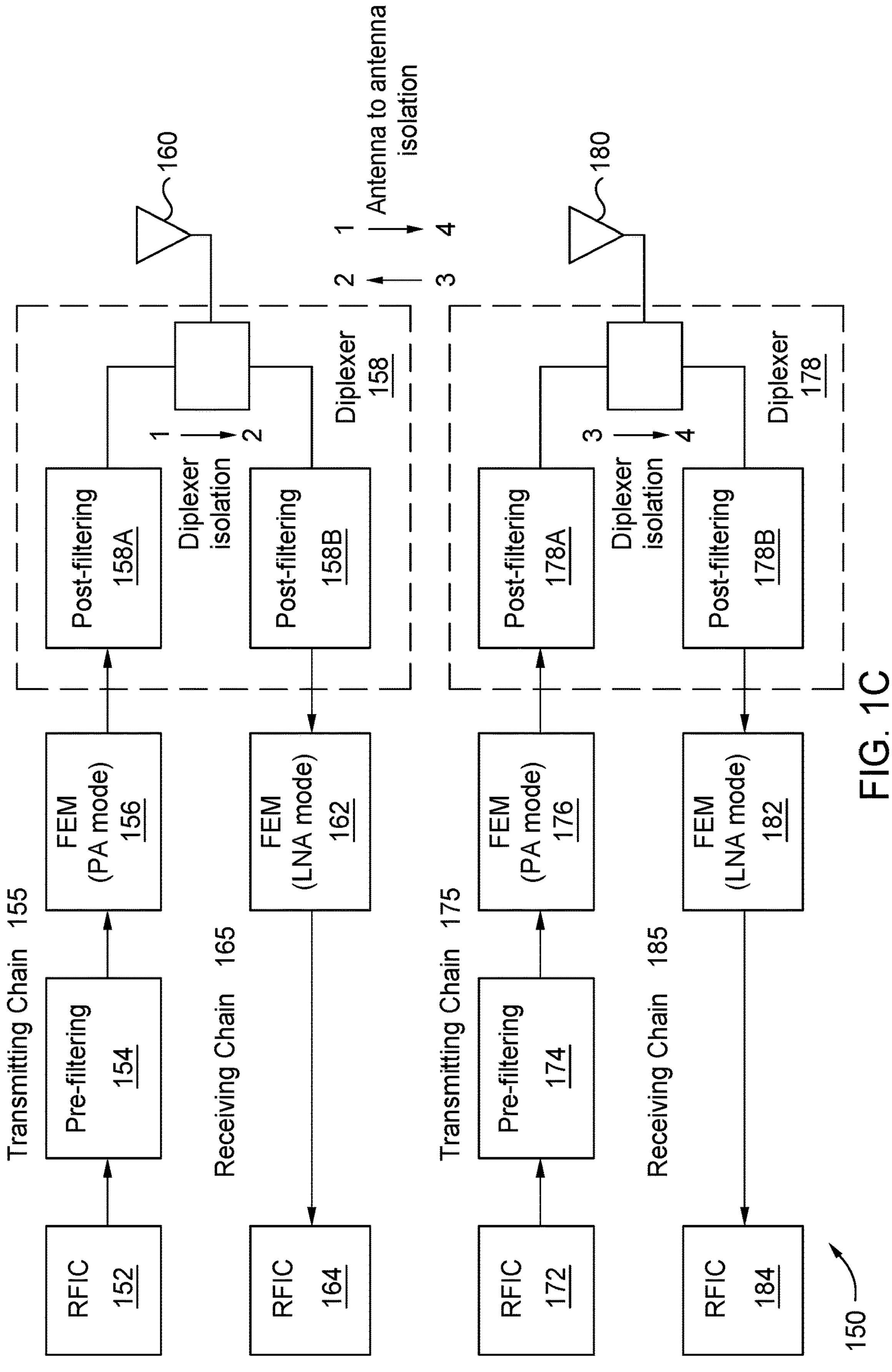

Transmitting Chain 155
RFIC 152
Pre-filtering 154
FEM (PA mode) 156
Post-filtering 158A
Receiving Chain 165
RFIC 164
FEM (LNA mode) 162
Post-filtering 158B
Diplexer isolation
1
2
Diplexer 158
160
Antenna to antenna isolation
1
4
2
3
Transmitting Chain 175
RFIC 172
Pre-filtering 174
FEM (PA mode) 176
Post-filtering 178A
Receiving Chain 185
RFIC 184
FEM (LNA mode) 182
Post-filtering 178B
Diplexer isolation
3
4
Diplexer 178
180
150

FIG. 1C

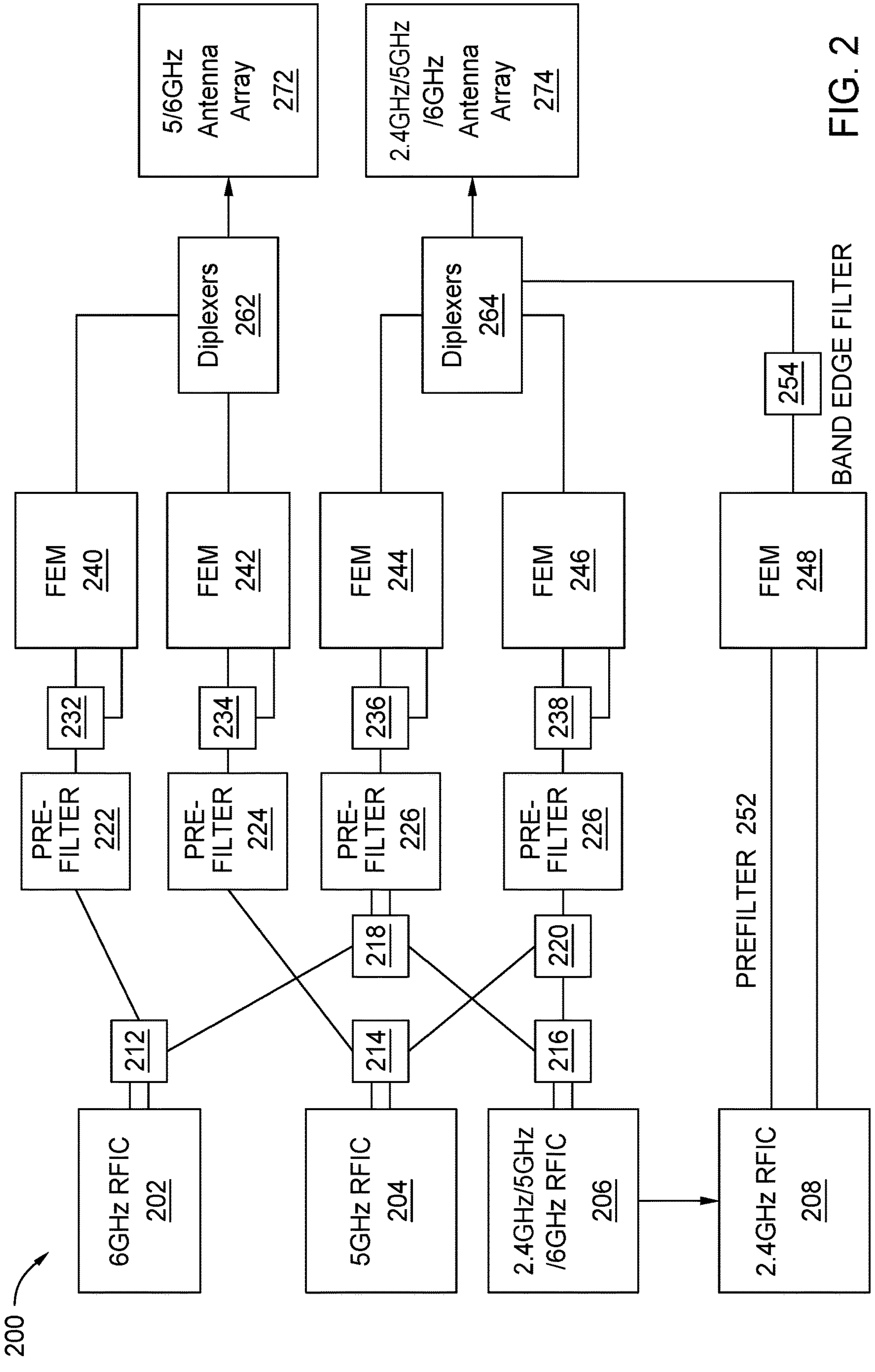

200
6GHz RFIC 202
5GHz RFIC 204
2.4GHz/5GHz/6GHz RFIC 206
2.4GHz RFIC 208
212
214
216
218
220
PRE-FILTER 222
PRE-FILTER 224
PRE-FILTER 226
PRE-FILTER 226
PREFILTER 252
232
234
236
238
FEM 240
FEM 242
FEM 244
FEM 246
FEM 248
254
BAND EDGE FILTER
Diplexers 262
Diplexers 264
5/6GHz Antenna Array 272
2.4GHz/5GHz/6GHz Antenna Array 274

FIG. 2

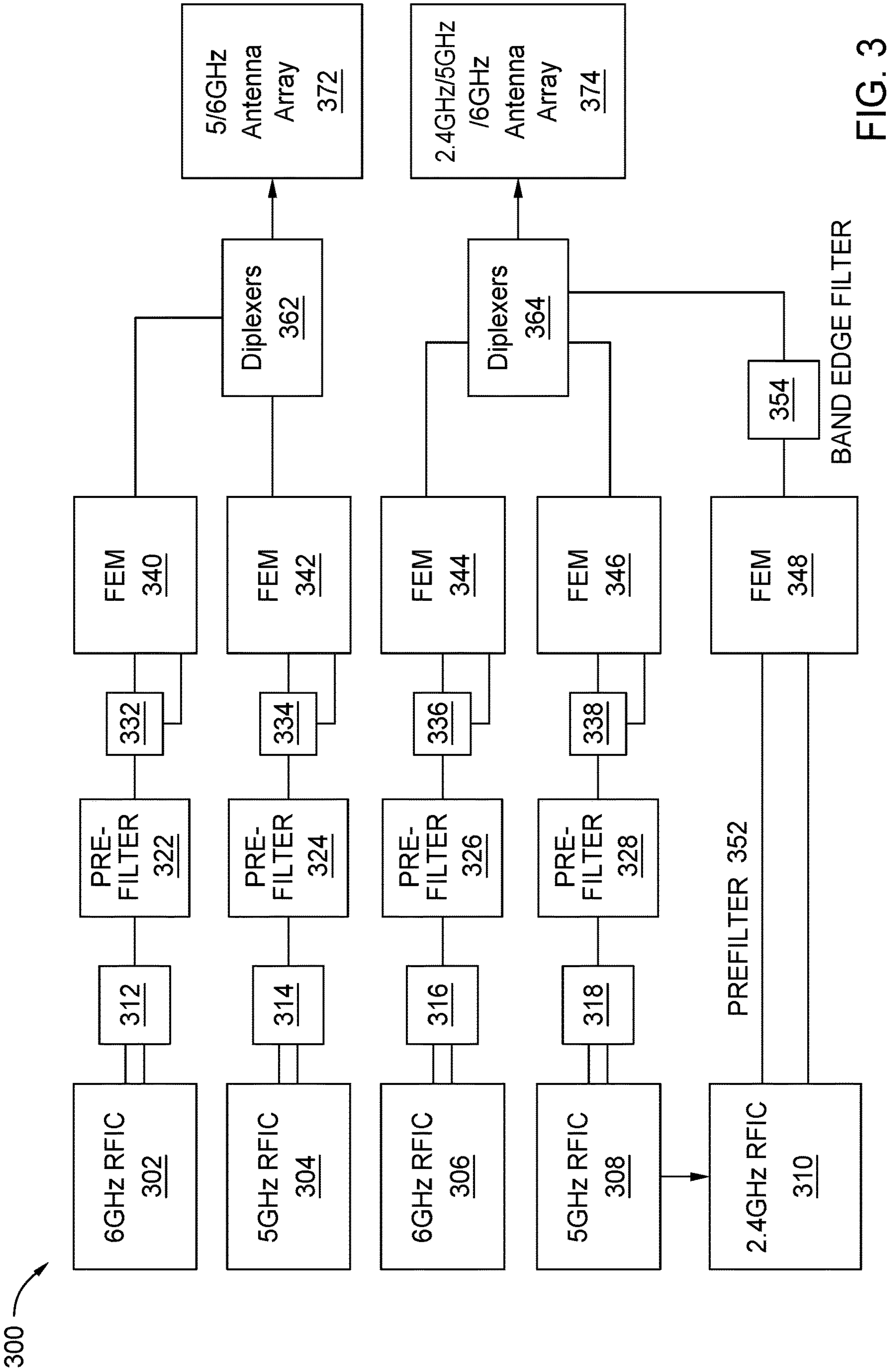

300
6GHz RFIC 302
312
PRE-FILTER 322
332
FEM 340
5GHz RFIC 304
314
PRE-FILTER 324
334
FEM 342
Diplexers 362
5/6GHz Antenna Array 372
6GHz RFIC 306
316
PRE-FILTER 326
336
FEM 344
5GHz RFIC 308
318
PRE-FILTER 328
338
FEM 346
Diplexers 364
2.4GHz/5GHz /6GHz Antenna Array 374
2.4GHz RFIC 310
PREFILTER 352
FEM 348
354
BAND EDGE FILTER

FIG. 3

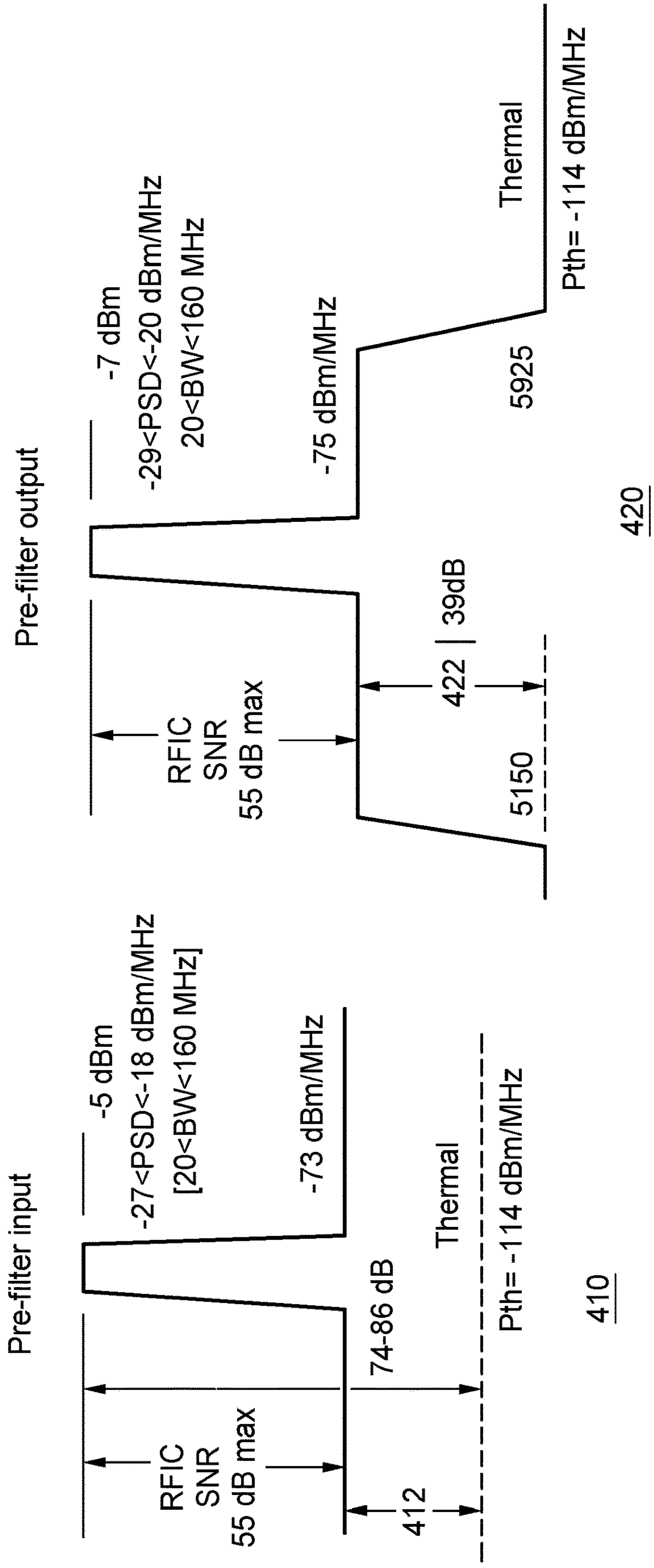

Pre-filter input
-5 dBm
-27<PSD<-18 dBm/MHz
[20<BW<160 MHz]
-73 dBm/MHz
RFIC
SNR
55 dB max
74-86 dB
Thermal
Pth= -114 dBm/MHz
412
410
Pre-filter output
-7 dBm
-29<PSD<-20 dBm/MHz
20<BW<160 MHz
-75 dBm/MHz
RFIC
SNR
55 dB max
422
39dB
5150
5925
Thermal
Pth= -114 dBm/MHz
420

FIG. 4

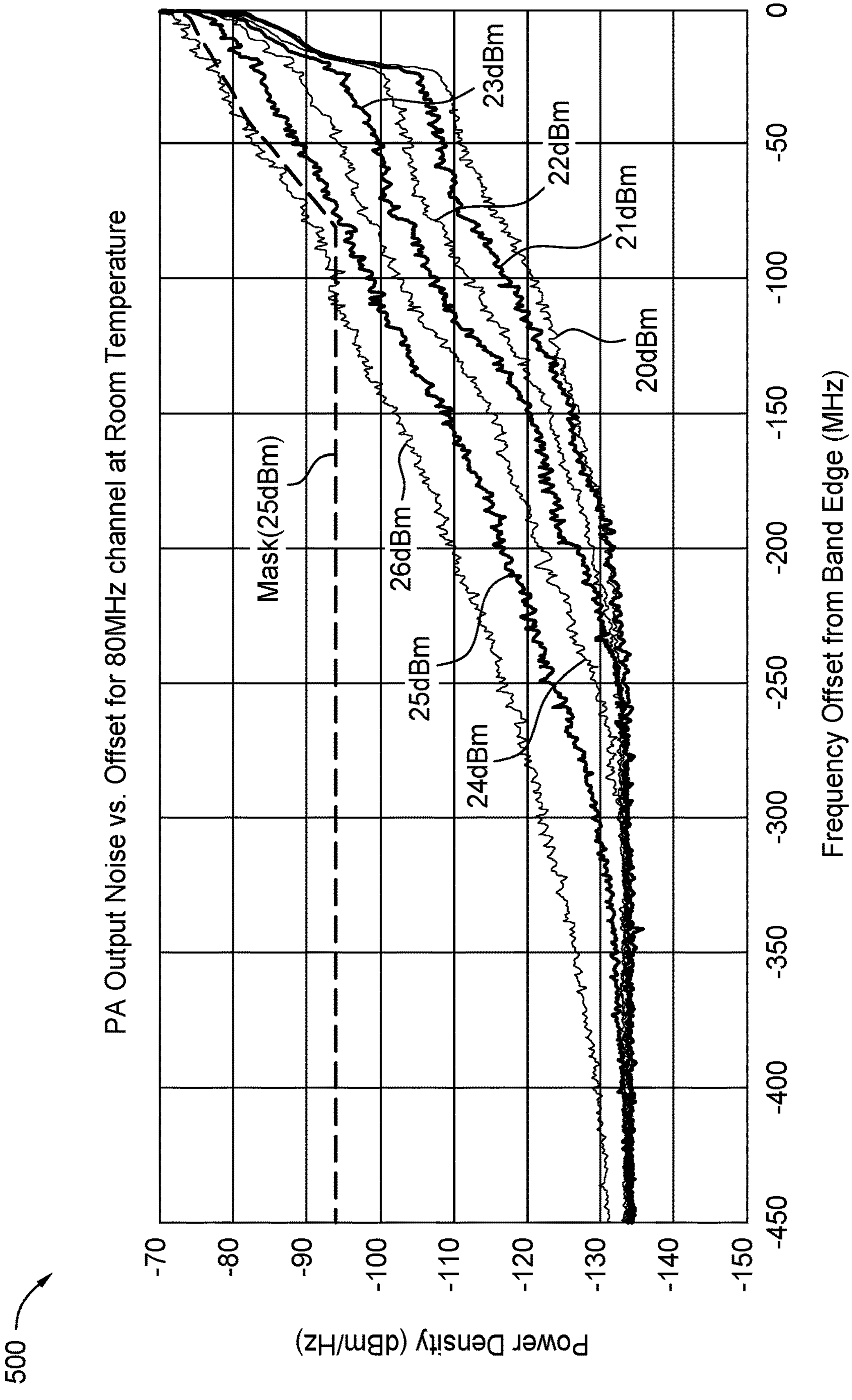

PA Output Noise vs. Offset for 80MHz channel at Room Temperature
Power Density (dBm/Hz)
-70
-80
-90
-100
-110
-120
-130
-140
-150
Frequency Offset from Band Edge (MHz)
-450
-400
-350
-300
-250
-200
-150
-100
-50
0
Mask(25dBm)
26dBm
25dBm
24dBm
23dBm
22dBm
21dBm
20dBm
500

FIG. 5

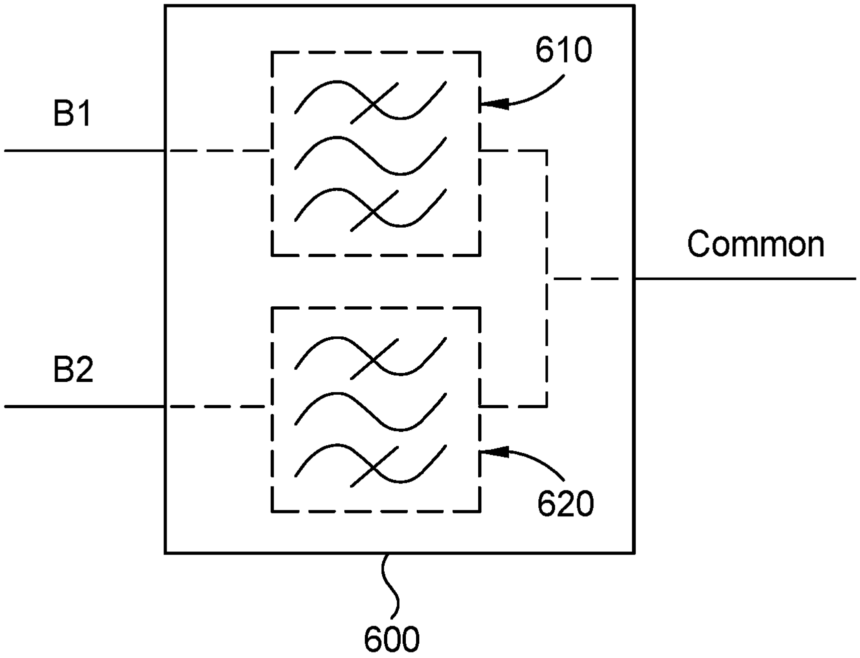


FIG. 6

WIFI RF FRONT END AND ANTENNA MULTIPLEXING

TECHNICAL FIELD

[0001] Embodiments presented in this disclosure generally relate to wireless communication. More specifically, embodiments disclosed herein relate to wireless antenna multiplexing.

BACKGROUND

[0002] Modern wireless access points (APs) commonly employ multiple serving radios that operate simultaneously. For example, an AP may include a 2.4 GHz radio and a 5 GHz radio. But APs with multiple simultaneously operated radios face serious coexistence problems. This can be even more challenging when the APs operate in continuous band segments of Unlicensed National Information Infrastructure (U-NII) 1-8 (i.e., U-NII-1-U-NII-8). Existing solutions employ separate antenna arrays for each radio, plus highly selective switchable post-front-end module (FEM) band-pass filters which incur substantial losses. This approach has many downsides, including requiring a large number of antenna arrays, and leading to RF output power dissipation through those losses. This results in poor power and thermal efficiency, poor reception (RX) and transmission (TX) performance, and significantly increased costs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] So that the manner in which the above-recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate typical embodiments and are therefore not to be considered limiting; other equally effective embodiments are contemplated.

[0004] FIG. **1**A illustrates antenna coexistence for a multi-radio AP using separate antennas, according to one embodiment.

[0005] FIG. **1**B illustrates antenna coexistence for a multi-radio AP using a diplexer, according to one embodiment.

[0006] FIG. **1**C illustrates antenna coexistence for a multi-radio AP using separate antennas and a diplexer, according to one embodiment.

[0007] FIG. **2** illustrates an architecture for RF front end and antenna multiplexing, according to one embodiment.

[0008] FIG. **3** illustrates a further architecture for RF front end and antenna multiplexing, according to one embodiment.

[0009] FIG. **4** illustrates pre-FEM filtering results using an architecture for RF front end and antenna multiplexing, according to one embodiment.

[0010] FIG. **5** illustrates a reduction in unwanted emissions using an architecture for RF front end and antenna multiplexing, according to one embodiment.

[0011] FIG. **6** illustrates a dipole architecture for use in RF front end and antenna multiplexing, according to one embodiment.

[0012] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially used in other embodiments without specific recitation.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

[0013] Embodiments include a wireless access point (AP), including a first antenna array, a second antenna array, a plurality of diplexers, a first radio-frequency integrated circuit (RFIC) configured to operate at a first frequency band including a first plurality of sub-bands, and a second RFIC configured to operate at a second frequency band including a second plurality of sub-bands. The first RFIC and the second RFIC are both coupled to the first antenna array and the second antenna array. Adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands are assigned to different antenna arrays of the first and second antenna arrays using the plurality of diplexers.

[0014] Embodiments further include an antenna system for wireless communication, including: a plurality of diplexers and a first antenna array coupled to a first radio-frequency integrated circuit (RFIC) configured to operate at a first frequency band including a first plurality of sub-bands, and a second RFIC configured to operate at a second frequency band including a second plurality of sub-bands. The antenna system further includes a second antenna array coupled to both the first RFIC and the second RFIC. Adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands are assigned to different antenna arrays of the first and second antenna arrays using the plurality of diplexers.

[0015] Embodiments further include a method. The method includes transmitting and receiving data at a wireless access point (AP) using a first radio-frequency integrated circuit (RFIC) configured to operate at a first frequency band including a first plurality of sub-bands. The method further includes transmitting and receiving data at the AP using a second RFIC configured to operate at a second frequency band comprising a second plurality of sub-bands. The first RFIC and the second RFIC are both coupled to a first antenna array and a second antenna array. Adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands are assigned to different antenna arrays of the first and second antenna arrays using a plurality of diplexers.

Example Embodiments

[0016] As discussed above, employing multiple serving radios that operate simultaneously in an AP is challenging. This is even more challenging as APs begin to use 6 GHz radios simultaneously with adjacent 5 GHz radios, which can create significant coexistence challenges. One or more techniques disclosed herein relate to an improved RF front-end architecture that reduces antenna array requirements by multi-radio mapping (e.g., for 6 GHz radios, 5 GHz radios, 2.4 GHz radios, or any other suitable band) and significantly reduces, or effectively eliminates, typical post-FEM filtering losses with diplexing techniques.

[0017] In an embodiment, this is achieved through a combination of any of multiple techniques. For example, an improved architecture can use sub band pre-filtering to reduce thermal noise before power amplification, thereby relaxing the post-filtering requirements (and resulting insertion loss). This can be done using relatively inexpensive pre-FEM band-pass filtering after a radio-frequency integrated circuit (RFIC). This is a significant improvement over existing techniques that use switchable post-FEM band pass filters.

[0018] Further, an improved architecture can exploit frequency sub band selectivity available in 5/6 GHz diplexers using bulk acoustic wave (BAW) or surface acoustic wave (SAW) resonators, and can cross couple multiple diplexed signals to multiple antenna arrays to leverage the array isolation for adjacent sub band coexistence. For example, radio sub band operation can be mapped across multiple antenna arrays taking into account coexistence. In this example, low 5 GHz sub-bands can be mapped with low 6 GHz sub-bands, and high 5 GHz sub-bands can be mapped with high 6 GHz sub-bands, so that adjacent sub bands are mapped to opposite physical antenna arrays. In an embodiment, antenna arrays can be designed for enhanced isolation (e.g., approximately 40 dB isolation) to achieve adjacent sub band coexistence.

[0019] Finally, an improved architecture can use backoff of power amplifiers (PAs) from their saturated power output (Psat) levels to target off-channel intermodulation (IM) product levels compatible with the overall sub-band isolation of the antenna system. That is, the improved architecture can operate FEM PAs at relatively low levels compared to prior solutions (e.g., 10 dB below Psat). This can achieve lower IM products (e.g., reducing distortion) and reduce post-FEM filtering requirements. In this example, as illustrated below in relation to FIG. **6**, post-FEM filtering can be done using low-loss bulk acoustic wave (BAW) based diplexers.

[0020] In an embodiment, using a combination of these multiple techniques can result in sufficient level of antenna isolation (e.g., 70-80 dB of antenna isolation) to operate multiple simultaneous radios with shared antenna arrays. For example, pre-FEM band-pass filtering (e.g., as discussed further below with regard to FIG. **4**) can provide partial isolation, physical antenna isolation (e.g., as discussed below with regard to FIGS. **2-3**) can provide additional isolation, and the use of BAW diplexers (e.g., as discussed below with regard to FIG. **6**) can provide sufficient isolation for multiple simultaneous radio operation using shared antenna arrays.

[0021] Using one or more of these techniques can provide significant advantages. For example, it can allow for full utilization of 5 GHz and 6 GHz antenna arrays (e.g., with two radios mapped to each array), rather than requiring an antenna array for each radio. This results in a doubling of space and cost efficiency, and enables more capacity per AP. This can be particularly important in high density venues (e.g., arenas, stadiums, and the like).

[0022] As another example, one or more of the techniques disclosed herein can provide a significant reduction of post-FEM losses (e.g., a 4-5 dB reduction in losses). This can lead to improved linearity and improved modulation coding scheme (MCS) data rates, or to power savings (e.g., depending on design preferences). Further, one or more of the techniques disclosed herein can provide multi-radio scaling, with limited or no self-interference and no macro-cell/micro-cell radio range limitations, and improved receiver performance commensurate with reduced post-FEM losses.

[0023] FIG. **1**A illustrates an architecture **100** for antenna coexistence for a multi-radio AP using separate antennas, according to one embodiment. In an embodiment, the architecture **100** illustrates a general model of the interaction of transmitter sections of one co-located radio with the receiver section of another. The architecture **100** assumes non-coordinated carrier-sense multiple access (CSMA) protocols (e.g., for WiFi).

[0024] In an embodiment, the architecture **100** includes a transmitting chain **110** with an RFIC **102**, pre-filtering **104**, a FEM **106** (e.g., operating in power amplifier (PA) mode), post-filtering **108**, and an antenna **112** (e.g., an antenna array). As illustrated, pre-filtering and post-filtering are relative to the power amplification in the transmitting chain **110** (e.g., the pre-filtering **104** occurs before power amplification in the FEM, and the post-filtering **108** occurs after the power amplification in the FEM). The architecture **100** further includes a receiving chain **120**, including an antenna **122** (e.g., an antenna array), post-filtering **124**, a FEM **126** (e.g., operating in low-noise amplifier (LNA) mode), and an RFIC **128**.

[0025] In an embodiment, transmitting chain **110** and the receiving chain **120** are co-located (e.g., in an AP). That is, the receiving chain **120** is not the desired destination for the transmitting chain **110**. Instead, the transmitting chain **110** and receiving chain **120** relate to separate RFICs **102** and **128**, and should be isolated. In an embodiment, the dominant interference mechanism between the transmitting chain **110** and the receiving chain **120** is unwanted emissions from the transmitting chain **110** infiltrating the receiving chain **120** due to coupling between the antennas **112** and **122**. As illustrated, this is reduced by providing separate antennas **112** and **122** for the transmitting chain **110** and the receiving chain **120** and isolating the antennas **112** and **122**.

[0026] FIG. **1**B illustrates an architecture **130** for antenna coexistence for a multi-radio AP using a diplexer, according to one embodiment. In an embodiment, the architecture **130** uses a shared antenna **140** (e.g., an antenna array). The architecture **130** uses this shared antenna **140** (e.g., instead of separate antennas **112** and **122** used in the architecture **100** illustrated in FIG. **1**A), by including a diplexer **138**. The architecture **130** includes a transmitting chain **135** with an RFIC **132**, pre-filtering **134**, and an FEM **136** (e.g., operating in PA mode), and a receiving chain **145** with an FEM **142** (e.g., operating in LNA mode) and an RFIC **144**.

[0027] In an embodiment, the receiving chain **145** is again not the desired destination for the transmitting chain **135**. Instead, the transmitting chain **135** and receiving chain **145** relate to separate RFICs **132** and **144**, and should be isolated. In the architecture **130**, this is achieved using a shared antenna **140** and a diplexer **138** that includes post-filtering **138**A in the transmitting chain **135** and post-filtering **138**B in the receiving chain **145**. By using antenna sharing with the diplexer **138**, the dominant interference mechanism between the transmitting chain **135** and the receiving chain **145** is now the conducted isolation characteristics of the diplexer **138**.

[0028] FIG. **1**C illustrates an architecture **150** for antenna coexistence for a multi-radio AP using separate antennas and a diplexer, according to one embodiment. In an embodiment, the architecture **150** supports four RFICs **152**, **164**, **172**, and **184**, and multiple transmitting chains **155** and **175** and receiving chains **165** and **185**. The architecture **150** both isolates transmitting and receiving chains with shared antennas using diplexers (e.g., as illustrated above in the architecture **130** illustrated in FIG. **1**B), and isolates between separate antennas (e.g., as illustrated above in the architecture **100** illustrated in FIG. **1**A).

[0029] The architecture **150** includes a transmitting chain **155** with an RFIC **152**, pre-filtering **154**, and an FEM **156** (e.g., operating in PA mode), and a receiving chain **165** with an FEM **162** (e.g., operating in LNA mode) and an RFIC **164**. The transmitting chain **155** and the receiving chain **165** share an antenna **160** (e.g., an antenna array) using a diplexer **158**, which includes post-filtering **158**A in the transmitting chain **155** and post-filtering **158**B in the receiving chain **165**.

[0030] The architecture **150** further includes another transmitting chain **175** with an RFIC **172**, pre-filtering **174**, and an FEM **176** (e.g., operating in PA mode), and another receiving chain **185** with an FEM **182** (e.g., operating in LNA mode) and an RFIC **184**. The transmitting chain **175** and the receiving chain **185** share an antenna **180** (e.g., an antenna array) using a diplexer **178**, which includes post-filtering **178**A in the transmitting chain **175** and post-filtering **178**B in the receiving chain **185**.

[0031] As illustrated, the architecture **150** includes two antennas **160** and **180**, and four RFICs **152**, **164**, **172**, and **184**. When multiple antennas (e.g., multiple antenna arrays) are added to support more than two radios, the interference mechanisms are two fold, and bi-directional across the antenna to antenna coupling. Thus, the architecture **150** includes both isolation within the shared antennas **160** and **180** using the respective diplexers **158** and **178**, and isolation between the antennas **160** and **180**. For example, the transmitting chain **155** is isolated from the receiving chain **165** using the diplexer **158**, and from the receiving chain **185** using the separate antennas **160** and **180**. Similarly, the transmitting chain **175** is isolated from the receiving chain **185** using the diplexer **178**, and from the receiving chain **165** using the separate antennas **160** and **180**.

[0032] FIG. **2** illustrates an architecture **200** for RF front end and antenna multiplexing, according to one embodiment. In an embodiment, the architecture **200** includes four simultaneous radios: RFICs **202**, **204**, **206**, and **208**. For example, the RFIC **202** can be a 6 GHz RFIC, the RFIC **204** can be a 5 GHz RFIC, the RFIC **206** can be an RFIC that operates at any of 2.4 GHz, 5 GHz, or 6 GHz, and the RFIC **208** can be a 2.4 GHz RFIC. These are merely examples, and the RFICs **202**, **204**, **206**, and **208** can operate at any suitable frequency band or combinations of bands. Further, the use of four simultaneous radios is also merely an example, and the architecture **200** can be applied to any suitable number of simultaneous radios (e.g., three simultaneous radios or five simultaneous radios as illustrated further in FIG. **3**).

[0033] In an embodiment, the architecture **200** supports output from any of the four RFICs **202**, **204**, **206**, and **208**. For example, the architecture **200** can include a number of switches (e.g., double pole double throw (DPDT) switches, single pole double throw (SPDT) switches, or any other suitable switches) **212**, **214**, **216**, **218**, **220**, **232**, **234**, **236**, and **238** to facilitate providing output from any of the four RFICs **202**, **204**, **206**, and **208**. For example, the switches **212**, **214**, and **216** can be DPDT switches. In this example, the switches **218**, **220**, **232**, **234**, **236**, and **238** can be SPDT switches. This is merely an example, and any suitable type and number of switches can be used.

[0034] In an embodiment, the architecture **200** includes pre-filters **222**, **224**, **226**, and **228** before the respective FEMs **240**, **242**, **244**, **246**, and **248**. For example, the pre-filters **222**, **224**, **226**, and **228** can be band-pass filters between the respective RFIC outputs and FEM inputs. In an embodiment, as discussed further below with regard to FIG. **4**, including pre-FEM band-pass filters reduces the noise floor of the out-of-sub-band signals from the RFIC to the thermal noise floor, and can reduce (or eliminate) the need for post-FEM filtering. This is a significant improvement over existing techniques that use switchable post-FEM band pass filters. Further, the RFIC **208** can include pre-filtering **252** before the FEM **248**, and a band edge filter **254** after the FEM **248**. In an embodiment, the 2.4 GHz subsystems (e.g., the 2.4 GHz RFIC **208**, FEM **248**, and band edge filter **254** illustrated in FIG. **2** and the 2.4 GHz RFIC **310**, FEM **348**, and band edge filter **354** illustrated in FIG. **3**) are treated differently from the 5 and 6 GHz subsystems due to their lack of interaction and interference with the 5 and 6 GHz subsystems (e.g., due to the large frequency separation). In the case of the 2.4 GHz subsystems, coexistence requirements may be more easily met with conventional filtering and diplexing approaches.

[0035] While the architecture **200** includes four FEMs **240**, **242**, **244**, and **246**, as illustrated, this is merely an example. The architecture **200** can instead include three FEMs, or any other suitable number of FEMs.

[0036] Further, in an embodiment, the architecture **200** includes two antenna arrays **272** and **274**. These antenna arrays **272** and **274** can be shared among the four RFICs **202**, **204**, **206**, and **208** using multiple diplexers **262** and **264**. The diplexers **262** and **264** are described further, below, with regard to FIG. **6**A. Further, in an embodiment, the diplexers **262** and **264** can each include multiple diplexing components. For example, the diplexer **264** can include multiple diplexing components to support three inputs, from all of the FEMs **244**, **246**, and **248**, to the antenna array **274**. Further, the diplexers **262** and **264** can include very low loss post-FEM filtering, as discussed below in relation to FIG. **6**A.

[0037] In an embodiment, the architecture **200** can segregate the 5 and 6 GHz bands into multiple sub-bands (e.g., four sub-bands) for simultaneous operation. For example, low 5 GHz sub-bands (e.g., from the 5 GHz RFIC **204**) can be mapped with low 6 GHz sub-bands (e.g., from the 6 GHz RFIC **202**), and high 5 GHz sub-bands can be mapped with high 6 GHz sub-bands, so that adjacent sub bands are mapped to opposite physical antenna arrays (e.g., to the antenna arrays **272** and **274**).

[0038] As illustrated, the architecture **200** supports output from four RFICs **202**, **204**, **206**, and **208**, using two shared antenna arrays **272** and **274**, while isolating (e.g., at least partially isolating) the receiving chain of any given radio in the architecture **200** from the transmitting chains of other radios in the architecture **200**. As discussed further below with regard to FIGS. **4**-**6**B, this reduces the noise floor of the out-of-subband signals from the RFIC to thermal noise floor, minimizes unwanted emissions, and limits post-FEM filtering losses.

[0039] FIG. **3** illustrates a further architecture **300** for RF front end and antenna multiplexing, according to one embodiment. In an embodiment, the architecture **300** includes five simultaneous radios: RFICs **302**, **304**, **306**, **308**, and **310**. For example, the RFIC **3** can be a 6 GHz RFIC, the RFIC **304** can be a 5 GHz RFIC, the RFIC **306** can be a 6 GHz RFIC, the RFIC **308** can be a 5 GHz RFIC, and the RFIC **310** can be a 2.4 GHz RFIC. These are merely examples, and the RFICs **302**, **304**, **306**, **308**, and **310** can operate at any suitable frequency band or combinations of bands. Further, the use of five simultaneous radios is also merely an example, and the architecture **300** can be applied to any suitable number of simultaneous radios (e.g., three simultaneous radios or four simultaneous radios as illustrated further in FIG. **2**, above).

[0040] In an embodiment, the architecture **300** supports output from any of the five RFICs **302**, **304**, **306**, **308**, and **310**. For example, the architecture **300** can include a number of switches (e.g., DPDT switches, SPDT switches, or any other suitable switches) **312**, **314**, **316**, **318**, **332**, **334**, **336**, and **338** to facilitate providing output from any of the five RFICs **302**, **304**, **306**, **308**, and **310**. For example, the switches **312**, **314**, **316**, and **318** can be DPDT switches. In this example, the switches **332**, **334**, **336**, and **338** can be SPDT switches. This is merely an example, and any suitable type and number of switches can be used.

[0041] In an embodiment, the architecture **300** includes pre-filters **322**, **324**, **326**, and **328** before the respective FEMs **340**, **342**, **344**, **346**, and **348**. For example, the pre-filters **322**, **324**, **326**, and **328** can be band-pass filters between the respective RFIC outputs and FEM inputs. In an embodiment, as discussed further below with regard to FIG. **4**, including pre-FEM band-pass filters reduces the noise floor of the out-of-sub-band signals from the RFIC to the thermal noise floor, and can reduce (or eliminate) the need for post-FEM filtering. This is a significant improvement over existing techniques that use switchable post-FEM band pass filters. Further, the RFIC **310** can include pre-filtering **352** before the FEM **348**, and a band edge filter **354** after the FEM **348**. As discussed above in relation to the 2.4 GHz RFIC **208** illustrated in FIG. **2**, in an embodiment the 2.4 GHz subsystems are treated differently from the 5 and 6 GHz subsystems due to their lack of interaction and interference with the 5 and 6 GHz subsystems.

[0042] Further, in an embodiment, the architecture **300** includes two antenna arrays **372** and **374**. These antenna arrays **372** and **374** can be shared among the five RFICs **302**, **304**, **306**, **308**, and **310** using multiple diplexers **362** and **364**. The diplexers **362** and **364** are described further, below, with regard to FIG. **6**A. Further, in an embodiment, the diplexers **362** and **364** can each include multiple diplexing components. For example, the diplexer **364** can include multiple diplexing components to support three inputs, from all of the FEMs **344**, **346**, and **348**, to the antenna array **374**. Further, the diplexers **362** and **364** can include very low loss post-FEM filtering, as discussed below in relation to FIG. **6**A.

[0043] In an embodiment, the architecture **300** can segregate the 5 and 6 GHz bands into multiple sub-bands (e.g., four sub-bands) for simultaneous operation. For example, low 5 GHz sub-bands can be mapped with low 6 GHz sub-bands, and high 5 GHz sub-bands can be mapped with high 6 GHz sub-bands, so that adjacent sub bands are mapped to opposite physical antenna arrays (e.g., to the antenna arrays **372** and **374**).

[0044] As illustrated, the architecture **300** supports output from five RFICs **302**, **304**, **306**, **308**, and **310**, using two shared antenna arrays **372** and **374**, while isolating (e.g., at least partially isolating) the receiving chain of any given radio in the architecture **300** from the transmitting chains of other radios in the architecture **300**. As discussed further below with regard to FIGS. **4**-**6**B, this reduces the noise floor of the out-of-subband signals from the RFIC to thermal noise floor, minimizes unwanted emissions, and limits post-FEM filtering losses.

[0045] FIG. **4** illustrates pre-FEM filtering results using an architecture for RF front end and antenna multiplexing, according to one embodiment. In an embodiment, FIG. **4** illustrates providing 40 dB of stopband filtering between an RFIC and FEM (e.g., as illustrated above in relation to FIGS. **2**-**3**). A pre-filtering input is shown in a graph **410**, and a pre-filtering output is shown in a graph **420**. The pre-filtering significantly reduces the noise floor of the out-of-subband signals from the RFIC to the thermal noise floor.

[0046] As illustrated, an example RFIC has a 55 dB maximum signal to noise ratio (SNR). Prior to the filtering, the distance between the bottom of the RFIC SNR and the thermal noise floor, labeled as **412**, is 20-30 dB. The filtering significantly decreases thermal noise, so that after filtering the distance between the bottom of the RFIC SNR and the thermal noise floor, labeled as **422**, has increased to 39 dB.

[0047] FIG. **5** illustrates a reduction in unwanted emissions using an architecture for RF front end and antenna multiplexing, according to one embodiment. In an embodiment, a graph **500** illustrates a PA with 80 MHz channels. As illustrated, an increase in output power (represented along the y-axis) increases unwanted out of band emissions.

[0048] As discussed above, using one or more techniques disclosed herein (e.g., as illustrated in FIGS. **2**-**3**) allows for a significant reduction in power amplification. The graph **500** illustrates the significant, non-linear, decrease in unwanted emissions that accompanies operating at a lower power amplification. Using lessened power amplification (e.g., in FEMs) results in significantly lessened unwanted emissions from the FEMs. This reduces the need for post-FEM filtering, because unwanted emissions are reduced due to the lessened power amplification at the FEM and need not be filtered out.

[0049] FIG. **6** illustrates a dipole architecture for use in RF front end and antenna multiplexing, according to one embodiment. A dipole **600** and includes two BAW band-pass filters **610** and **620** with corresponding inputs B**1** and B**2**, and a common output. In an embodiment, the dipole **600** can be used in any of the architectures illustrated in FIGS. **1**B, **1**C, **2**, and **3**. While the dipole **600** is illustrated as using BAW band-pass filters, this is merely an example. Any suitable technology can be used (e.g., SAW band-pass filters or any other suitable technology).

[0050] Modern BAW technology has enabled diplexer designs with very low insertion loss (1-1.5 dB) with reasonable B**1**-B**2** isolation (e.g. 40 dB). Using these diplexers instead of switchable post FEM band pass filters (e.g., as used in existing systems) can save 2.5-3 dB of insertion loss, and enables a significant improvement to the error vector magnitude (EVM) operating point for the PA.

[0051] In the current disclosure, reference is made to various embodiments. However, the scope of the present disclosure is not limited to specific described embodiments. Instead, any combination of the described features and elements, whether related to different embodiments or not, is contemplated to implement and practice contemplated embodiments. Additionally, when elements of the embodiments are described in the form of "at least one of A and B," or "at least one of A or B," it will be understood that embodiments including element A exclusively, including element B exclusively, and including element A and B are each contemplated. Furthermore, although some embodiments disclosed herein may achieve advantages over other possible solutions or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the scope of the present disclosure. Thus, the aspects, features, embodiments and advantages disclosed herein are merely illustrative and are not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to "the invention" shall not be construed as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).

[0052] As will be appreciated by one skilled in the art, the embodiments disclosed herein may be embodied as a system, method or computer program product. Accordingly, embodiments may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, embodiments may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

[0053] Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

[0054] Computer program code for carrying out operations for embodiments of the present disclosure may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

[0055] Aspects of the present disclosure are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatuses (systems), and computer program products according to embodiments presented in this disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the block(s) of the flowchart illustrations and/or block diagrams.

[0056] These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other device to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the block(s) of the flowchart illustrations and/or block diagrams.

[0057] The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process such that the instructions which execute on the computer, other programmable data processing apparatus, or other device provide processes for implementing the functions/acts specified in the block(s) of the flowchart illustrations and/or block diagrams.

[0058] The flowchart illustrations and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments. In this regard, each block in the flowchart illustrations or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustrations, and combinations of blocks in the block diagrams and/or flowchart illustrations, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

[0059] In view of the foregoing, the scope of the present disclosure is determined by the claims that follow.

We claim:

1. A wireless access point (AP), comprising:

a first antenna array;

a second antenna array;

a plurality of diplexers;

a first radio-frequency integrated circuit (RFIC) configured to operate at a first frequency band comprising a first plurality of sub-bands; and

a second RFIC configured to operate at a second frequency band comprising a second plurality of sub-bands,

wherein the first RFIC and the second RFIC are both coupled to the first antenna array and the second antenna array, and

wherein adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands are assigned to different antenna arrays of the first and second antenna arrays using the plurality of diplexers.

2. The wireless AP of claim **1**, wherein the first frequency band comprises a 5 GHz band and the second frequency band comprises a 6 GHz frequency band.

3. The wireless AP of claim **2**, wherein the adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands comprise a highest sub-band for the 5 GHz band and a lowest sub-band for the 6 GHz frequency band.

4. The wireless AP of claim **1**, further comprising:
a first filter coupled between the first RFIC and a first front-end-module (FEM) providing power amplification; and
a second filter coupled between the second RFIC and a second FEM providing power amplification.

5. The wireless AP of claim **4**, wherein the first filter and the second filter each comprise band-pass filters.

6. The wireless AP of claim **5**, wherein the first FEM and the second FEM are each configured to amplify power below a saturated output power (Psat) level.

7. The wireless AP of claim **6**, wherein the first FEM and the second FEM are each configured to amplify power approximately 10 dB below the Psat level.

8. The wireless AP of claim **1**, further comprising a third RFIC and a fourth RFIC, wherein the third RFIC and the fourth RFIC are both configured to use at least one of the first and second antenna arrays.

9. The wireless AP of claim **8**, further comprising:
four FEMs, each of the FEMs coupled to at least one of the RFICs and providing power amplification for the respective at least one of the RFICs.

10. The wireless AP of claim **1**, wherein the plurality of diplexers each comprise a plurality of bulk acoustic wave (BAW) band-pass filters.

11. An antenna system for wireless communication, comprising:
a plurality of diplexers;
a first antenna array coupled to:
 a first radio-frequency integrated circuit (RFIC) configured to operate at a first frequency band comprising a first plurality of sub-bands, and
 a second RFIC configured to operate at a second frequency band comprising a second plurality of sub-bands; and
a second antenna array coupled to both the first RFIC and the second RFIC,
 wherein adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands are assigned to different antenna arrays of the first and second antenna arrays using the plurality of diplexers.

12. The antenna system of claim **11**,
wherein the first frequency band comprises a 5 GHz band and the second frequency band comprises a 6 GHz frequency band, and
wherein the adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands comprise a highest sub-band for the 5 GHz band and a lowest sub-band for the 6 GHz frequency band.

13. The antenna system of claim **11**, further comprising:
a first filter coupled between the first RFIC and a first front-end-module (FEM) providing power amplification; and
a second filter coupled between the second RFIC and a second FEM providing power amplification.

14. The antenna system of claim **13**,
wherein the first filter and the second filter each comprise band-pass filters, and
wherein the first FEM and the second FEM are each configured to amplify power below a saturated output power (Psat) level.

15. A method, comprising:
transmitting and receiving data at a wireless access point (AP) using a first radio-frequency integrated circuit (RFIC) configured to operate at a first frequency band comprising a first plurality of sub-bands; and
transmitting and receiving data at the AP using a second RFIC configured to operate at a second frequency band comprising a second plurality of sub-bands,
 wherein the first RFIC and the second RFIC are both coupled to a first antenna array and a second antenna array, and
 wherein adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands are assigned to different antenna arrays of the first and second antenna arrays using a plurality of diplexers.

16. The method of claim **15**,
wherein the first frequency band comprises a 5 GHz band and the second frequency band comprises a 6 GHz frequency band, and
wherein the adjacent portions of the first plurality of sub-bands and the second plurality of sub-bands comprise a highest sub-band for the 5 GHz band and a lowest sub-band for the 6 GHz frequency band.

17. The method of claim **15**, wherein the AP further comprises:
a first filter coupled between the first RFIC and a first front-end-module (FEM) providing power amplification; and
a second filter coupled between the second RFIC and a second FEM providing power amplification.

18. The method of claim **17**, wherein the first FEM and the second FEM are each configured to amplify power below a saturated output power (Psat) level.

19. The method of claim **15**, further comprising:
transmitting and receiving data at the AP using a third RFIC coupled to at least one of the first antenna array or the second antenna array; and
transmitting and receiving data at the AP using a fourth RFIC coupled to at least one of the first antenna array or the second antenna array.

20. The method of claim **19**, wherein each of the respective first RFIC, second RFIC, third RFIC, and fourth RFIC is coupled to at least one of four FEMs providing power amplification.

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