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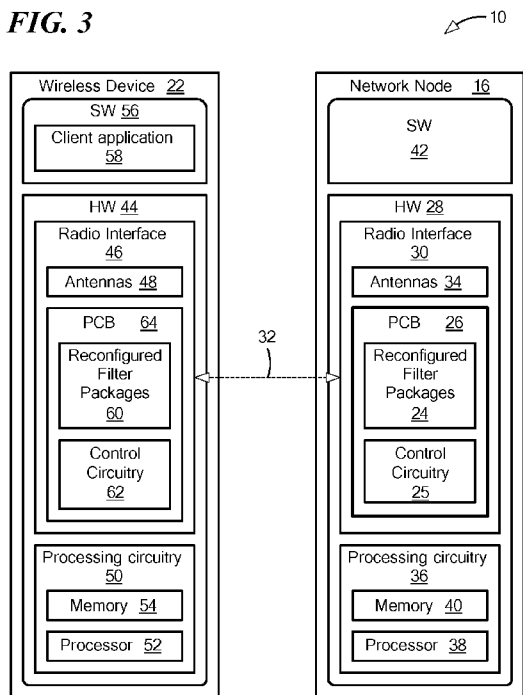
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(54) **Title:** FILTER WITH RELATIVE PHASE CONTROL

FIG. 3



(57) **Abstract:** A method and electronic circuit for filtering with relative phase control are disclosed. According to one aspect, an electronic circuit includes a first filter package comprising a plurality of interconnected filter elements configured to have a nominal frequency response of a plurality of second filter packages. The electronic circuit further includes control circuitry external to the first filter package and configured to alter a frequency response of the first filter package from the nominal frequency response to control a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the filter package, a magnitude of the relative phase being configured to exceed 90 degrees.

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FILTER WITH RELATIVE PHASE CONTROL

TECHNICAL FIELD

The present disclosure relates to wireless communications, and in particular, to
5 filters with relative phase control.

BACKGROUND

The Third Generation Partnership Project (3GPP) has developed and is developing
standards for Fourth Generation (4G) (also referred to as Long Term Evolution (LTE)) and
10 Fifth Generation (5G) (also referred to as New Radio (NR)) wireless communication
systems. Such systems provide, among other features, broadband communication between
network nodes, such as base stations, and mobile wireless devices (WD), as well as
communication between network nodes and between WDs. The 3GPP is also developing
standards for Sixth Generation (6G) wireless communication networks.

15 The mobile cellular communications network is a driving force of economic
prosperity, providing increasing levels of wireless connectivity to billions of devices.
Each evolution of network technology has generally been accompanied with new
frequency bands allocated by governments and international agencies to enable new
services and capabilities. Current and new frequency mobile cellular bands are often
20 noncontiguous and interleaved with existing incumbent services such as fixed
microwave services, fixed or mobile satellite services, weather or military radar, radio
astronomy, etc.

Government and international agencies create regulations to protect incumbent
operators of these services such as limits on cellular equivalent isotropic radiated power
25 (EIRP) and out-of-band emissions. Common examples in the United States of America
limit EIRP to 3280 W/MHz and out-of-band emissions to -13 dBm/MHz. In some cases,
out-of-band EIRP emissions are limited to levels such as -27 dBm/MHz EIRP, stricter
than the internationally accepted spurious limit of -30 dBm/MHz TRP or total radiated
power, which does not include antenna gain. Some governments and agencies require
30 exclusion zones, such as surrounding radio astronomy sites, often located in high
mountainous areas. Other governments, in protecting civilian and military radar
applications have specified listen-before-talk (LBT) protocols required to dynamically
detect the presence of an incumbent.

Significant technology has been developed to ensure non-interfering coexistence

of adjacent bands. The primary technology has been and continues to be intermediate frequency (IF) and radio frequency (RF) filters employed to attenuate out-of-band radio frequency energy before it is radiated by antenna elements. These filters often provide attenuations of 70 dB or more and may achieve significant reductions in out-of-band total radiated power (TRP) to meet stringent regulations such as -30 dBm/MHz. Legacy radio base stations (RBS) (hereinafter also referred to as network nodes) such as second, third and fourth generation (2G, 3G and 4G) radio base stations, generally used external sector antennas to provide “cellular” coverage. These antennas had typical gains in the range of 15 dBi so that spurious out-of-band radiated emissions in protected bands may see EIRP levels of -15 dBm/MHz.

The introduction of fifth generation (5G) radios has brought advanced antenna systems (AAS), also known as beamforming antennas, with typical gains of 25 dBi, but with 10 dB higher gains expected within a few years. AAS radios therefore have increased out-of-band radiated emissions which may be 20 dB higher than legacy 3G and 4G network nodes. This increased EIRP has not been accompanied with a corresponding improvement in filter technology. In fact, the opposite is true, as larger antenna arrays result in physical limitations on available space for filters, reducing achievable attenuation.

Innovations unique to network nodes with AAS, such as precoder matrix indicator (PMI) restrictions, provide the means to spatially manage potential antenna patterns and have found utility in avoiding or correcting interference cases for in-band fixed incumbents such as weather radar or satellite communications systems. However, these features do not address the generalized problem of out-of-band radiated emissions (i.e., EIRP) since in-band antenna patterns do not have good alignment with out-of-band antenna patterns.

Therefore, the dominant means to mitigate out-of-band radiated emissions remains the use of filters. To achieve the greater attenuation levels, network nodes employ cascaded filters, which adds costs to the radio design. Additional costs are incurred in the power amplification, often performed at the final stage in advance of a single low loss filter before the antenna element. Power amplifiers introduce a broadband noise floor as well as “side band” emissions cause by unmanaged nonlinearities in the signal amplification process. If not attenuated sufficiently, these unwanted emissions may result in the network node not meeting government mandated out-of-band emission levels.

Finally, current technology has been unable to develop an “ideal” brick wall filter. This is to say that all filters have a pass band, to allow the intended signals to be transmitted, and a reject band where signals are blocked. An ideal brick wall filter would have no in-band attenuation, and infinite out-of-band attenuation, but this is not possible. In-band attenuation is often in the 0.5 dB range for high powered “macro” base station radios and reach a level of 60-70 dB of attenuation after a typical guard band of 40-100 MHz. Unfortunately, it is this transition zone between the pass and rejection bands of reduced attenuation, that the highest levels of non-linear amplifier side band emissions exist and are fed into the AAS elements. These antennas have wide operational ranges, and often transmit adjacent channel but out-of-band signals with the same beamforming gain as in-band signals.

As there are no known technologies to address this concern, operators often use a portion of their spectrum as a guard-band. Operators request radio base station products with filters that attenuate the top 20 or 40 MHz of their spectrum to meet regulatory out-of-band radiated emissions into incumbent bands.

Existing technology used to reduce out-of-band emissions in the adjacent channel region consists of two main tools – filter technology and power amplifier linearization algorithms, referred to as digital predistortion DPD. 3GPP defines Adjacent Channel Leakage Ratio (ACLR) as the ratio of the transmitted power to the power in the adjacent radio channel. The ACLR is measured after the transmitter filter, as a point where test equipment may assess these two powers before the signals are fed into the antennas. The term ACLR1 refers to the first adjacent channel, where the highest levels of unwanted out-of-band emissions occur. The ACLR1 region spans the passband to rejection band of the filter where filter attenuation is increasing rapidly, typically over a range of 40-100MHz.

Filter and DPD technologies are used to reduce spurious emissions in the ACLR1 region. As discussed, filter technology may achieve significant out-of-band attenuation in this region in the range of 70 dB and has been the dominant means to suppress unwanted emissions. Digital predistortion is predominantly employed to linearize power amplifier operation to meet in band transmitter error vector magnitude (EVM) requirements so that transmitted high order quadrature amplitude modulated (QAM) signals may be received by user equipment (UEs). Sidelobes are caused by transmitter non-linearities generating intermodulation products and are therefore improved by linearizing the transmitter.

While existing filter and DPD technology has been sufficient to minimize out-of-band emissions and meet 3GPP ACLR1 specifications for 3G and 4G products that use sector antennas with typical gains in the range of 15 dBi, this has become more difficult with 5G AAS-equipped network nodes where beamforming antenna gains today achieve
5 26 dBi and are expected to move to 36 dBi in the near future.

Existing DPD and filter technology are well understood and mature and have evolved over decades to achieve the current high performance seen in 3G, 4G and 5G radios. While DPD improvements are possible, current technology has reached a level of performance which is not readily improved. DPD is not only employed to linearize
10 existing power amplifier designs, but it is used to achieve the maximum power performance possible with the available technology, which causes devices to operate in highly non-linear regions. A focus of existing DPD technologies is therefore to achieve transmitter error vector magnitude specifications while operating in these non-linear regions. The dynamic range of the feedback paths has been optimized for high
15 transmitted signal levels.

Proposals for algorithms to reduce intermodulation products within the carrier band to further improve ACLR distortion have been made. In fact, non-linear algorithms are common tools in the reduction of ACLR. Such tools seek to minimize detectable ACLR in these products to such an extent that the remaining leakage power
20 has minimal correlation with intermodulation (IM) products. This leakage power is often 40 - 50 dB reduced from in band signals and approaching measurable quantization levels. The leakage power then appears as random noise, yet still contains correlated components. In short, while the use of DPD has made significant advancements in ACLR reduction, correlated components still exist, possibly due to clipping noise, or
25 transmitter reverse intermodulation, or possibly, but less likely, transmitter spatial reverse intermodulation. While this area still has potential gains, it is unknown if algorithm improvements will further reduce out-of-band correlation components.

Existing filter technology is also well understood and has reached its performance limits.

30 Cellular communications have approached performance limits for transmitted power, made possible with precision cavity filters, characterized by their physically large size, and visible tuning screws. Cavity filters have an advantage of low insertion loss, minimizing power loss in this final stage between power amplification and antenna transmission. The myriad of adjustment screws enables manufacturers to precision tune

these filters, compensating for manufacturing variations, ensuring that the final product achieves tightly specified customer defined attenuation masks. While improved specifications and tighter masks are possible, they come at the cost of higher insertion loss, and increased size as more poles and zeros are added to the filter, and these larger sizes often cannot fit into the allocated space of an AAS radio with hundreds of filters.

As AAS radios evolve from hundreds of antenna elements to thousands, the space and performance of the filters used with each port is further limited. Metal cavity filter technology is being replaced by ceramic waveguides, sheet metal waveguides, and 3D printed filters, to achieve lower costs and higher densities. These new technologies do not achieve improvements in specifications, rather more often result in performance reductions such as higher insertion loss and less stringent masks.

Fortunately, the evolution to larger numbers of antenna elements and higher beamforming gain reduces the required transmitted power per antenna element, enabling filter designs with higher insertion loss. The smaller, non-tuned filters achieve similar rejection band performance, but suffer from reduced precision in the ACLR1 region. While the evolved miniaturized filters, regardless of the technology, may include some form of manufacturing tuning, these devices will still see similar or reduced performance in the ACLR1 region. Bulk acoustic wave (BAW) filters at 3.7 GHz or commercial parts require 40 – 100 MHz of guard band between the pass and rejection bands, where ACLR1 emissions are attenuated far below the 50-70 dB typical in the rejection band. Note that in the design of RF filters, higher selectivity requires increased size.

Filter resonant sections, each with specified physical dimensions and corresponding impedances, cascade to determine the transfer function defining the input to output characteristics. Larger filters with more sections enable higher numbers of poles and zeros and the possibility of steeper roll offs for reduced guard bands. FIG. 1 shows a typical filter with pass band, and a roll-off of approximately 100 MHz to the rejection band starting at 4500 MHz.

Current filter technologies are designed with the goal of improving transmitter emissions or receiver rejection, and not to address issues unique to high gain beamforming systems. They provide no management or specification of out-of-band phase variations.

The inability to control the out-of-band phase variations in the ACLR1 region is a lost opportunity for improved spectrum use - not only for high power transmitter systems, such as 5G and 6G advanced antenna systems to achieve low beamforming gain

in this region, but also for multiple input-multiple output (MIMO) receiver systems to reduce out-of-band beamforming gain which impacts blocking performance.

SUMMARY

5 Some embodiments advantageously provide methods and electronic circuits for filtering with relative phase control.

 Some embodiments may be applied to transmission and reception, for network nodes and wireless devices (WDs) or any similar arrangement where massive antenna wireless functions are required to exist in adjacent bands.

10 Some embodiments employ filters with controls to modify the relative out-of-band phase of the filtered signal. These control capabilities impact the out-of-band phase while maintaining filter parameters such as insertion loss, passband, out-of-band rejection, etc. One example embodiment is a discrete filter component with a single control input, electrically accessible by an external pin. The control input point is
15 selected so that changes to the external load impedance controls the relative phase of in-band and out-of-band filtered signals. The external load impedance may be implemented by, for example, use of a printed circuit board (PCB) populated with resistors, capacitors, inductors, or track delay-line lengths mounted thereon. Some embodiments enable a large advanced antenna system (AAS) macro or other beamforming radio
20 product array to employ a common filter component on all or most antenna feeds. By populating different components on different PCBs for each filter, or by creating different PCB delay-line track length changes in the PCB layout for each filter, the in-band to out-of-band relative phases at each antenna or antenna port may be individually configured using a filter that is common to all antennas or antenna ports.

25 According to one aspect, a method is provided for configuring a filter response of a first filter package to obtain an out-of-band gain reduction while substantially maintaining an in-band return loss. The method includes configuring a plurality of interconnected filter elements of the first filter package to enable external control of a relative phase between an out-of-band filtered signal and an in-band filtered signal
30 output by the first filter package, a magnitude of the relative phase being configurable to exceed 90 degrees.

 According to this aspect, in some embodiments, configuring the plurality of interconnected filter elements includes, for each of at least one circuit point within the first filter package, electrically connecting the circuit point to an external pin of the filter

package. In some embodiments, configuring the interconnected filter elements includes electrically connecting an external load to an input of the first filter package. In some embodiments, configuring the interconnected filter elements includes applying a first control signal to an input of the first filter package to alter a frequency response of the interconnected filter elements. In some embodiments, configuring the interconnected filter elements includes applying a second control signal to an input of the first filter package to alter a coupling path between the interconnected filter elements. In some embodiments, configuring the interconnected filter elements includes applying a third control signal to a first input of the first filter package and applying a fourth control signal to a second input of the first filter package to alter a delay of at least one electrical path between the interconnected filter elements. In some embodiments, configuring the interconnected filter elements includes inputting an electrical signal to an input of the first filter package to alter a piezoelectric substrate within the first filter package. In some embodiments, configuring the interconnected filter elements includes applying one of an electrostatic field, a magnetostatic field, and an electromagnetic field to the first filter package. In some embodiments, configuring the interconnected filter elements includes staggering frequencies of a plurality of at least one of band edge poles and band edge zeros of a filter response of the first filter package. In some embodiments, configuring the interconnected filter elements includes altering a frequency response of at least one of a surface acoustic wave, SAW, filter, a bulk acoustic wave, BAW, filter, a thin film bulk acoustic resonator, FBAR, a discrete lumped element filter, a ceramic filter and a cavity filter, located with the first filter package. In some embodiments, configuring the interconnected filter elements includes configuring the magnitude of the relative phase is configured to exceed 180 degrees. In some embodiments, the first filter package is one of a plurality of second filter packages having a same topology of interconnected filter elements. In some embodiments, the method also includes configuring the interconnected filter elements of each of a plurality of the second filter packages to configure each second filter package to have a different filter response according to a placement of the first filter package in a multiple input-multiple output phased array antenna system.

According to another aspect, an electronic circuit is provided for out-of-band phase control. The electronic circuit includes a first filter package comprising a plurality of interconnected filter elements configured to have a nominal frequency response of a plurality of second filter packages. The electronic circuit also includes control circuitry

external to the first filter package and configured to alter a frequency response of the first filter package from the nominal frequency response to control a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the first filter package, a magnitude of the relative phase being configured to exceed 90 degrees.

5 According to this aspect, in some embodiments, the first filter package includes, for each of at least one circuit point within the first filter package, an electrical connection connecting the circuit point to an external pin of the filter package. In some embodiments, the control circuitry includes an external load impedance. In some
10 embodiments, the control circuitry is configured to apply a first control signal to an input of the first filter package to alter a frequency response of the interconnected filter elements. In some embodiments, the control circuitry is configured to apply a second control signal to an input of the first filter package to alter a coupling path between the interconnected filter elements. In some embodiments, the control circuitry is configured to apply a third control signal to a first input of the first filter package and applying a
15 fourth control signal to a second input of the first filter package to alter a delay of at least one electrical path between the interconnected filter elements. In some embodiments, the control circuitry is configured to input an electrical signal to an input of the first filter package to alter a piezoelectric substrate within the first filter package. In some embodiments, the control circuitry is configured to apply one of an electrostatic
20 field, a magnetostatic field, and an electromagnetic field to the first filter package. In some embodiments, the control circuitry is configured to stagger frequencies of a plurality of at least one of band edge poles and band edge zeros of a filter response of the first filter package. In some embodiments, the control circuitry is configured to configure the magnitude of the relative phase to exceed 180 degrees.

25

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present embodiments, and the attendant advantages and features thereof, will be more readily understood by reference to the following detailed description when considered in conjunction with the accompanying
30 drawings wherein:

FIG. 1 is an example response of a pass-band filter;

FIG. 2 is a schematic diagram of an example network architecture illustrating a communication system according to principles disclosed herein;

FIG. 3 is a block diagram of a network node in communication with a wireless

device over a wireless connection according to some embodiments of the present disclosure;

FIG. 4 is a flowchart of an example process in a network node for filtering with relative phase control;

5 FIG. 5 is a schematic diagram of a filter package;

FIG. 6 is a schematic diagram of a filter package with control pins according to principles disclosed herein;

FIG. 7 illustrates gain reduction for various differences between in band and out-of-band phase;

10 FIG. 8 illustrates a out-of-band phase variations for different filters in an advanced antenna system (AAS);

FIG. 9 illustrates a bandpass filter response typically provided by a manufacturer;

FIG. 10 illustrates an out-of-band phase response of a filter;

FIG. 11 illustrates another out-of-band phase response of a filter;

15 FIG. 12 illustrates a two port filter with nine resonant elements;

FIG. 13 illustrates a filter topology; and

FIG. 14 illustrates a 64x32 element cross-polarized AAS.

DETAILED DESCRIPTION

20 Before describing in detail example embodiments, it is noted that the embodiments reside primarily in combinations of apparatus components and processing steps related to filters with relative phase control. Accordingly, components have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments so as not to obscure the disclosure
25 with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

As used herein, relational terms, such as “first” and “second,” “top” and “bottom,” and the like, may be used solely to distinguish one entity or element from another entity or element without necessarily requiring or implying any physical or logical relationship or
30 order between such entities or elements. The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the concepts described herein. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes” and/or

“including” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

5 In embodiments described herein, the joining term, “in communication with” and the like, may be used to indicate electrical or data communication, which may be accomplished by physical contact, induction, electromagnetic radiation, radio signaling, infrared signaling or optical signaling, for example. One having ordinary skill in the art will appreciate that multiple components may interoperate and modifications and
10 variations are possible of achieving the electrical and data communication.

 In some embodiments described herein, the term “coupled,” “connected,” and the like, may be used herein to indicate a connection, although not necessarily directly, and may include wired and/or wireless connections.

 The term “network node” used herein may be any kind of network node comprised
15 in a radio network which may further comprise any of base station (BS), radio base station, base transceiver station (BTS), base station controller (BSC), radio network controller (RNC), g Node B (gNB), evolved Node B (eNB or eNodeB), Node B, multi-standard radio (MSR) radio node such as MSR BS, multi-cell/multicast coordination entity (MCE), relay node, donor node controlling relay, radio access point (AP), transmission
20 points, transmission nodes, Remote Radio Unit (RRU) Remote Radio Head (RRH), a core network node (e.g., mobile management entity (MME), self-organizing network (SON) node, a coordinating node, positioning node, MDT node, etc.), an external node (e.g., 3rd party node, a node external to the current network), nodes in distributed antenna system (DAS), a spectrum access system (SAS) node, an element management system (EMS),
25 etc. The network node may also comprise test equipment. The term “radio node” used herein may be used to also denote a wireless device (WD) such as a wireless device (WD) or a radio network node.

 In some embodiments, the non-limiting terms wireless device (WD) or a user equipment (UE) are used interchangeably. The WD herein may be any type of wireless
30 device capable of communicating with a network node or another WD over radio signals, such as wireless device (WD). The WD may also be a radio communication device, target device, device to device (D2D) WD, machine type WD or WD capable of machine to machine communication (M2M), low-cost and/or low-complexity WD, a sensor equipped with WD, Tablet, mobile terminals, smart phone, laptop embedded equipped (LEE),

laptop mounted equipment (LME), USB dongles, Customer Premises Equipment (CPE), an Internet of Things (IoT) device, or a Narrowband IoT (NB-IOT) device etc.

Also, in some embodiments the generic term “radio network node” is used. It may be any kind of a radio network node which may comprise any of base station, radio base station, base transceiver station, base station controller, network controller, RNC, evolved Node B (eNB), Node B, gNB, Multi-cell/multicast Coordination Entity (MCE), relay node, access point, radio access point, Remote Radio Unit (RRU) Remote Radio Head (RRH).

Note that although terminology from one particular wireless system, such as, for example, 3GPP LTE and/or New Radio (NR), may be used in this disclosure, this should not be seen as limiting the scope of the disclosure to only the aforementioned system. Other wireless systems, including without limitation Wide Band Code Division Multiple Access (WCDMA), Worldwide Interoperability for Microwave Access (WiMax), Ultra Mobile Broadband (UMB) and Global System for Mobile Communications (GSM), may also benefit from exploiting the ideas covered within this disclosure.

Note further, that functions described herein as being performed by a wireless device or a network node may be distributed over a plurality of wireless devices and/or network nodes. In other words, it is contemplated that the functions of the network node and wireless device described herein are not limited to performance by a single physical device and, in fact, may be distributed among several physical devices.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms used herein should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

Some embodiments are directed to filters with relative phase control. Returning to the drawing figures, in which like elements are referred to by like reference numerals, there is shown in FIG. 2 a schematic diagram of a communication system 10, according to an embodiment, such as a 3GPP-type cellular network that may support standards such as LTE and/or NR (5G), which comprises an access network 12, such as a radio access network, and a core network 14. The access network 12 comprises a plurality of network nodes 16a, 16b, 16c (referred to collectively as network nodes 16), such as NBs, eNBs, gNBs or other types of wireless access points, each defining a corresponding coverage

area 18a, 18b, 18c (referred to collectively as coverage areas 18). Each network node 16a, 16b, 16c is connectable to the core network 14 over a wired or wireless connection 20. A first wireless device (WD) 22a located in coverage area 18a is configured to wirelessly connect to, or be paged by, the corresponding network node 16a. A second WD 22b in
5 coverage area 18b is wirelessly connectable to the corresponding network node 16b. While a plurality of WDs 22a, 22b (collectively referred to as wireless devices 22) are illustrated in this example, the disclosed embodiments are equally applicable to a situation where a sole WD is in the coverage area or where a sole WD is connecting to the corresponding network node 16. Note that although only two WDs 22 and three network nodes 16 are
10 shown for convenience, the communication system may include many more WDs 22 and network nodes 16.

Also, it is contemplated that a WD 22 may be in simultaneous communication and/or configured to separately communicate with more than one network node 16 and more than one type of network node 16. For example, a WD 22 may have dual
15 connectivity with a network node 16 that supports LTE and the same or a different network node 16 that supports NR. As an example, WD 22 may be in communication with an eNB for LTE/E-UTRAN and a gNB for NR/NG-RAN.

A network node 16 (eNB or gNB) is configured to include filter packages 24 which are configured to include a plurality of interconnected filter elements configured to
20 have a nominal frequency response of a plurality of second filter packages. The network node 16 also includes control circuitry 25 which is external to a first filter package and configured to alter a frequency response of the first filter package from the nominal frequency response to control a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the first filter package 24, a magnitude of the relative
25 phase being configured to exceed 90 degrees. The filter packages 24 and the control circuitry 25 may be mounted on a printed circuit board, which collectively may also be referred to herein as electronic circuit 26. Similarly, a WD 22 may also be configured to include filter packages 60 which are configured to include a plurality of interconnected filter elements configured to have a nominal frequency response of a plurality of second
30 filter packages. The WD 22 may also include control circuitry 62 which is external to a filter package and configured to alter a frequency response of the first filter package 60 from the nominal frequency response to control a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the first filter package 60, a magnitude of the relative phase being configured to exceed 90 degrees. The filter

packages 60 and the control circuitry such as processor 52 may be mounted on a printed circuit board to form electronic circuit 64.

Example implementations, in accordance with an embodiment, of the WD 22 and network node 16 discussed in the preceding paragraphs will now be described with reference to FIG. 3.

The communication system 10 includes a network node 16 provided in a communication system 10 and including hardware 28 enabling it to communicate with the WD 22. The hardware 28 may include a radio interface 30 for setting up and maintaining at least a wireless connection 32 with a WD 22 located in a coverage area 18 served by the network node 16. The radio interface 30 may be formed as or may include, for example, one or more RF transmitters, one or more RF receivers, and/or one or more RF transceivers. The radio interface 30 includes an array of antennas 34 to radiate and receive signal(s) carrying electromagnetic waves. The radio interface 30 is configured to include filter packages 24 which are configured to include a plurality of interconnected filter elements configured to have a nominal frequency response of a plurality of second filter packages. The radio interface 30 also includes control circuitry 25 which is external to a filter package and configured to alter a frequency response of the first filter package from the nominal frequency response to control a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the filter package, a magnitude of the relative phase being configured to exceed 90 degrees.

In the embodiment shown, the hardware 28 of the network node 16 further includes processing circuitry 36. The processing circuitry 36 may include a processor 38 and a memory 40. In particular, in addition to or instead of a processor, such as a central processing unit, and memory, the processing circuitry 36 may comprise integrated circuitry for processing and/or control, e.g., one or more processors and/or processor cores and/or FPGAs (Field Programmable Gate Array) and/or ASICs (Application Specific Integrated Circuitry) adapted to execute instructions. The processor 38 may be configured to access (e.g., write to and/or read from) the memory 40, which may comprise any kind of volatile and/or nonvolatile memory, e.g., cache and/or buffer memory and/or RAM (Random Access Memory) and/or ROM (Read-Only Memory) and/or optical memory and/or EPROM (Erasable Programmable Read-Only Memory).

Thus, the network node 16 further has software 42 stored internally in, for example, memory 40, or stored in external memory (e.g., database, storage array, network storage device, etc.) accessible by the network node 16 via an external connection. The

software 42 may be executable by the processing circuitry 36. The processing circuitry 36 may be configured to control any of the methods and/or processes described herein and/or to cause such methods, and/or processes to be performed, e.g., by network node 16.

Processor 38 corresponds to one or more processors 38 for performing network node 16

5 functions described herein. The memory 40 is configured to store data, programmatic software code and/or other information described herein. In some embodiments, the software 42 may include instructions that, when executed by the processor 38 and/or processing circuitry 36, causes the processor 38 and/or processing circuitry 36 to perform the processes described herein with respect to network node 16.

10 The communication system 10 further includes the WD 22 already referred to. The WD 22 may have hardware 44 that may include a radio interface 46 configured to set up and maintain a wireless connection 32 with a network node 16 serving a coverage area 18 in which the WD 22 is currently located. The radio interface 46 may be formed as or may include, for example, one or more RF transmitters, one or more RF receivers, and/or one
15 or more RF transceivers. The radio interface 46 includes an array of antennas 48 to radiate and receive signal(s) carrying electromagnetic waves. WD 22 may also be configured to include filter packages 60 which are configured to include a plurality of interconnected filter elements configured to have a nominal frequency response of a plurality of second filter packages. The radio interface 46 may also include control circuitry 62 which is
20 external to a first filter package and configured to alter a frequency response of the first filter package 60 from the nominal frequency response to control a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the first filter package 60, a magnitude of the relative phase being configured to exceed 90 degrees. The filter packages 60 and the control circuitry such as processor 52 may be mounted on a
25 printed circuit board to form electronic circuit 64.

The hardware 44 of the WD 22 further includes processing circuitry 50. The processing circuitry 50 may include a processor 52 and memory 54. In particular, in addition to or instead of a processor, such as a central processing unit, and memory, the processing circuitry 50 may comprise integrated circuitry for processing and/or control,
30 e.g., one or more processors and/or processor cores and/or FPGAs (Field Programmable Gate Array) and/or ASICs (Application Specific Integrated Circuitry) adapted to execute instructions. The processor 52 may be configured to access (e.g., write to and/or read from) memory 54, which may comprise any kind of volatile and/or nonvolatile memory, e.g., cache and/or buffer memory and/or RAM (Random Access Memory) and/or ROM

(Read-Only Memory) and/or optical memory and/or EPROM (Erasable Programmable Read-Only Memory).

Thus, the WD 22 may further comprise software 56, which is stored in, for example, memory 54 at the WD 22, or stored in external memory (e.g., database, storage array, network storage device, etc.) accessible by the WD 22. The software 56 may be executable by the processing circuitry 50. The software 56 may include a client application 58. The client application 58 may be operable to provide a service to a human or non-human user via the WD 22.

The processing circuitry 50 may be configured to control any of the methods and/or processes described herein and/or to cause such methods, and/or processes to be performed, e.g., by WD 22. The processor 52 corresponds to one or more processors 52 for performing WD 22 functions described herein. The WD 22 includes memory 54 that is configured to store data, programmatic software code and/or other information described herein. In some embodiments, the software 56 and/or the client application 58 may include instructions that, when executed by the processor 52 and/or processing circuitry 50, causes the processor 52 and/or processing circuitry 50 to perform the processes described herein with respect to WD 22.

In some embodiments, the inner workings of the network node 16 and WD 22 may be as shown in FIG. 3 and independently, the surrounding network topology may be that of FIG. 2.

The wireless connection 32 between the WD 22 and the network node 16 is in accordance with the teachings of the embodiments described throughout this disclosure. More precisely, the teachings of some of these embodiments may improve the data rate, latency, and/or power consumption and thereby provide benefits such as reduced user waiting time, relaxed restriction on file size, better responsiveness, extended battery lifetime, etc. In some embodiments, a measurement procedure may be provided for the purpose of monitoring data rate, latency and other factors on which the one or more embodiments improve.

FIG. 4 is a flowchart of an example process of enabling configuration of a filter response of a filter package 24, 60 to be used in a network node 16 and/or a wireless device 22 to implement filtering with relative phase control. The process includes configuring interconnected filter elements 66 (FIG. 12) of a first filter package 24, 60 to enable external control of a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the first filter package 24, 60, a magnitude of the relative

phase being configurable to exceed 90 degrees (Block S10).

In some embodiments, configuring the plurality of interconnected filter elements 66 includes, for each of at least one circuit point within the first filter package 24, 60, electrically connecting the circuit point to an external pin of the filter package 24, 60. In 5 some embodiments, configuring the interconnected filter elements 66 includes electrically connecting an external load to an input of the first filter package 24, 60. In some embodiments, configuring the interconnected filter elements 66 includes applying a first control signal to an input of the first filter package 24, 60 to alter a frequency response of the interconnected filter elements 66. In some embodiments, configuring the 10 interconnected filter elements 66 includes applying a second control signal to an input of the first filter package 24, 60 to alter a coupling path between the interconnected filter elements 66. In some embodiments, configuring the interconnected filter elements 66 includes applying a third control signal to a first input of the first filter package 24, 60 and applying a fourth control signal to a second input of the first filter package 24, 60 to 15 alter a delay of at least one electrical path between the interconnected filter elements 66. In some embodiments, configuring the interconnected filter elements 66 includes inputting an electrical signal to an input of the first filter package 24, 60 to alter a piezoelectric substrate within the first filter package 24, 60. In some embodiments, configuring the interconnected filter elements 66 includes applying one of an 20 electrostatic field, a magnetostatic field, and an electromagnetic field to the first filter package 24, 60. In some embodiments, configuring the interconnected filter elements 66 includes staggering frequencies of a plurality of at least one of band edge poles and band edge zeros of a filter response of the first filter package 24, 60. In some embodiments, configuring the interconnected filter elements 66 includes altering a frequency response 25 of at least one of a surface acoustic wave, SAW, filter, a bulk acoustic wave, BAW, filter, a thin film bulk acoustic resonator, FBAR, a discrete lumped element filter, a ceramic filter and a cavity filter, located with the first filter package 24, 60. In some embodiments, configuring the interconnected filter element includes configuring the magnitude of the relative phase is configured to exceed 180 degrees. In some 30 embodiments, the first filter package 24, 60 is one of a plurality of second filter packages 24, 60 having a same topology of interconnected filter elements 66. In some embodiments, the method also includes configuring the interconnected filter elements 66 of each of a plurality of the second filter packages 24, 60 to configure each second filter package 24, 60 to have a different filter response according to a placement of the first

filter package 24, 60 in a multiple input-multiple output phased array antenna system.

Having described the general process flow of arrangements of the disclosure and having provided examples of hardware and software arrangements for implementing the processes and functions of the disclosure, the sections below provide details and examples
5 of arrangements for filters with relative phase control.

Typical commercial filters use ladder implementations of high-Q resonant elements. The filter is often designed using technologies such as surface acoustic wave (SAW), or bulk acoustic wave (BAW) on resonant materials, and often delivered in a package designed for surface mounting on a printed circuit board. Package pins are
10 employed for input and output, with remaining pins used to assure robust grounding. Such a package is shown in FIG. 5.

In some embodiments, one or more control pins are configured to alter the characteristics of a filter in an electronic circuit 25, 64 that is enclosed in a package that may be accessed electrically by external pins that are connected to an internal point in
15 the filter circuit package. An example is shown in FIG. 6, where instead of a ground pin an external one or more control pins are provided. These control pins enable control of the out of band phase response of the filter.

In some embodiments, these control elements may be statically configured, such as for a WD 22 with a 3x3 beamforming array, consisting of 9 antennas, each antenna
20 receiving an output of a filter and/or providing an input to the filter. In such a static case, the control may be statically configured to have equal spaced offsets of 40 degrees, calculated as $360/9$ degrees. Unequally spaced offsets may also be implemented. Thus, in addition or alternatively, the individual filters may be dynamically controlled varying the out of band phase offset over a range which would typically span 360 degrees.

Controlling the relative phase of the out-of-band signal with respect to the in-band signal is a goal of some MIMO antenna systems which employ algorithms to align in-band signal phase by compensating for filter group delay variations across the band which are often quite significant nearing the band edge. If out-of-band phase variations impact both the in-band and out-of-band signals, these algorithms will compensate for
30 these variations, nullifying them.

Under the conditions where the out-of-band phase variations may be modified and uncompensated by algorithms used to correct the in-band signals, large beamforming gain reductions are possible.

FIG. 7 is a graph of simulation results for a 32-branch system where the

maximum phase difference of the out-of-band random signal is adjusted by different amounts. No beamforming gain reductions are observed if out-of-band phases are the same for all branches – shown as line “0”.

5 As out-of-band phase offsets are introduced between branches, the beamforming gains reduce. Out-of-band phase variations up to 90 degrees due to component variations and manufacturing tolerances yield negligible < 2 dB reductions in out-of-band gain. It is not until the out-of-band phase variations exceed 180 degrees that useful gain reductions are achieved.

10 These simulations show 50% percentile gain reductions of 17 dB are possible if compensation for the out-of-band phase variations are designed to cover a full 360-degree range. It is expected that the out-of-band gain reduction for systems employing this technology is on the order of $10 \cdot \log(N)$ where in this case $N = 32$ elements, yielding approximately 15 dB of gain reductions. 5G and 6G antenna systems with 256-1024 antennas may have gain reductions of 24-30 dB, impossible to achieve with filters alone.

15 Typical out-of-band phase variations for different filters used in an advanced antenna system are less than 30 degrees and will result in no gain reductions in the stopband or ACLR1 region shown in FIG. 8 from 3.98 GHz to 4.1 GHz. These plots are for cavity filters, which are manufactured to achieve high performance operation. However, similar results are possible for all technologies such as BAW, SAW, FBAR
20 which are mass produced manufactured filters with consistent in-band and out-of-band phase performance.

In some embodiments, the out-of-band phase response of the filter is deliberately modified without substantially impacting the in band phase response. Some
25 embodiments are applicable to high powered advanced antenna systems to reduce out-of-band antenna array gain and therefore transmitted out-of-band EIRP in the stopband or ACLR1 region. Some embodiments are applicable to advanced antenna systems to reduce out-of-band array gain for received signals in this same stop-band region, thereby improving rejection of potential adjacent band interference sources. Some embodiments are applicable to devices with a plurality of antennas – two or more, achieving out-of-
30 band array gain reduction through filter design.

Multiple ways of achieving out-of-band array gain reduction without also impacting the in band array gain are disclosed herein. In high powered advanced antenna systems, high performance filters designed with specified pole and zero locations may shift poles or zeros directly affecting the phase of the out-of-band region. For example,

the locations of zeros and poles for a possible filter in the 4200-4400 MHz region may be adjusted. In this example, the locations of zeros may be shifted, such as $z(1)$ from 4175 MHz to 4177.5 MHz for one antenna branch.

In some embodiments, the frequencies of the band edge poles or zeros may be shifted by small amounts, possibly by 1.0 MHz so that for an 8 antenna MIMO system, the zeros would be at 4172 MHz to 4179 MHz. The filter design may then be selected to ensure that the staggering achieves an out-of-band phase response with the necessary degrees of variation to achieve the design targets.

Filters may be implemented in many ways with multiple topologies. According to some embodiments, a single change to a filter topologies may achieve a desired impact of changing the relative phase of the in-band and out-of-band signals.

An example of a filter for a 3GPP frequency band for cellular communications is a bandpass filter designed for 6725-7125 MHz. Manufacturer datasheets typically provide insertion loss measurements labeled in FIG. 9 as m6, m7, and m8 for the passband, and out-of-band attenuation and frequency measurements shown as m11, m5, m8, m10.

Manufacturer datasheets do not show filter design characteristics, including in-band and out-of-band signal phase. The S_{12} phase (input to output) of the filtered signal may have a relative phase ($\pm 180^\circ$), and the lower right plot showing integrated phase. In one example, an existing mass-produced filter has a center frequency at 6927 MHz with six poles and two zeros.

Small changes, such as moving a zero from 7195 MHz to 7167 MHz, and another zero from 7159 MHz to 7225 MHz has a negligible effect on in-band parameters such as insertion loss, while introducing significant changes in the out-of-band signal phase. An out-of-band phase difference of 170° between one filter and another in the ACLR1 region between 0 and 100 MHz from the passband edge is shown in FIG. 10. Further refinement of parameters results in a phase offset of 143° at 40 MHz from the passband edge in the ACLR1 region. This is shown in FIG. 11.

These two examples demonstrate that small changes in filter parameters, such as the locations of poles and/or zeros may achieve significant changes of the relative phase between the in-band and out-of-band response.

There are many different types of filters known by those of ordinary skill in the art of filter design, including:

- Discrete lumped element (LC) filters, which have limited performance

and are often used to perform low pass or high pass functions such as rejection of intermediate frequencies, or attenuation of mixer higher order harmonics. These filters are most often realized with discrete inductors and capacitors surface mounted on a PCB, allowing designers freedom to measure and tune component values during product testing phase;

- Ceramic filters, which often have good performance, but their larger size compared to surface acoustic wave (SAW) filters and bulk acoustic wave (BAW) filters often results in higher cost and limited applications. The filter structure is most often a linear array of coupled cavities, which limits coupling capabilities of more advanced filter structures. While still common in older radio designs, ceramic filters are not often used in highly integrated products;

- Surface Acoustic Wave (SAW) and Bulk Acoustic Wave (BAW) filters have taken a dominant role in radio communications applications with their small size, excellent performance, and low cost. SAW and BAW filters leverage acoustic properties of piezoelectric substrates with printed metalized signal layers to enable complex topologies to be realized. High insertion losses and low power handling capabilities may limit these filters' applications to low power radios where best in class receive sensitivity is not required; and

- Cavity filters offer the highest performance and come in many types - the most common being tuned metal cavities. These filters are commonly used in high power base station applications often immediately connected to the antenna ports, thereby minimizing power loss and ensuring lowest possible noise figure. While cast metal cavities traditionally dominated this space, cavity filters such as ceramic waveguides, sheet metal waveguides, and sheet metal with metal injection molding are finding applications, as higher antenna port counts are necessitating smaller and lower cost filters.

These filter types may be described schematically, as shown in FIG. 12 for nine resonant filter elements 66 in a typical two port filter with Port1 as input, and Power 2 as output, and a signal path traversing the nine resonant filter elements 66. Note that the signal path is not solely a linear path, from one resonant element to the next, but including multiple coupling paths connecting two, three, four or multiple elements. This is shown by the arrowed lines in FIG. 12.

This lumped element design may be thought of as a topology of nine elements as shown in FIG. 13. The topology of FIG. 13 is a single example of many different

possible filter topologies. The filter transfer function from non-resonant input S to output L, may be described using a matrix that characterizes the coupling paths from S to L through the nine resonant elements, each of which has a defined frequency.

Some embodiments provide control of a packaged filter out-of-band phase by at least one of:

- modifying the resonant frequency of one or more elements;
- modifying connections affecting the coupling between two or more elements; and/or
- causing a change to a piezoelectric substrate that affects one or more of the resonant frequencies and coupling between elements.

In some embodiments, these changes and modifications are applied to change the relative phase between the filter's in-band and out of band response by least 90°.

In some embodiments, one or more of the following control signals may be applied to obtain the desired out-of-band phase response of the filter without degrading the in band response of the filter:

- a control signal affecting one or more of the resonant elements of the filter;
- a control signal affecting one or more of the coupling paths between filter elements 66; and/or
- two or more control signals applied to add a delay to one of the coupling paths between filter elements 66.

The control signals may include a digital control signal.

In some embodiments, an electric signal affecting at least a portion of the piezoelectric substrate material of the filter may be applied to affect one or more of the resonant elements, or one or more of the coupling paths of the filter.

The control signals and methods for adjusting the relative phase of the in-band and out-of-band responses of the filter may be applied to mass-produced filters for use in MIMO antenna systems.

One method of control of the relative phase between the in-band and out-of-band responses may include connection of an external impedance to shift the frequency of one or more pole(s) or zero(s) in the filter, thereby changing the in band and out-of-band relative group delay. Configuring different impedances enables filters to have different relative in-band and out-of-band phase group delay performance.

One method of control includes connection of an external differential impedance

across two or more points to shift the frequency of one or more pole(s) or zero(s) in the filter. This would affect the in band and out-of-band relative group delay. Allowing multiple filters to be configured with different impedances enables filters to have different relative in-band and out-of-band phase group delay performance.

5 The control may be digital and employ an external interface to select one of a set of relative phase delays, each of the set shifting the frequency of one or more pole(s) or zero(s) in the filter, thereby selecting specific in band and out-of-band relative group delays.

10 The control may use external electromagnetics to configure the relative in band to out-of-band delay, such as magnetics, DC currents, or input/output impedance variations.

 The control may affect one or more coupling paths within the filter,

 The control may affect one or more resonant cavities within the filter.

 Some embodiments may be employed for transmission and/or reception.

15 For transmission, advantages of some embodiments include the mitigation of out-of-band beamforming gain in multiantenna systems. Some embodiments decorrelate the phase of the out-of-band signal while not adversely impacting the in band phase. This decorrelation forces out-of-band signals to be non-coherent and not beamformed. The resulting gain of an N-element antenna system may be reduced by $10\log(N)$, reducing to
20 the sub-element gain. Some embodiments achieve minimal array gain in the guard band, significantly reducing out-of-band unwanted emissions (OBUE).

 For reception, some embodiments have the same effect of significantly reducing transmitter OBUE. Also, some embodiments, improve receiver out-of-band blocking performance.

25 Current regulatory standards governing out-of-band performance such as OBUE are specified as total radiated power (TRP). This conducted power specification is historical, based on legacy 1G, 2G, 3G, and even 4G radio systems where per-antenna port OBUE power is readily measured with a spectrum analyzer at the few radio-to-antenna port connectors. Legacy products had few antenna port connectors, all of which
30 were cabled, making this measurement straight forward. However, with the advent of massive MIMO, many 5G radios have inaccessible antenna ports due to high levels of integration (most evident in millimeter wave radios), requiring an alternate means to measure TRP. This may be done in a reverberation chamber. Reverberation chambers use reflectors to decorrelate antenna beams and enable the non-beamformed total power

to be directly measured. Radio equipment manufacturers then declare beamforming gain which is applied to the in-band signals, with little consideration for the possibility of out-of-band signal beamforming gain. This approximation is good given the typical beamforming gains of 5G systems in the range of $15 \text{ dB} = 10 \cdot \log(32)$.

5 Some embodiments provide a single filter element 66 which may be employed in a MIMO system and configured to deliver different relative phase offsets between in-band and out-of-band signals.

 As an example, one possible future 6G radio is described by Qualcomm as their 4096 element array proposed at 13 GHz with a $36 \text{ dB} = 10 \cdot \log_{10}(4096)$ beamforming
10 array gain. This is shown in FIG. 14.

 At 13 GHz, antenna elements are typically 1-2 cm in size, necessitating very small support circuitry including filters. At these frequencies, total radiated power (TRP) is limited by regulations to 46 dBm (40W), so that the power for each antenna element would be in the range of 10mW, making it useful for SAW or BAW
15 applications. This system would likely employ sub-arrays, perhaps of 4, 8, or 16 elements, reducing the number of feeds from 4096 to a more manageable 1024, 512, or 256. Regardless, even 256 SAW or BAW filters is a lot of elements.

 Some embodiments enable a manufacturer of such an array to use the same SAW filter component and configure it via elements on the main printed circuit board, to the
20 desired relative phase offsets between in-band and out-of-band depending on location within the array. In some embodiments, programmed offsets would effectively eliminate the 36 dB of array gain in adjacent band transmissions.

 Given the number of satellite bands, and the need to limit out-of-band EIRP as much as possible to avoid impacting adjacent band satellite systems, or aviation systems,
25 some embodiments achieve this with minimal implementation costs.

 Some embodiments, beamforming gains are not realized in the guard band region, thereby ensuring that TRP remains a valid approximation of out-of-band emissions.

 As will be appreciated by one of skill in the art, the concepts described herein may
30 be embodied as a method, data processing system, computer program product and/or computer storage media storing an executable computer program. Accordingly, the concepts described herein may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects all generally referred to herein as a “circuit” or “module.” Any process, step,

action and/or functionality described herein may be performed by, and/or associated to, a corresponding module, which may be implemented in software and/or firmware and/or hardware. Furthermore, the disclosure may take the form of a computer program product on a tangible computer usable storage medium having computer program code embodied
5 in the medium that may be executed by a computer. Any suitable tangible computer readable medium may be utilized including hard disks, CD-ROMs, electronic storage devices, optical storage devices, or magnetic storage devices.

Some embodiments are described herein with reference to flowchart illustrations and/or block diagrams of methods, systems and computer program products. It will be
10 understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, may be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer (to thereby create a special purpose computer), special purpose computer, or other programmable data processing
15 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 flowchart and/or block diagram block or blocks.

These computer program instructions may also be stored in a computer readable
20 memory or storage medium that may direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer readable memory produce an article of manufacture including instruction means which implement the function/act specified in the flowchart and/or block diagram block or blocks.

25 The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions/acts specified in the
30 flowchart and/or block diagram block or blocks.

It is to be understood that the functions/acts noted in the blocks may occur out of the order noted in the operational illustrations. 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/acts

involved. Although some of the diagrams include arrows on communication paths to show a primary direction of communication, it is to be understood that communication may occur in the opposite direction to the depicted arrows.

Computer program code for carrying out operations of the concepts described
5 herein may be written in an object oriented programming language such as Python, Java® or C++. However, the computer program code for carrying out operations of the disclosure may also be written in conventional procedural programming languages, such as the "C" programming language. 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
10 user's computer and partly on a remote computer or entirely on the remote computer. In the latter scenario, the remote computer may be connected to the user's computer through 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).

15 Many different embodiments have been disclosed herein, in connection with the above description and the drawings. It will be understood that it would be unduly repetitious and obfuscating to literally describe and illustrate every combination and subcombination of these embodiments. Accordingly, all embodiments may be combined in any way and/or combination, and the present specification, including the drawings, shall
20 be construed to constitute a complete written description of all combinations and subcombinations of the embodiments described herein, and of the manner and process of making and using them, and shall support claims to any such combination or subcombination.

It will be appreciated by persons skilled in the art that the embodiments described
25 herein are not limited to what has been particularly shown and described herein above. In addition, unless mention was made above to the contrary, it should be noted that all of the accompanying drawings are not to scale. A variety of modifications and variations are possible in light of the above teachings, without departing from the scope of the following claims.

30

What is claimed is:

1. A method of enabling configuration of a filter response of a first filter package (24, 60) to obtain an out-of-band gain reduction while substantially maintaining an in-band gain, the method comprising:
5 configuring (S10) a plurality of interconnected filter elements (66) of the first filter package (24, 60) to enable external control of a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the first filter package (24, 60), a
10 magnitude of the relative phase being configurable to exceed 90 degrees.
2. The method of Claim 1, wherein configuring the plurality of interconnected filter elements (66) includes, for each of at least one circuit point within the first filter package (24, 60), electrically connecting the circuit point to an external pin of the filter
15 package (24, 60).
3. The method of any of Claims 1 and 2, wherein configuring the interconnected filter elements (66) includes electrically connecting an external load to an input of the first filter package (24, 60).
20
4. The method of any of Claims 1-3, wherein configuring the interconnected filter elements (66) includes applying a first control signal to an input of the first filter package (24, 60) to alter a frequency response of the interconnected filter elements (66).
- 25 5. The method of any of Claims 1-4, wherein configuring the interconnected filter elements (66) includes applying a second control signal to an input of the first filter package (24, 60) to alter a coupling path between the interconnected filter elements (66).
6. The method of any of Claims 1-5, wherein configuring the interconnected filter elements (66) includes applying a third control signal to a first input of the first filter package (24, 60) and applying a fourth control signal to a second input of the first filter package (24, 60) to alter a delay of at least one electrical path between the interconnected filter elements (66).
30

7. The method of any of Claims 1-6, wherein configuring the interconnected filter elements (66) includes inputting an electrical signal to an input of the first filter package (24, 60) to alter a piezoelectric substrate within the first filter package (24, 60).
- 5 8. The method of any of Claims 1-7, wherein configuring the interconnected filter elements (66) includes applying one of an electrostatic field, a magnetostatic field, and an electromagnetic field to the first filter package (24, 60).
9. The method of any of Claims 1-8, wherein configuring the interconnected
10 filter elements (66) includes staggering frequencies of a plurality of at least one of band edge poles and band edge zeros of a filter response of the first filter package (24, 60) to control the relative phase.
10. The method of any of Claims 1-9, wherein configuring the interconnected
15 filter elements (66) includes altering a frequency response of at least one of a surface acoustic wave, SAW, filter, a bulk acoustic wave, BAW, filter, a thin film bulk acoustic resonator, FBAR, a discrete lumped element filter, a ceramic filter and a cavity filter, located with the first filter package (24, 60).
- 20 11. The method of any of Claims 1-10, wherein configuring the interconnected filter elements includes configuring the magnitude of the relative phase is configured to exceed 180 degrees.
12. The method of any of Claims 1-11, wherein the first filter package (24, 60)
25 is one of a plurality of second filter packages (24, 60) having a same topology of interconnected filter elements (66).
13. The method of Claim 12, further comprising configuring the interconnected
30 filter elements (66) of each of a plurality of the second filter packages (24, 60) to configure each second filter package (24, 60) to have a different filter response according to a placement of the first filter package (24, 60) in a multiple input-multiple output phased array antenna system.
14. An electronic circuit (25, 64), comprising:

a first filter package (24, 60) comprising a plurality of interconnected filter elements (66) configured to have a nominal frequency response of a plurality of second filter packages (24, 60); and

5 control circuitry (25, 62) external to the first filter package (24, 60) and configured to alter a frequency response of the first filter package (24, 60) from the nominal frequency response to control a relative phase between an out-of-band filtered signal and an in-band filtered signal output by the first filter package (24, 60), a magnitude of the relative phase being configured to exceed 90 degrees.

10 15. The electronic circuit (26, 64) of Claim 14, wherein the first filter package (24, 60) includes, for each of at least one circuit point within the first filter package (24, 60), an electrical connection connecting the circuit point to an external pin of the filter package (24, 60).

15 16. The electronic circuit (26, 64) of any of Claims 14 and 15, wherein the control circuitry (26, 62) includes an external load impedance.

17. The electronic circuit (26, 64) of any of Claims 14-16, wherein the control circuitry (26, 62) is configured to apply a first control signal to an input of the first filter package (24, 60) to alter a frequency response of the interconnected filter elements (66).

18. The electronic circuit (26, 64) of any of Claims 14-17, wherein the control circuitry (25, 62) is configured to apply a second control signal to an input of the first filter package (24, 60) to alter a coupling path between the interconnected filter elements (66).

25 19. The electronic circuit (26, 64) of any of Claims 14-18, wherein the control circuitry (25, 62) is configured to apply a third control signal to a first input of the first filter package (24, 60) and applying a fourth control signal to a second input of the first filter package (24, 60) to alter a delay of at least one electrical path between the

30 interconnected filter elements (66).

20. The electronic circuit (26, 64) of any of Claims 14-19, wherein the control circuitry (25, 62) is configured to input an electrical signal to an input of the first filter package (24, 60) to alter a piezoelectric substrate within the first filter package (24, 60).

21. The electronic circuit (26, 64) of any of Claims 14-20, wherein the control circuitry (25, 62) is configured to apply one of an electrostatic field, a magnetostatic field, and an electromagnetic field to the first filter package (24, 60).

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22. The electronic circuit (26, 64) of any of Claims 14-21, wherein the control circuitry (25, 62) is configured to stagger frequencies of a plurality of at least one of band edge poles and band edge zeros of a filter response of the first filter package (24, 60).

10

23. The electronic circuit (26, 64) of any of Claims 14-22, wherein the control circuitry (25, 62) is configured to configure the magnitude of the relative phase to exceed 180 degrees.

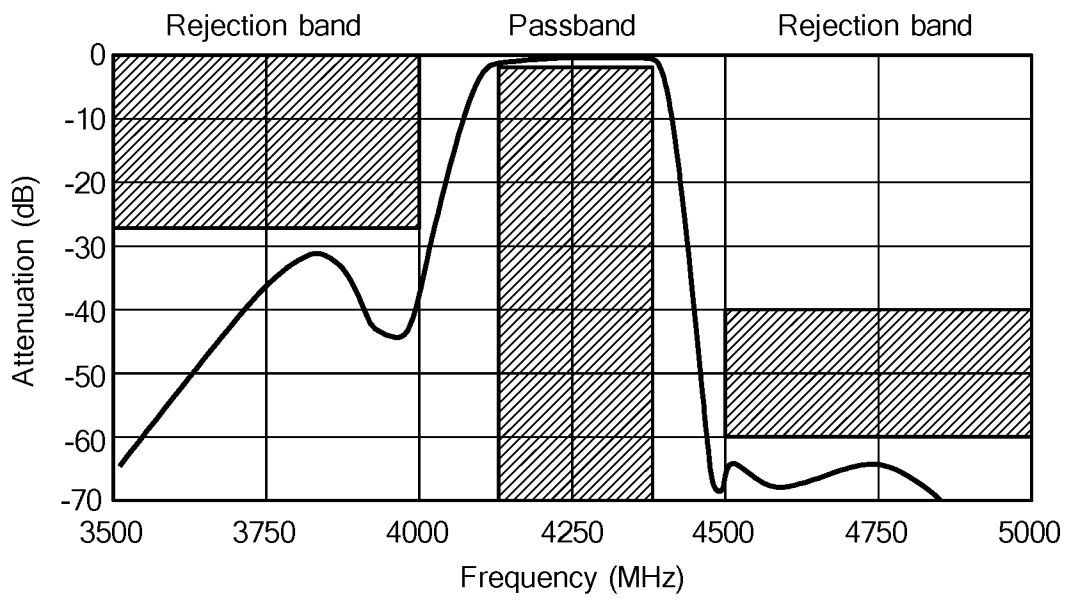


FIG. 1

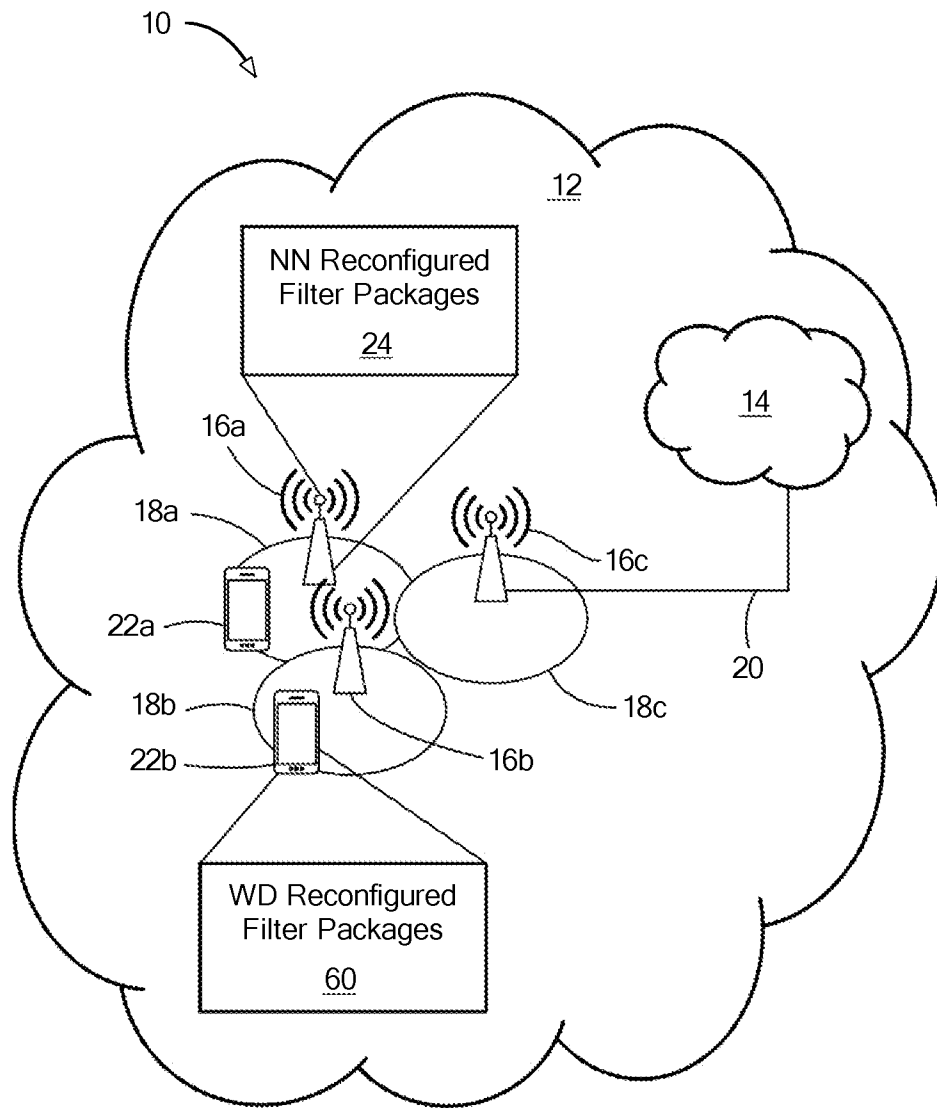


FIG. 2

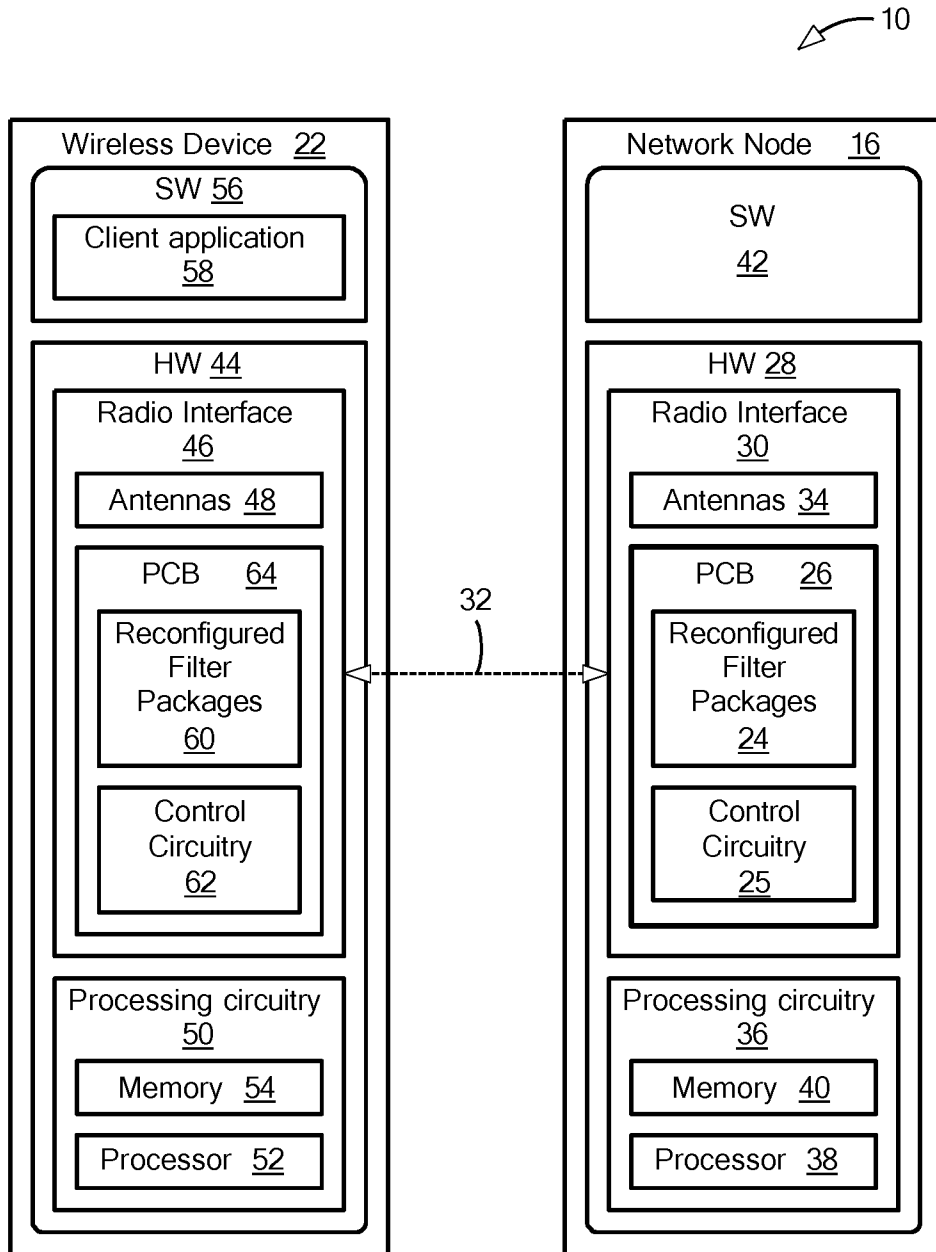


FIG. 3

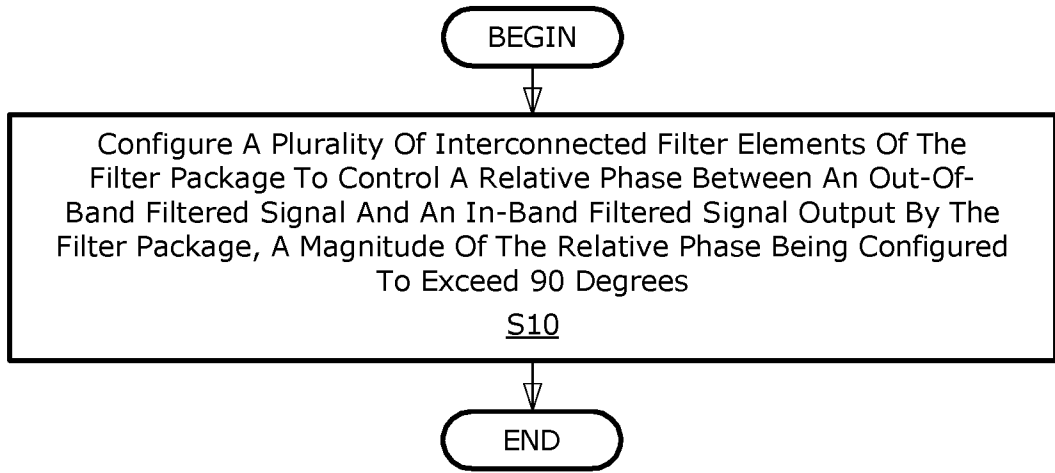


FIG. 4

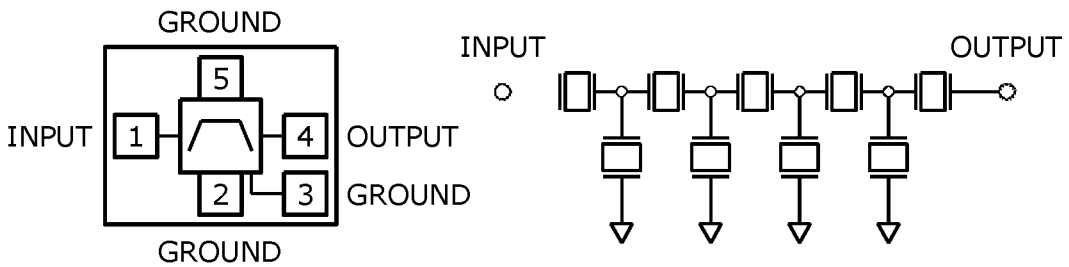


FIG. 5

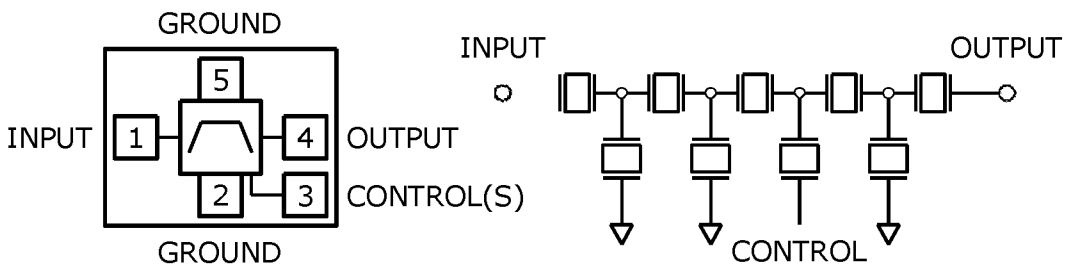


FIG. 6

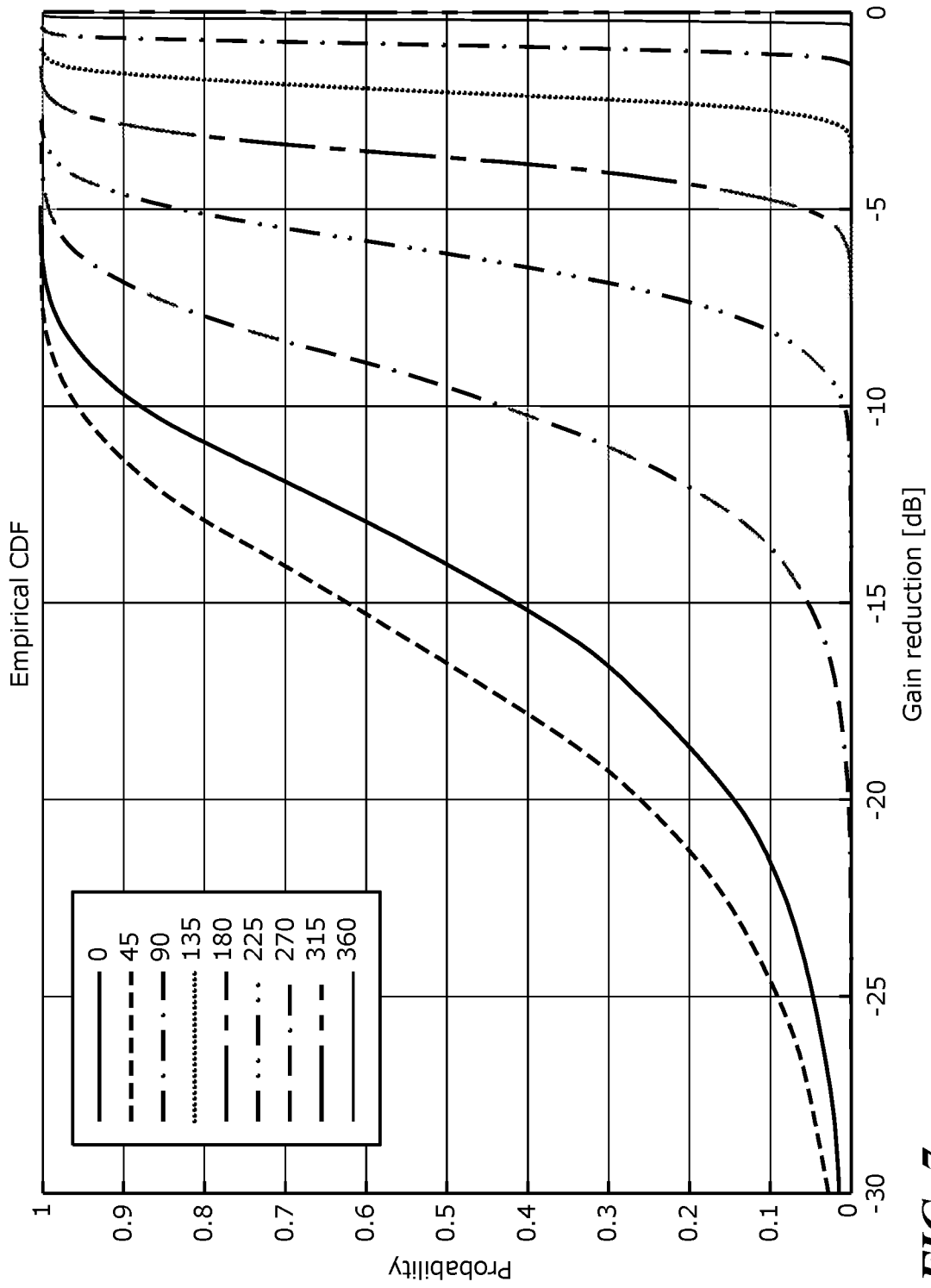


FIG. 7

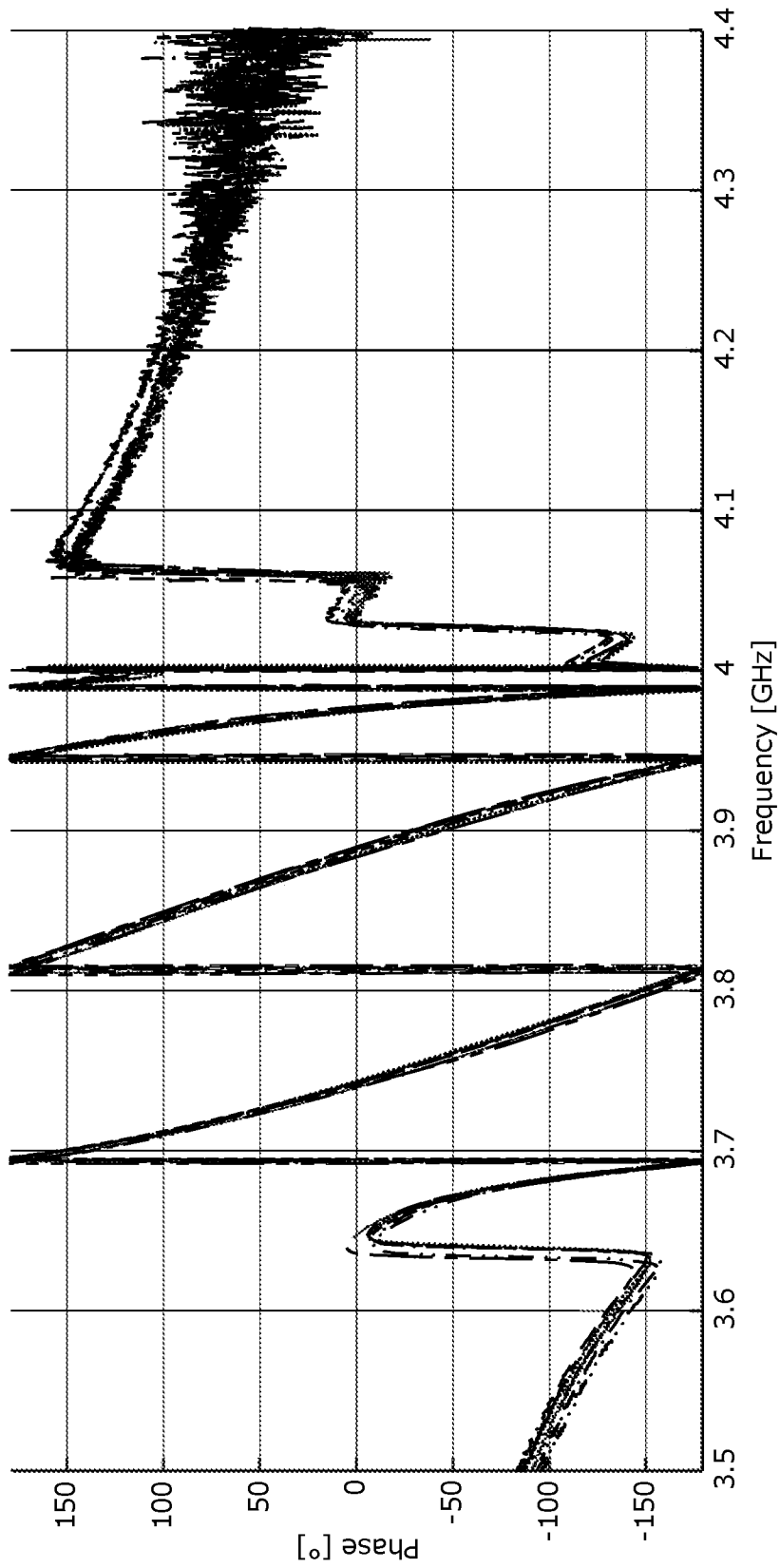


FIG. 8

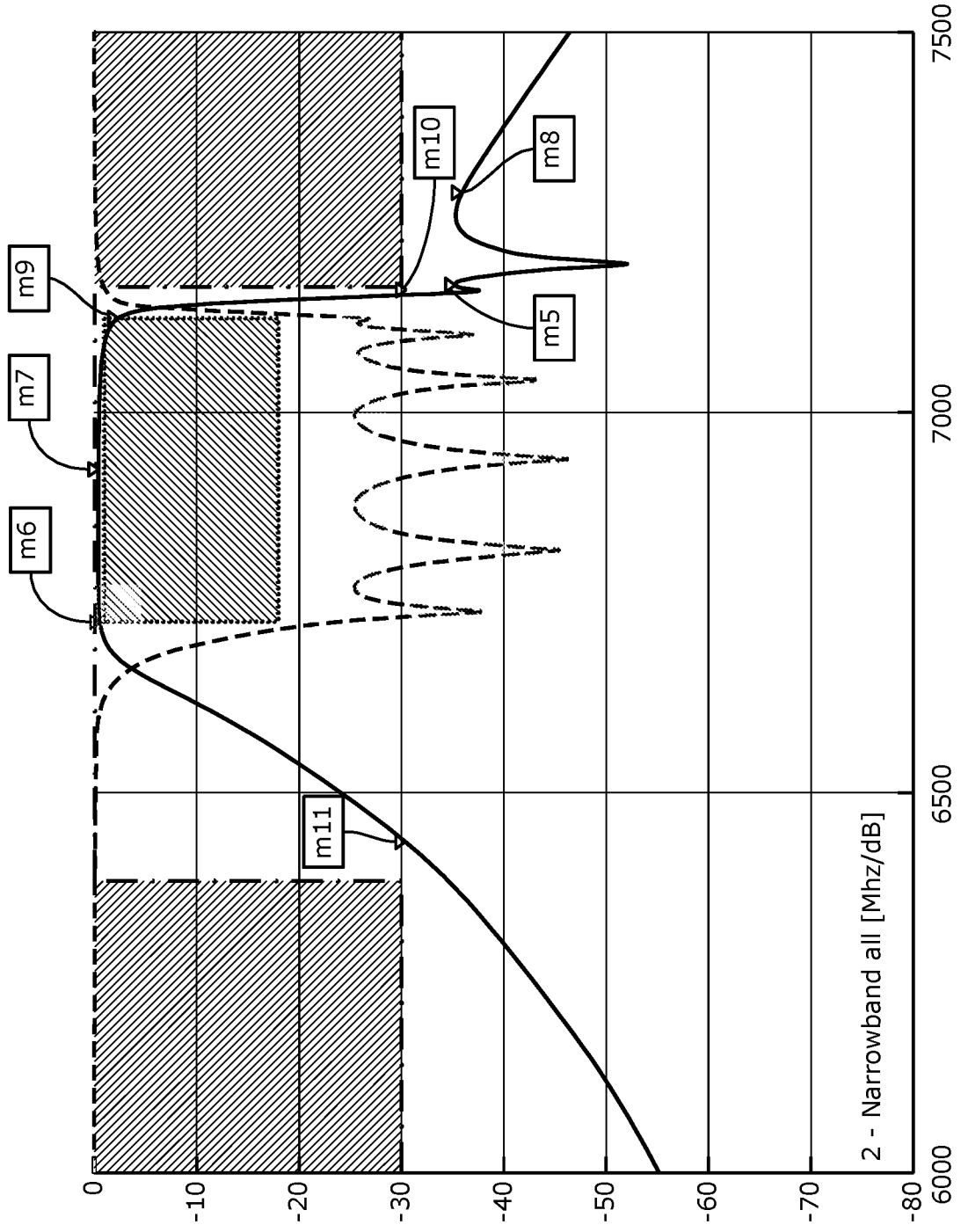


FIG. 9

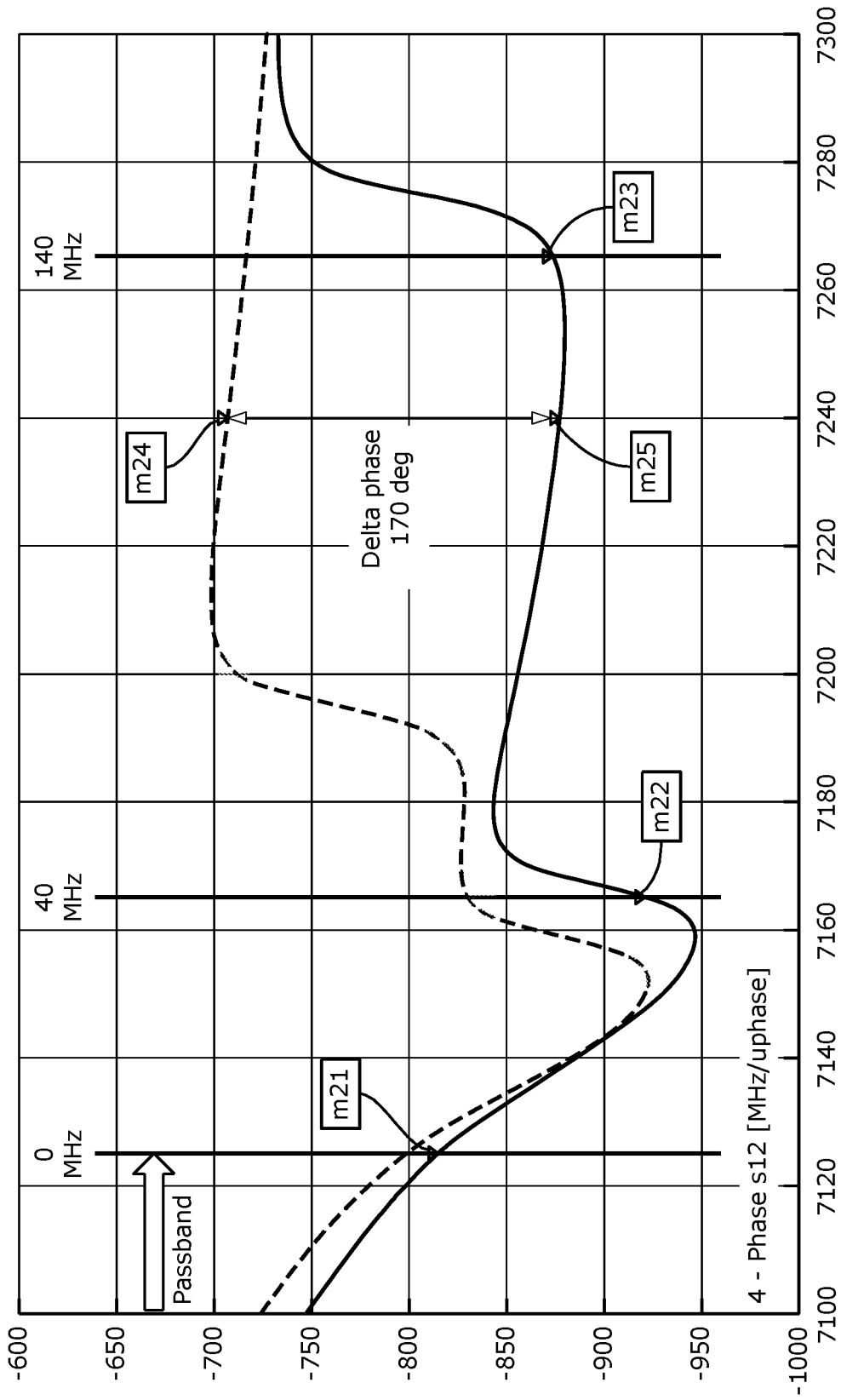


FIG. 10

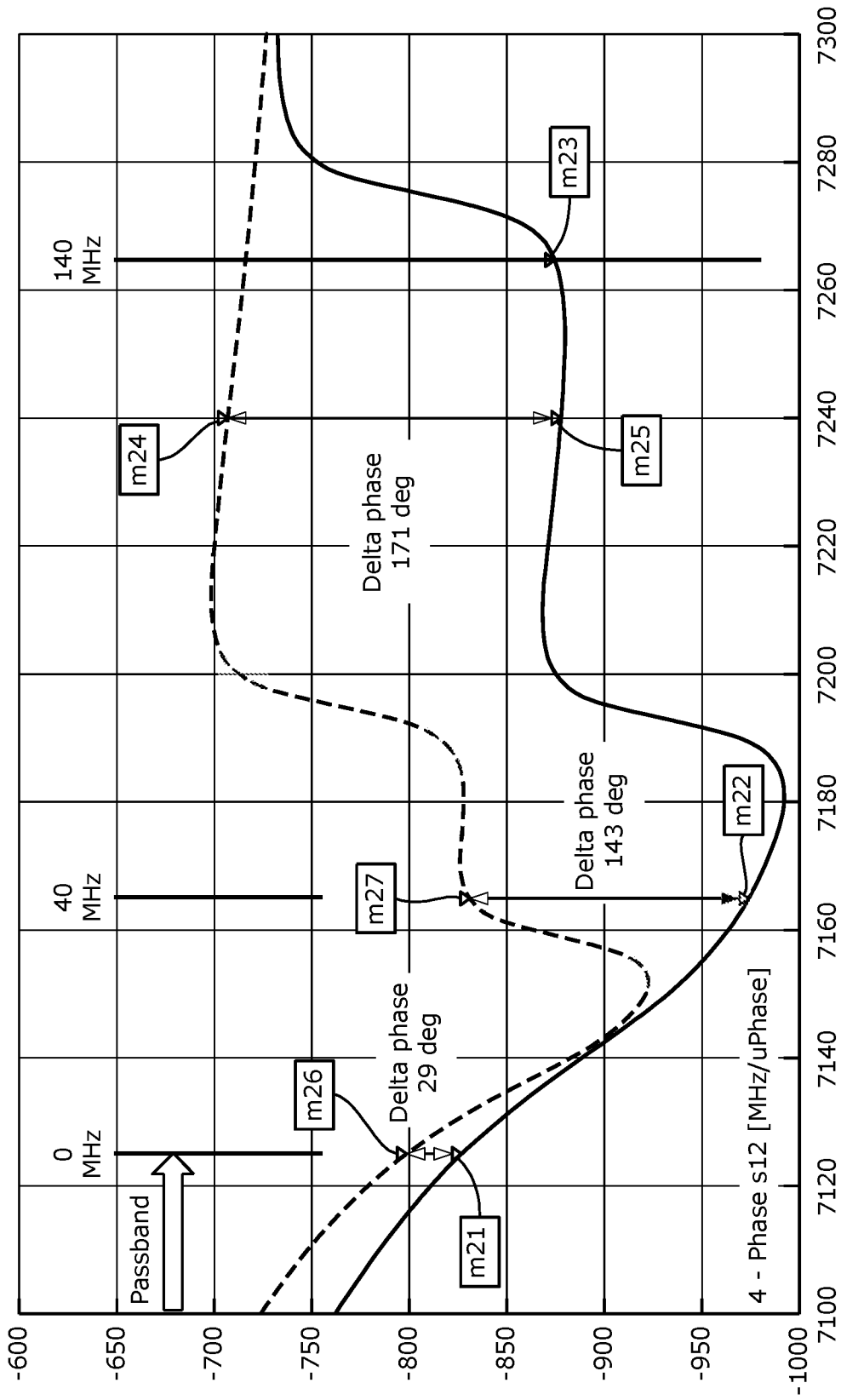


FIG. 11

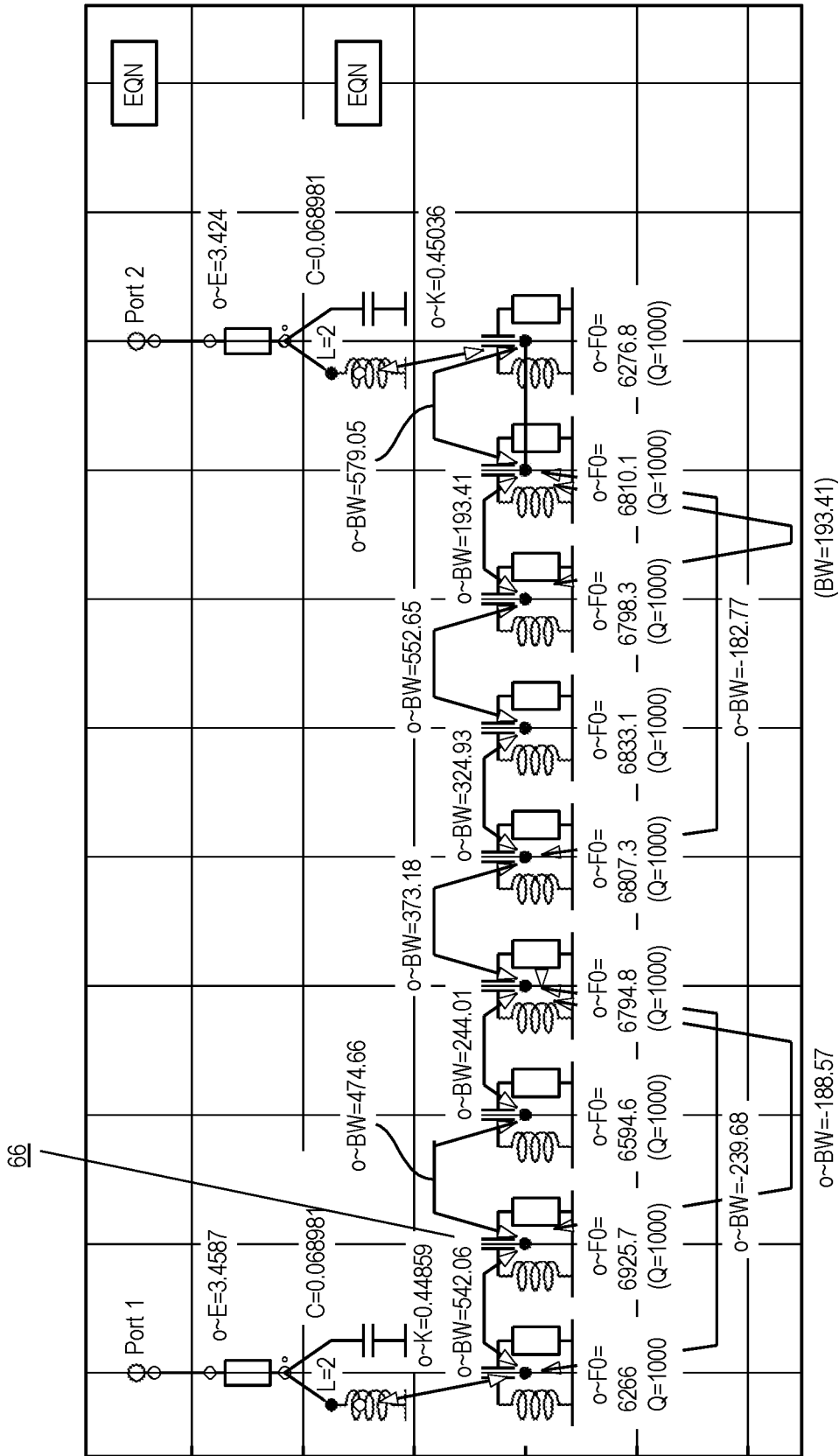


FIG. 12

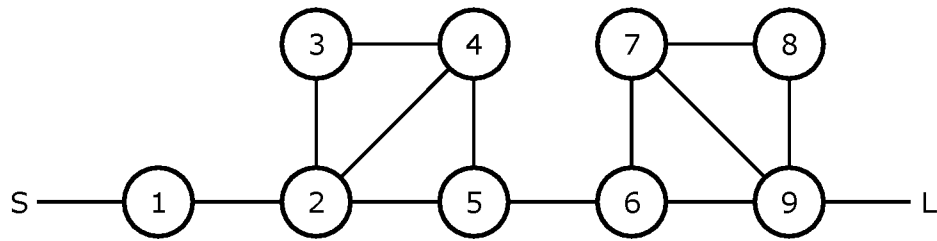


FIG. 13

Giga-MIMO
operating in 13 GHz band
64x32 cross-polarized antennas
Similar size as 3.5 GHz antenna panel

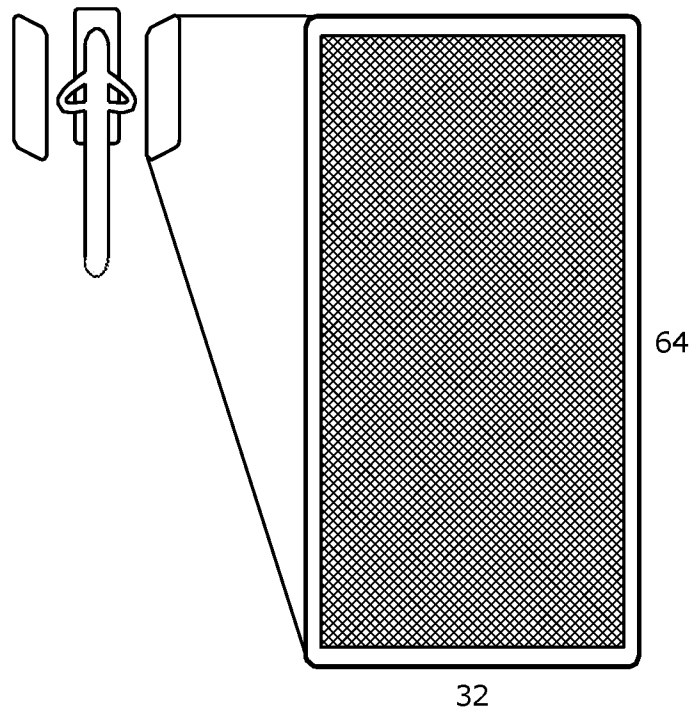


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2023/056273

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B1/04 H03H9/64
ADD.

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)
H03H H04B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2022/200574 A1 (NIELSEN JORGEN STAAL [CA] ET AL) 23 June 2022 (2022-06-23) paragraphs [0006], [0272] paragraph [0335] - paragraph [0337] figures 2, 4, 8, 10 -----	1-23
A	US 7 750 752 B1 (KOSINSKI JOHN A [US]) 6 July 2010 (2010-07-06) column 4, line 17 - line 43 figures 1-3 -----	1-23
A	US 2018/367118 A1 (JIAN CHUNYUN [CA]) 20 December 2018 (2018-12-20) figures 3, 4 -----	1-23
A	US 2002/047494 A1 (ZHU JIAHUA [US] ET AL) 25 April 2002 (2002-04-25) paragraphs [0008], [0040] figures 1-13 -----	1-23

Further documents are listed in the continuation of Box C.

See patent family annex.

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- "&" document member of the same patent family

Date of the actual completion of the international search

Date of mailing of the international search report

8 January 2024

16/01/2024

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Authorized officer

Avilés Martínez, I

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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