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Composite filter and communication device

Abstract

A splitter simultaneously inputs two signals having different frequencies within a transmission band to a transmission terminal. A transmission filter system and a reception filter system that are connected to an antenna terminal share a first hybrid coupler. Two transmission filters and a second hybrid coupler are located between the first hybrid coupler and the transmission terminal. A reception filter is located between the first hybrid coupler and the reception terminal.

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Background/Summary

TECHNICAL FIELD
(1) The present disclosure relates to a composite filter having two or more filters, and to a communication device including the composite filter.

BACKGROUND OF INVENTION

(2) A known composite filter includes two or more filters. Patent Literatures 1 to 4 indicated below disclose a duplexer as a composite filter. The duplexer includes a transmission filter that filters a high-frequency signal (transmission signal) input from a transmission terminal and outputs the high-frequency signal to an antenna, and a reception filter that filters the high-frequency signal (reception signal) input from the antenna and outputs a high-frequency signal to a reception terminal. In Patent Literatures 1 to 4, the transmission filter and the reception filter are connected to the antenna via a 90° hybrid coupler to enhance isolation between the transmission filter and the reception filter.

CITATION LIST

Patent Literature

(3) Patent Literature 1: PCT International Publication No. WO 2009/078095 Patent Literature 2: PCT Japanese Translation Patent Publication No. 2015-530810 Patent Literature 3: PCT Japanese Translation Patent Publication No. 2013-545325 Patent Literature 4: PCT Japanese Translation Patent Publication No. 2014-511626

SUMMARY

(4) In an aspect of the present disclosure, a composite filter includes a common terminal, a first terminal, and a second terminal. The composite filter performs at least one of a process of simultaneously inputting two signals having different frequencies within a first passband to the first terminal and a process of simultaneously inputting two signals having different frequencies within a second passband to the second terminal. The composite filter includes a first filter system connecting the common terminal and the first terminal to each other and a second filter system connecting the common terminal and the second terminal to each other. The first filter system and the second filter system share a first 90° hybrid coupler connected to the common terminal. The first 90° hybrid coupler includes a first port, a second port, a third port, and a fourth port. The third port is electrically connected to the first port and the second port. The fourth port is electrically connected to the first port and the second port. The fourth port is a port to which a signal with a phase shifted by 90° relative to a phase of a signal distributed from the first port to the third port is distributed from the first port. The first port is connected to the common terminal. The first filter system includes a first filter, a second filter, and a second 90° hybrid coupler. The first filter is connected to the third port and corresponds to the first passband. The second filter is connected to the fourth port and corresponds to the first passband. The second 90° hybrid coupler connects the first filter and the second filter to the first terminal. The second 90° hybrid coupler includes a fifth port, a sixth port, a seventh port, and an eighth port. The seventh port is electrically connected to the fifth port and the sixth port. The eighth port is electrically connected to the fifth port and the sixth port. The eighth port is a port to which a signal with a phase shifted by 90° relative to a phase of a signal distributed from the fifth port to the seventh port is distributed from the fifth port. The fifth port is connected to the first filter. The sixth port is connected to the second filter. The eighth port is connected to the first terminal. The second filter system electrically connects the third port and the fourth port to the second terminal and relatively shifts a phase of a signal flowing from the third port toward the second terminal by 90° relative to a phase of a signal flowing from the fourth port toward the second terminal to change a phase difference between the two signals by 90°.

(5) In an aspect of the present disclosure, a communication device includes the aforementioned composite filter, an antenna connected to the common terminal, and an integrated circuit element. The integrated circuit element connects the first terminal and the second terminal to each other and performs at least one of the process of simultaneously inputting two signals having different frequencies within the first passband to the first terminal and the process of simultaneously inputting two signals having different frequencies within the second passband to the second terminal.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a circuit diagram illustrating the configuration of a splitter according to a first embodiment.

(2) FIG. **2**A is a schematic diagram illustrating an example of the operation of a 90° hybrid coupler.

(3) FIG. **2**B is a schematic diagram illustrating another example of the operation of the 90° hybrid coupler.

(4) FIG. **3**A is a schematic diagram illustrating the operation of the splitter when one signal is input to a transmission terminal.

(5) FIG. **3**B is a schematic diagram illustrating the operation of the splitter when one signal is input to an antenna terminal.

(6) FIG. **4**A is another schematic diagram illustrating the operation of the splitter when two signals are input to the transmission terminal.

(7) FIG. **4**B is another schematic diagram illustrating the operation of the splitter when signals are input to the transmission terminal and the antenna terminal.

(8) FIG. **5** is a circuit diagram illustrating the configuration of a splitter according to a second embodiment.

(9) FIG. **6** is a circuit diagram illustrating the configuration of a splitter according to a third embodiment.

(10) FIG. **7** is a plan view schematically illustrating an example of the configuration of a resonator included in the splitter in FIG. **1**.

(11) FIG. **8** is a circuit diagram schematically illustrating an example of the configuration of a splitter unit included in the splitter in FIG. **1**.

(12) FIG. **9** is a plan view illustrating an example of a chip included in the splitter unit in FIG. **8**.

(13) FIG. **10** is a circuit diagram illustrating the configuration of a variation of the splitter in FIG. **6**.

(14) FIG. **11**A is a plan view illustrating an example of the structure of a splitter according to an embodiment.

(15) FIG. **11**B is a plan view illustrating another example of the structure of the splitter according to the embodiment.

(16) FIG. **11**C is a plan view illustrating yet another example of the structure of the splitter according to the embodiment.

(17) FIG. **12** is a block diagram illustrating the configuration of a communication device as a usage example of the splitter according to the embodiment.

DESCRIPTION OF EMBODIMENTS

(18) Embodiments according to the present disclosure will be described below with reference to the drawings. The drawings to be used in the following description are schematic. Therefore, for example, the dimensional ratios in each drawing do not necessarily match those in actuality.

(19) After describing a first embodiment, only the differences from the previously-described embodiment or embodiments will basically be described. Matters not particularly mentioned may be the same as and/or similar to those in the previously-described embodiment or embodiments, or may be assumed from the previously-described embodiment or embodiments.

(20) In the present disclosure, the expression "phase is shifted" may imply that the phase is advanced and/or delayed. However, for the sake of convenience, the expression "phase is shifted" used when designating the shift amount has the meaning of either one of the two. For example, when the expression "phase is shifted by 90°" is used for explaining the function of multiple elements (e.g., 90° hybrid couplers) within a single composite filter, the multiple elements each have a function for advancing the phase by 90° or a function for delaying the phase by 90°. For

example, when each element includes two terminals and the phase of a signal flowing from one of the terminals to the other terminal and the phase of a signal flowing from the other terminal to the one terminal are to be shifted by 90°, the phases of the two signals are both advanced by 90° or delayed by 90°.

First Embodiment

(21) (General Overview of Splitter)

(22) FIG. **1** is a circuit diagram illustrating the configuration of a splitter **1** serving as a composite filter according to a first embodiment.

(23) More specifically, the splitter **1** serves as a duplexer. For example, the splitter **1** includes a transmission filter system **2**T that filters a transmission signal from a transmission terminal **7** and outputs the transmission signal to an antenna terminal **5**, and a reception filter system **2**R that filters a reception signal from the antenna terminal **5** and outputs the reception signal to a reception terminal **9**.

(24) The transmission filter system **2**T includes transmission filters **13**A and **13**B (sometimes hereinafter referred to as "transmission filters **13**" collectively or without distinguishing the two from each other) that are directly responsible for filtering the transmission signal. The reception filter system **2**R includes a reception filter **15** that is directly responsible for filtering the reception signal. Each transmission filter **13** corresponds to a transmission band. The reception filter **15** corresponds to a reception band. In other words, each transmission filter **13** and the reception filter **15** have passbands that are different from (i.e., do not overlap) each other. In the splitter **1**, a part that includes the transmission filters **13** and the reception filter **15** and that directly contributes to filtering may sometimes be referred to as a splitter unit **3**.

(25) In the transmission filters **13** and/or the reception filter **15**, a nonlinear distortion (distortion signal), such as an inter-modulation distortion (IMD), is known to occur due to nonlinearity of the transmission filters **13** and/or the reception filter **15**. In the present disclosure, an inter-modulation distortion has a broad meaning including a passive inter-modulation (PIM), unless otherwise noted. This nonlinear distortion deteriorates the properties of the splitter **1**. More specifically, for example, when a frequency of a nonlinear distortion in each transmission filter **13** is located within the passband of the reception filter **15**, the nonlinear distortion passes through the reception filter **15** and enters the reception terminal **9**, thus lowering the reception sensitivity.

(26) The splitter **1** includes 90° hybrid couplers **17** and **19** ("90°" may sometimes be omitted hereinafter). The hybrid couplers **17** and **19** perform distribution, phase adjustment, and/or synthesis on the transmission signal and/or the reception signal. In this process, for example, the nonlinear distortion is distributed, and the distributed nonlinear distortions are given opposite phases and are subsequently synthesized, thereby cancelling each other out. In other words, the nonlinear distortion is reduced. In detail, in this embodiment, for example, PIM is reduced. On the other hand, the splitter **1** basically maintains the intensities of the transmission signal and the reception signal.

(27) The transmission filter system **2**T and the reception filter system **2**R share the hybrid coupler **17**. The hybrid coupler **17** is connected to the antenna terminal **5**. In the hybrid coupler **17**, the transmission filter system **2**T and the reception filter system **2**R branch off from each other.

(28) The transmission filter system **2**T includes the hybrid coupler **19** connected to the transmission terminal **7**. A signal path from the transmission terminal **7** toward the antenna terminal **5** bifurcates at the hybrid coupler **19**. The transmission filter **13**A is located in one of the paths, and the transmission filter **13**B is located in the other path. The transmission filters **13**A and **13**B correspond to the same passband. The transmission filters **13**A and **13**B are located between the hybrid coupler **19** and the hybrid coupler **17**. An unused port **19**c of the hybrid coupler **19** is connected to a termination resistor **23**.

(29) The reception filter system **2**R includes the reception filter **15**, as mentioned above. The reception filter **15** is located between the hybrid coupler **17** and the reception terminal **9**.

(30) (Filters)

(31) Each of the transmission filters **13** is a bandpass filter with a predetermined transmission band as a passband. Likewise, the reception filter **15** is a bandpass filter with a predetermined reception band as a passband. The transmission band and the reception band may be compliant with, for example, various kinds of standards. The transmission band may include two or more transmission bands compliant with a predetermined standard. The same applies to the reception band.

(32) The transmission filters **13**A and **13**B correspond to the same transmission band. In other words, the passbands of the transmission filters **13**A and **13**B are identical to each other substantially and/or in design. The transmission filters **13**A and **13**B are identical or similar to each other and have identical properties substantially or in design. Alternatively, the transmission filters **13**A and **13**B may be finely adjusted to have slightly different passbands and/or slightly different properties.

(33) The transmission filters **13** and the reception filter **15** may each have, for example, a known configuration or an advanced version of the known configuration. For example, the transmission filters **13** and/or the reception filter **15** may each be a piezoelectric filter including a piezoelectric member, a dielectric filter that utilizes an electromagnetic wave within a dielectric member, an LC filter having a combination of an inductor and a capacitor, or a combination of two or more of these filters. Examples of a piezoelectric filter include a type that utilizes an elastic wave and a type that does not utilize an elastic wave (e.g., a type that uses a piezoelectric vibrator). An elastic wave is, for example, SAW (surface acoustic wave), BAW (bulk acoustic wave), a boundary elastic wave, or a Lamb wave (although these elastic waves are not necessarily distinguishable).

(34) (90° Hybrid Coupler)

(35) As is commonly known, the hybrid coupler **17** includes four ports **17**a to **17**d provided for receiving and/or outputting signals, and functions as a distributor, a synthesizer, and a 90° phase shifter. The hybrid coupler **17** may have, for example, a known configuration or an advanced version of the known configuration. For example, although not illustrated, the hybrid coupler **17** may be of a distributed constant type or a concentrated constant type. A well-known type of the hybrid coupler **17** is a branch-line coupler.

(36) FIG. **2**A is a schematic diagram illustrating an example of the operation of the hybrid coupler **17**. FIG. **2**B is a schematic diagram illustrating another example of the operation of the hybrid coupler **17**.

(37) In each of the illustrated examples, the ports **17**a and **17**b at the left side of the drawing are electrically connected to the ports **17**c and **17**d at the right side of the drawing. The expression "electrically connected" implies that a signal is allowed to flow. Therefore, for example, as illustrated in FIG. **2**A, a signal input to the port **17**a is outputtable from the ports **17**c and **17**d.

(38) For the sake of convenience, this embodiment may sometimes be described based on the positional relationship of the ports **17**a to **17**d in the diagram illustrating the hybrid coupler **17**. However, the positional relationship of the four ports **17**a to **17**d in the diagram does not necessarily need to match the positional relationship of the four ports **17**a to **17**d in actuality.

(39) As illustrated in FIG. **2**A, a signal s**1** input to the port **17**a at the left side of the drawing is distributed to the ports **17**c and **17**d at the right side of the drawing so as to be output as signals s**1-0** and s**1-90**. The distribution ratio in this case (i.e., the ratio between the intensity of the signal s**1-0** and the intensity of the signal s**1-90**) is 1:1. The intensity is, for example, the voltage, current, and/or power. The phase of the signal s**1-0** is, for example, the same as the phase of the signal s**1**. On the other hand, the phase of the signal s-**90** has been, for example, shifted by 90° relative to the phase of the signal s**1-0**.

(40) Although the same applies thereinafter, there may be a fixed phase difference between the signal s**1** prior to the distribution and the signals s**1-0** and s**1-90** after the distribution. The fact that the phase of the signal s**1-0** and the phase of the signal s**1-90** have been shifted by 90° is the essence of a 90° hybrid coupler. For the sake of convenience, this embodiment may sometimes be

described as if the signal s**1** prior to the distribution and the signal s**1-0** after the distribution have the same phase.

(41) The above operation is similarly performed in a case where a signal is input to each of the other ports **17**b to **17**d. In other words, a signal input to one of the two ports located at one of the left and right sides of the drawing is distributed at the distribution ratio of 1:1 and output from the two ports located at the other one of the left and right sides of the drawing. In this case, the phase of the signal output from the port located at the opposite side, in the up-down direction of the drawing, of the port that has received the signal is shifted by 90° relative to the phase of the signal output from the port located at the same side, in the up-down direction of the drawing, as the port that has received the signal.

(42) Since a device that operates in the above-described manner is called a 90° hybrid coupler, the relationship of the four ports of the hybrid coupler **17** is identifiable simply from a description related to one or more of the ports. For example, it is assumed that the port **17**d is a port to which a signal with a phase shifted by 90° relative to the phase of a signal distributed from the port **17**a to the port **17**c is distributed from the port **17**a. It is derived from this description that the port **17**a and the remaining port **17**b are located at the same side in the left-right direction of the drawing, the port **17**c and the port **17**d are located at the opposite side thereof, the port **17**a and the port **17**c are located at the same side in the up-down direction of the drawing, and the port **17**b and the port **17**d are located at the opposite side thereof. When the relationship of the four ports is described in accordance with the signal distributed from the port **17**a, as in the above description, the hybrid coupler **17** does not need to be provided such as to actually receive a signal via the port **17**a.

(43) As illustrated in FIG. **2**B, when the signal s**1** is input to the port **17**a at the left side of the drawing and a signal s**2** is simultaneously input to the port **17**b at the left side of the drawing, the signals s**1** and s**2** are distributed, as described above, and the distributed signals are synthesized. For example, the port **17**c outputs a signal obtained as a result of synthesizing the signal s**1-0** split from the signal s**1** and having the same phase as the phase of the signal s**1** and a signal s**2-90** split from the signal s**2** and having a phase shifted by 90° from the phase of the signal s**2**. The port **17**d outputs a signal obtained as a result of synthesizing the signal s**1-90** split from the signal s**1** and having a phase shifted by 90° from the phase of the signal s**1** and a signal s**2-0** split from the signal s**2** and having the same phase as the phase of the signal s**2**. Although the above description relates to a case where the two ports **17**a and **17**b at the left side of the drawing receive signals, the same applies to a case where the two ports **17**c and **17**d at the right side of the drawing receive signals.

(44) As mentioned above, there may be a phase difference between the signal s**1** and the signal s**1-0** and a phase difference between the signal s**2** and the signal s**2-0**. In this case, the two phase differences are the same. Two phase differences in a case where signals are oriented in opposite directions are also the same as the aforementioned two phase differences. From another viewpoint, for example, the hybrid coupler **17** is configured such that the phase of the signal s**2-90** flowing from the port **17**b toward the port **17**c is relatively shifted by 90° relative to the phase of the signal s**1-0** flowing from the port **17**a toward the port **17**c and that the phase difference between the two signals changes by 90° (i.e., the phase difference between the signals s**1** and s**2** and the phase difference between the signals s**1-0** and s**2-90** are different from each other by 90°). The expression "relatively shifted by 90°" may imply that the phases of the signals prior to the shift (i.e., the phase of the signal s**1** and the phase of the signal s**2**) do not match.

(45) Although the hybrid coupler **17** has been described above, the above description may be applied to the hybrid coupler **19** by replacing **17** and **17**a to **17**d with **19** and **19**a to **19**d, respectively.

(46) Referring back to FIG. **1**, in the hybrid coupler **17**, the port **17**a is connected to the antenna terminal **5**. The port **17**b is connected to the reception filter **15**. The port **17**c is connected to the transmission filter **13**A. The port **17**d is connected to the transmission filter **13**B.

(47) In the hybrid coupler **19**, the port **19**a is connected to the transmission filter **13**A. The port **19**b

is connected to the transmission filter **13**B. The port **19**c is connected to the termination resistor **23**, as mentioned above. The port **19**d is connected to the transmission terminal **7**.

(48) (Termination Resistor)

(49) The termination resistor **23** has, for example, a predetermined resistance value and connects the port **19**c of the hybrid coupler **19** to a reference potential section (not illustrated). Accordingly, for example, reflection of a signal flowing from the port **19**a and/or the port **19**b toward the port **19**c is reduced. The resistance value of the termination resistor **23** may be appropriately set in accordance with the impedance at the hybrid coupler **19** than the termination resistor **23**, and is normally 50Ω. The termination resistor **23** may have a known configuration or an advanced version of the known configuration. For example, although not particularly illustrated, the termination resistor **23** may be an electronic component mounted on a circuit substrate or may be a conductive pattern formed on a circuit substrate.

(50) (Operation of Composite Filter)

(51) FIG. **3**A illustrates the operation of the splitter **1** when a signal (e.g., the transmission signal) is input to the transmission terminal **7**. In this drawing, the flow of the signal is indicated by arrows. As indicated by explanatory legends at the right side of the drawing, the line types of the arrows are varied in accordance with changes in the phase of the signal. The phase of the signal when flowing through the transmission terminal **7** is 0°.

(52) The signal input from the transmission terminal **7** to the port **19**d of the hybrid coupler **19** is distributed to the ports **19**a and **19**b. A signal with a phase of 90° is output from the port **19**a, and the signal is input to the port **17**c of the hybrid coupler **17** after passing through the transmission filter **13**A. A signal with a phase of 0° is output from the port **19**b, and the signal is input to the port **17**d of the hybrid coupler **17** after passing through the transmission filter **13**B.

(53) The signal with the phase of 90° input to the port **17**c is distributed to the port **17**a while the phase is maintained. On the other hand, the signal with the phase of 0° input to the port **17**d is phase-shifted by 90° before being distributed to the port **17**a. Therefore, the two signals distributed to the port **17**a have the same phase (90°) and are synthesized before being output to the antenna terminal **5**.

(54) The signal with the phase of 90° input to the port **17**c is phase-shifted by 90° (i.e., is turned into a signal with a phase of 180°) before being distributed to the port **17**b. On the other hand, the signal with the phase of 0° input to the port **17**d is distributed to the port **17**b while the phase is maintained. Therefore, the two signals distributed to the port **17**b have opposite phases (0° and 180°) from each other and cancel each other out. In other words, no signal is output to the reception filter **15**.

(55) Accordingly, the signal input from the transmission terminal **7** is output to the antenna terminal **5**, but is not output to the reception filter **15** (reception terminal **9**). Although the above expression indicates that the two signals input to the ports **17**c and **17**d are distributed to the port **17**b for the sake of convenience, the fact that no signal is output from the port **17**b substantially implies that no signal is distributed to the port **17**b. In other words, if an insertion loss is neglected, the intensity of the signal output from the antenna terminal **5** is equal to the intensity of the signal input to the transmission terminal **7**.

(56) FIG. **3**B illustrates the operation of the splitter **1** when a signal (e.g., the reception signal) is input to the antenna terminal **5**. In this drawing, the flow of the signal input to the antenna terminal **5** is indicated by arrows. The line types of the arrows are varied in accordance with changes in the phase of the signal, as in FIG. **3**A (see the explanatory legends in FIG. **3**A). The phase of the signal when flowing through the antenna terminal **5** is 0°.

(57) The signal input from the antenna terminal **5** to the port **17**a of the hybrid coupler **17** is distributed to the ports **17**c and **17**d. A signal with a phase of 0° flows from the port **17**c to the transmission filter **13**A. A signal with a phase of 90° flows from the port **17**d to the transmission filter **13**B. Signals (e.g., reception signals) outside the passbands of the transmission filters **13**A and

13B are reflected by the transmission filters **13**A and **13**B so as to return to the ports **17***c* and **17***d*.

(58) The signal with the phase of 0° reflected by the transmission filter **13**A and input to the port **17***c* is phase-shifted by 90° before being distributed to the port **17***b*. On the other hand, the signal with the phase of 90° reflected by the transmission filter **13**B and input to the port **17***d* is distributed to the port **17***b* while the phase is maintained. Therefore, the two signals distributed to the port **17***b* have the same phase (90°) and are synthesized before being input to the reception filter **15**, and by extension, output to the reception terminal **9**.

(59) The signal with the phase of 0° reflected by the transmission filter **13**A and input to the port **17***c* is distributed to the port **17***a* while the phase is maintained. On the other hand, the signal with the phase of 90° reflected by the transmission filter **13**B and input to the port **17***d* is phase-shifted by 90° (i.e., is turned into a signal with a phase of 180°) before being distributed to the port **17***a*. Therefore, the two signals distributed to the port **17***a* have opposite phases (0° and 180°) from each other and cancel each other out. In other words, no signal is output to the antenna terminal **5**.

(60) Accordingly, the signal (i.e., the reception signal) input from the antenna terminal **5** is output to the reception terminal **9**, but is not output to the transmission terminal **7** and does not return to the antenna terminal **5**. Although the above expression indicates that the two signals input to the ports **17***c* and **17***d* are distributed to the port **17***a* for the sake of convenience, the fact that no signal is output from the port **17***a* substantially implies that no signal is distributed to the port **17***a*. In other words, if an insertion loss is neglected, the intensity of the signal output to the reception terminal **9** is equal to the intensity of the signal input to the antenna terminal **5**.

(61) (Nonlinear Distortion)

(62) The elements constituting the transmission filters **13** and the reception filter **15** may sometimes have nonlinearity. For example, in a piezoelectric filter, the relationship between stress applied to the piezoelectric member and a distortion (not a nonlinear distortion but a ratio of deformation amounts) occurring in the piezoelectric member is ideally linear. However, when the stress reaches a certain magnitude, a distortion is less likely to occur and further becomes saturated. In other words, the piezoelectric member has nonlinear properties in which an input and a response are not proportional to each other. As a result, when a filter receives one signal or two or more signals with relatively large electric power, a nonlinear distortion (distortion signal) occurs.

(63) For example, it is assumed that the frequencies of two signals (input voltages) input to a filter are defined as f**1** and f**2**, respectively, and m and n are integers (. . . , −3, −2. −1, 0, 1, 2, 3, . . .). In this case, a signal having a frequency of m×f**1**+n×f**2** (i.e., an output voltage and an output current from another viewpoint) is generated in the filter. |m|+|n| is called an order. A signal in which |m|+|n| is equal to or greater than 2 is a nonlinear distortion. A signal in which both m and n are not 0 is an inter-modulation distortion. A signal in which one of m and n is 0 is a harmonic.

(64) Examples of two signals that generate a nonlinear distortion include various signals. One example includes two transmission signals simultaneously input to the transmission terminal **7** in the splitter **1** shared in two or more frequency bands at a base station and/or the like. Other examples include an interference wave (noise) from the antenna terminal **5** and a transmission signal input to the transmission terminal **7**.

(65) When the term "nonlinear distortion" is simply used in the description of this embodiment, the values of m and n are arbitrary, unless otherwise noted. For example, the nonlinear distortion may be a third-order nonlinear distortion in which m=2 and n=−1, a third-order nonlinear distortion in which m=2 and n=1, an odd-numbered-order nonlinear distortion, or an even-numbered-order nonlinear distortion. Of these nonlinear distortions, the composite filter according to this embodiment can reduce the possibility in which a nonlinear distortion with |m+n|=1 flows toward the reception filter **15**. Examples of the nonlinear distortion with |m+n|=1 include odd-numbered-order inter-modulation distortions, such as a third-order inter-modulation distortion (m=2, n=−1) and a fifth-order inter-modulation distortion (m=3, n=−2).

(66) FIG. **4**A illustrates the operation of the splitter **1** when a nonlinear distortion (e.g., PIM) occurs

in each of the transmission filters **13** as a result of two signals (e.g., two transmission signals having frequencies within the passbands of the transmission filters **13**) with different frequencies being simultaneously input to the transmission terminal **7**. In this drawing, the flow of each signal is indicated by arrows. The line types of the arrows are varied in accordance with changes in the phase of each signal, as in FIG. **3**A. The phase of each signal when flowing through the transmission terminal **7** is 0°.

(67) In a signal path from the transmission terminal **7** to each of the transmission filters **13**A and **13**B, arrows are drawn parallel to each other to indicate that the two signals having different frequencies are flowing through the signal path. It is clear from the line types of the arrows that the two signals are phase-shifted by 90° by the hybrid coupler **19** and are distributed to the transmission filters **13**A and **13**B, similarly to the signals described with reference to FIG. **3**A. Each transmission filter **13** receives the two signals having different frequencies, so that a nonlinear distortion occurs. The nonlinear distortion partially flows from each transmission filter **13** to the hybrid coupler **17**.

(68) At the hybrid coupler **17** side from the transmission filters **13**A and **13**B, the flow of the aforementioned nonlinear distortion is indicated by an arrow. As mentioned above, the two signals with the different frequencies input to the transmission terminal **7** are phase-shifted by 90° before being distributed to the two transmission filters **13**. Assuming that the phases of the two signals input to the filters are φ**1** and φ**2**, respectively, the phase of the nonlinear distortion that is to occur is calculated from m×φ**1**+n×φ**2**, which is the same expression used for the frequency indicated above. Assuming that φ**1**=φ**2**=90°, the phase of the nonlinear distortion that is to occur is m×90° +n×90°=(m+n)×90°, whereby 90° when |m+n|=1. As a result, the nonlinear distortion occurring in the transmission filter **13**A and the nonlinear distortion occurring in the transmission filter **13**B have phases shifted by 90° relative to each other.

(69) The two nonlinear distortions with the aforementioned phases shifted by 90° relative to each other and flowing through the hybrid coupler **17** are processed similarly to the two signals flowing from the two transmission filters **13** to the hybrid coupler **17** in FIG. **3**A. In other words, the two nonlinear distortions are output from the hybrid coupler **17** to the antenna terminal **5** but are not output to the reception filter **15** (reception terminal **9**). Accordingly, the nonlinear distortions occurring in the transmission filters **13** due to the two signals input to the transmission terminal **7** are not output to the reception terminal **9**.

(70) FIG. **4**B illustrates the operation of the splitter **1** when a nonlinear distortion occurs in each of the transmission filters **13** as a result of a signal (e.g., a transmission signal) being input to the transmission terminal **7** and a signal (e.g., an interference wave) being input to the antenna terminal **5**. In this drawing, the flow of the signals is indicated by arrows. The line types of the arrows are varied in accordance with changes in the phase of each signal, as in FIG. **4**A (see the explanatory legends in FIG. **4**A). With regard to the signal input to the transmission terminal **7**, the phase of the signal when flowing through the transmission terminal **7** is 0°. With regard to the signal input to the antenna terminal **5**, the phase of the signal when flowing through the antenna terminal **5** is 0°.

(71) The arrows oriented toward the transmission filters **13**A and **13**B from the transmission terminal **7** via the hybrid coupler **19** indicate the flow of the signal input to the transmission terminal **7**. As described with reference to FIG. **3**A, the signal input to the transmission terminal **7** is phase-shifted by 90° before being distributed to the transmission filters **13**A and **13**B.

(72) The arrows oriented toward the transmission filters **13**A and **13**B from the antenna terminal **5** via the hybrid coupler **17** indicate the flow of the signal input to the antenna terminal **5**. As described with reference to FIG. **3**B, the signal input to the antenna terminal **5** is phase-shifted by 90° before being distributed to the transmission filters **13**A and **13**B.

(73) Therefore, each transmission filter **13** receives the two signals having different frequencies (i.e., the signal from the transmission terminal **7** and the signal from the antenna terminal **5**), so that a nonlinear distortion occurs. The nonlinear distortion partially flows from each transmission filter

13 to the hybrid coupler **17**.

(74) The following focuses on a nonlinear distortion in which m=2 and n=−1 (i.e., a third-order nonlinear distortion having a frequency of 2×f**1**−f**2**), assuming that the frequency of the signal input to the antenna terminal **5** is defined as f**1** and the frequency of the signal input to the transmission terminal **7** is defined as f**2**. The arrows oriented toward the hybrid coupler **17** from the transmission filters **13**A and **13**B indicate the flow of this third-order nonlinear distortion.

(75) The transmission filter **13**A receives a signal with a phase of 0° from the antenna terminal **5** and a signal with a phase of 90° from the transmission terminal **7**. Therefore, the phase of the nonlinear distortion having the frequency of 2×f**1**−f**2** is 2×0°−90°=−90°. On the other hand, the transmission filter **13**B receives a signal with a phase of 90° from the antenna terminal **5** and a signal with a phase of 0° from the transmission terminal **7**. Therefore, the phase of the nonlinear distortion having the frequency of 2×f**1**−f**2** is 2×90°−0°=180°.

(76) The nonlinear distortion with the phase of −90° generated by the transmission filter **13**A and input to the port **17**c of the hybrid coupler **17** is phase-shifted by 90° (i.e., is turned into a nonlinear distortion with a phase of 0°) before being distributed to the port **17**b. On the other hand, the nonlinear distortion with the phase of 180° generated by the transmission filter **13**B and input to the port **17**d of the hybrid coupler **17** is distributed to the port **17**b while the phase is maintained. Therefore, the two nonlinear distortions distributed to the port **17**b have opposite phases (0° and 180°) from each other and cancel each other out. In other words, the nonlinear distortions are not input to the reception filter **15**, and by extension, not output to the reception terminal **9**.

(77) Accordingly, in this embodiment, the composite filter (splitter **1**) includes a common terminal (antenna terminal **5**), a first terminal (transmission terminal **7**), and a second terminal (reception terminal **9**). In the splitter **1**, two signals having different frequencies within a first passband (transmission band) are simultaneously input to the transmission terminal **7**. The splitter **1** includes a first filter system (transmission filter system **2**T) that connects the antenna terminal **5** and the transmission terminal **7** to each other and a second filter system (reception filter system **2**R) that connects the antenna terminal **5** and the reception terminal **9** to each other. The transmission filter system **2**T and the reception filter system **2**R share a first 90° hybrid coupler (hybrid coupler **17**) connected to the antenna terminal **5**. The hybrid coupler **17** includes a first port (port **17**a) and a second port (port **17**b), a third port (port **17**c) electrically connected to the ports **17**a and **17**b, and a fourth port (port **17**d) electrically connected to the ports **17**a and **17**b. The port **17**d is a port to which a signal with a phase shifted by 90° relative to the phase of a signal distributed from the port **17**a to the port **17**c is distributed from the port **17**a. The port **17**a is connected to the antenna terminal **5**. The transmission filter system **2**T includes a first filter (transmission filter **13**A), a second filter (transmission filter **13**B), and a second 90° hybrid coupler (hybrid coupler **19**). The transmission filter **13**A is connected to the port **17**c and corresponds to the transmission band. The transmission filter **13**B is connected to the port **17**d and corresponds to the transmission band. The hybrid coupler **19** connects the transmission filters **13**A and **13**B to the transmission terminal **7**. The hybrid coupler **19** includes a fifth port and a sixth port (ports **19**a and **19**b), a seventh port (port **19**c) electrically connected to the ports **19**a and **19**b, and an eighth port (port **19**d) electrically connected to the ports **19**a and **19**b. The port **19**d is a port to which a signal with a phase shifted by 90° relative to the phase of a signal distributed from the port **19**a to the port **19**c is distributed from the port **19**a. The port **19**a is connected to the transmission filter **13**A. The port **19**b is connected to the transmission filter **13**B. The port **19**d is connected to the transmission terminal. The reception filter system **2**R (more specifically, the hybrid coupler **17** shared with the transmission filter system **2**T) electrically connects the port **17**c and the port **17**d to the reception terminal **9** (i.e., the port **17**b from another viewpoint) such that the phase of a signal flowing from the port **17**c to the reception terminal **9** is relatively shifted by 90° relative to the phase of a signal flowing from the port **17**d to the reception terminal **9** and that the phase difference between the two signals changes by 90°.

(78) Therefore, for example, as described above with reference to FIG. **4**A, the two nonlinear

distortions occurring in the two transmission filters **13** due to the two transmission signals input simultaneously to the transmission terminal cancel each other out in the hybrid coupler **17**, so that the nonlinear distortions to be input to the reception filter **15** are reduced (i.e., eliminated in theory). As a result, the splitter **1** can have improved reception sensitivity.

(79) The reception filter system **2R** may include a third filter (reception filter **15**). The reception filter **15** corresponds to a second passband (reception band) different from the first passband (transmission band), and may connect the port **17***b* of the hybrid coupler **17** and the reception terminal **9** to each other.

(80) In this case, for example, the reception filter system **2R** has a simple configuration, as compared with a third embodiment to be described later. From another viewpoint, size reduction can be readily achieved. Furthermore, for example, in the case where the first filter system is the transmission filter system **2T** and the second filter system is the reception filter system **2R**, as in this embodiment, power durability can be enhanced while achieving a simplified configuration and/or size reduction, as mentioned above. Details are as follows. In the first filter system (i.e., the transmission filter system **2T** in this embodiment), a signal input to the first terminal (i.e., the transmission terminal **7** in this embodiment) is distributed by the hybrid coupler **19** so as to be input to the first filter and the second filter (i.e., the transmission filters **13**A and **13**B in this embodiment). Thus, the electric power input to each of the first filter and the second filter is reduced. On the other hand, the intensity of the transmission signal input to the transmission terminal **7** is normally higher than the intensity of the reception signal input from the antenna terminal **5**. Therefore, the transmission filter system **2T** is provided with two transmission filters **13**, and the reception filter system **2R** is provided with one reception filter **15**, thereby enhancing power durability while achieving a simplified configuration and/or size reduction.

(81) The composite filter (splitter **1**) may include the termination resistor **23** connected to the seventh port (port **19***c*).

(82) In this case, for example, a reflection loss in the transmission filter system **2T** can be reduced. From another viewpoint, a voltage standing wave ratio (VSWR) in the transmission terminal **7** can be reduced (i.e., can be reduced to 1, which is a minimum value, in theory). Details are as follows. As described above with reference to FIG. **3**A, the signal input to the transmission terminal **7** is distributed to the transmission filters **13**A and **13**B by the hybrid coupler **19**. The hybrid coupler **19** turns a signal reflected by the transmission filter **13**A and flowing from the port **19***a* to the port **19***d* (i.e., the transmission terminal **7** from another viewpoint) into a signal having a phase difference of 180° relative to the signal input to the transmission terminal **7**. On the other hand, a signal reflected by the transmission filter **13**B and flowing from the port **19***b* to the port **19***d* maintains the same phase as the signal input to the transmission terminal **7**. Therefore, the two signals cancel each other out. In other words, the signal input to the transmission terminal **7** does not return to the transmission terminal **7** even if the signal is partially reflected by the transmission filters **13**A and **13**B. The hybrid coupler **19** turns a signal reflected by the transmission filter **13**A and flowing from the port **19***a* to the port **19***c* (i.e., the termination resistor **23** from another viewpoint) into a signal having a phase difference of 90° relative to the signal input to the transmission terminal **7**. On the other hand, the hybrid coupler **19** also turns a signal reflected by the transmission filter **13**B and flowing from the port **19***b* to the port **19***c* into a signal having a phase difference of 90° relative to the signal input to the transmission terminal **7**. Therefore, these two signals are synthesized before being input to the termination resistor **23**. Accordingly, a reflection wave is entirely input to the termination resistor **23** in theory. Thus, by properly setting the impedance of the termination resistor **23**, a reflection wave returning to the transmission terminal **7** is reduced (i.e., eliminated in theory), so that VSWR in the transmission terminal **7** can be reduced. From another viewpoint, the necessity to enhance impedance matching between the transmission filters **13**A and **13**B is reduced, thereby enhancing the degree of design freedom in the transmission filters **13**A and **13**B.

(83) In the first embodiment described above, the splitter **1** is an example of a composite filter. The

antenna terminal **5** is an example of a common terminal. The transmission terminal **7** is an example of a first terminal. The reception terminal **9** is an example of a second terminal. The transmission filter system **2T** is an example of a first filter system. The reception filter system **2R** is an example of a second filter system. The transmission filter **13**A is an example of a first filter. The transmission filter **13**B is an example of a second filter. The reception filter **15** is an example of a third filter. The transmission band is an example of a first passband. The reception band is an example of a second passband. The hybrid coupler **17** is an example of a first hybrid coupler. The port **17***a* is an example of a first port. The port **17***b* is an example of a second port. The port **17***c* is an example of a third port. The port **17***d* is an example of a fourth port. The hybrid coupler **19** is an example of a second hybrid coupler. The port **19***a* is an example of a fifth port. The port **19***b* is an example of a sixth port. The port **19***c* is an example of a seventh port. The port **19***d* is an example of an eighth port.

Second Embodiment

(84) (Configuration of Splitter)

(85) FIG. **5** is a circuit diagram illustrating the configuration of a splitter **201** serving as a composite filter according to a second embodiment.

(86) Briefly speaking, the splitter **201** is obtained by interchanging the transmission filters **13** and the reception filter **15** with each other in the splitter **1** according to the first embodiment. Details are as follows.

(87) A reception filter system **202**R includes the hybrid coupler **17**, two reception filters **15**A and **15**B (sometimes hereinafter referred to as "reception filters **15**" collectively or without distinguishing the two from each other), the hybrid coupler **19**, and the termination resistor **23** in that order from the antenna terminal **5** toward the reception terminal **9**. With regard to the connection relationship among these components, the description of the connection relationship in the transmission filter system **2T** according to the first embodiment may be used. However, the terms "transmission filters **13**A and **13**B (**13**)" are replaced with the terms "reception filters **15**A and **15**B (**15**)", and the term "transmission terminal **7**" is replaced with the term "reception terminal **9**".

(88) The two reception filters **15** correspond to the same passband (but the reception band unlike the first embodiment), similarly to the two transmission filters **13** according to the first embodiment. With regard to the fact that the two reception filters **15** may have the same configuration and the same properties, the description of the two transmission filters **13** according to the first embodiment may be used.

(89) A transmission filter system **202**T includes a transmission filter **13** and a hybrid coupler **17** in that order from the transmission terminal **7** toward the antenna terminal **5**. With regard to the connection relationship between these components, the description of the connection relationship in the reception filter system **2R** according to the first embodiment may be used. However, the term "reception filter **15**" is replaced with the term "transmission filter **13**", and the term "reception terminal **9**" is replaced with the term "transmission terminal **7**".

(90) (Operation of Splitter)

(91) The operation of the splitter **201** is as follows.

(92) First, the operation of the splitter **1** when a signal (e.g., a transmission signal) is input to the transmission terminal **7** will be described. In the following description, the phase of the signal when flowing through the transmission terminal **7** is 0°.

(93) The signal input from the transmission terminal **7** to the port **17***b* of the hybrid coupler **17** via the transmission filter **13** is distributed to the port **17***c* and the port **17***d*. The signal output from the port **17***c* has a phase of 90° and is reflected by the reception filter **15**A so as to return to the port **17***c*. The signal output from the port **17***d* has a phase of 0° and is reflected by the reception filter **15**B so as to return to the port **17***d*.

(94) In FIG. **3**A, the signal with the phase of 90° is input to the port **17***c* and the signal with the

phase of 0° is input to the port **17***d*, similarly to the above description. Therefore, in this embodiment, the signal input to the transmission terminal **7** is output from the port **17***a* to the antenna terminal **5** and is not output from the port **17***b*, as in the first embodiment.

(95) The operation of the splitter **1** when a signal (e.g., a reception signal) is input to the antenna terminal **5** will now be described. In the following description, the phase of the signal when flowing through the antenna terminal **5** is 0°.

(96) The signal input from the antenna terminal **5** to the port **17***a* of the hybrid coupler **17** is distributed to the ports **17***c* and **17***d*. The signal output from the port **17***c* has a phase of 0° and is input to the port **19***a* of the hybrid coupler **19** via the reception filter **15**A. The signal output from the port **17***d* has a phase of 90° and is input to the port **19***b* of the hybrid coupler **19** via the reception filter **15**B.

(97) A signal distributed to the port **19***d* (reception terminal **9**) from the signal with the phase of 0° input to the port **19***a* is phase-shifted by 90°. A signal distributed to the port **19***d* from the signal with the phase of 90° input to the port **19***b* has its phase maintained at 90°. Therefore, the two signals have the same phase (90°) and are synthesized before being output from the port **19***d* to the reception terminal **9**.

(98) On the other hand, a signal distributed to the port **19***c* from the signal with the phase of 0° input to the port **19***a* has its phase maintained at 0°. A signal distributed to the port **19***c* from the signal with the phase of 90° input to the port **19***b* is phase-shifted by 90° so as to become a signal with a phase of 180°. Therefore, the two signals cancel each other out, so as not to be output from the port **19***c*.

(99) Accordingly, the signal input from the antenna terminal **5** is output to each reception filter **15** (reception terminal **9**) but is not output to the transmission filter **13** (transmission terminal **7**) due to the function of the hybrid coupler **17**. Although the above expression indicates that the signal input to the port **19***a* or **19***b* is distributed to the port **19***c* for the sake of convenience, the fact that no signal is output from the port **19***c* substantially implies that no signal is distributed to the port **19***c*. In other words, if an insertion loss is neglected, the intensity of the signal output to the reception terminal **9** is equal to the intensity of the signal input to the antenna terminal **5**.

(100) The operation of the splitter **1** when two signals are input to the transmission terminal **7** and a nonlinear distortion occurs in the transmission filter **13** will now be described. In the following description, it is assumed that the nonlinear distortion has a frequency within the reception band of each reception filter **15** and passes through the reception filter **15** without being reflected at the reception filter **15**. The phase of the nonlinear distortion when flowing from the transmission filter **13** toward the port **17***b* of the hybrid coupler **17** is 0°.

(101) The nonlinear distortion input to the port **17***b* from the transmission filter **13** is distributed to the port **17***c* and the port **17***d*. The nonlinear distortion output from the port **17***c* has a phase of 90° and is input to the port **19***a* of the hybrid coupler **19** via the reception filter **15**A. The nonlinear distortion output from the port **17***d* has a phase of 0° and is input to the port **19***b* of the hybrid coupler **19** via the reception filter **15**B.

(102) A nonlinear distortion distributed to the port **19***d* (reception terminal **9**) from the nonlinear distortion with the phase of 90° input to the port **19***a* is phase-shifted by 90° so as to become a nonlinear distortion with a phase of 180°. A nonlinear distortion distributed to the port **19***d* from the nonlinear distortion with the phase of 0° input to the port **19***b* has its phase maintained at 0°. Therefore, the two nonlinear distortions have opposite phases (180° and 0°) from each other and cancel each other out. In other words, no nonlinear distortion is output to the reception terminal **9**.

(103) On the other hand, a nonlinear distortion distributed to the port **19***c* from the nonlinear distortion with the phase of 90° input to the port **19***a* has its phase maintained at 90°. A nonlinear distortion distributed to the port **19***c* from the nonlinear distortion with the phase of 0° input to the port **19***b* is phase-shifted by 90° so as to become a nonlinear distortion with a phase of 90°. Therefore, the two nonlinear distortions have the same phase (90°) and are synthesized before

being input to the termination resistor **23**. In this embodiment, the transmission signal is reflected by each reception filter **15**, so that the reception filter **15** also receives a strong transmission signal. Thus, a nonlinear distortion also occurs in each reception filter **15**. However, the relationship of the phases of the nonlinear distortions occurring at the reception filter **15**A and the reception filter **15**B is the same as that of the nonlinear distortion occurring at the aforementioned transmission filter **13** and transmitted to each reception filter **15**, so that the nonlinear distortions are absorbed by the termination resistor **23** based on the same and/or similar principle and are not input to the reception terminal **9**.

(104) Accordingly, in this embodiment, the composite filter (splitter **201**) includes a common terminal (antenna terminal **5**), a first terminal (reception terminal **9**), and a second terminal (transmission terminal **7**). In the splitter **1**, two signals having different frequencies within a second passband (transmission band) different from a first passband (reception band) are simultaneously input to the transmission terminal **7**. The splitter **1** includes a first filter system (reception filter system **202**R) that connects the antenna terminal **5** and the reception terminal **9** to each other and a second filter system (transmission filter system **202**T) that connects the antenna terminal **5** and the transmission terminal **7** to each other. The transmission filter system **202**T and the reception filter system **202**R share a first 90° hybrid coupler (hybrid coupler **17**) connected to the antenna terminal **5**. The port **17**a is connected to the antenna terminal **5**. The reception filter system **202**R includes a first filter (reception filter **15**A), a second filter (reception filter **15**B), and a second 90° hybrid coupler (hybrid coupler **19**). The reception filter **15**A is connected to the port **17**c and corresponds to the reception band. The reception filter **15**B is connected to the port **17**d and corresponds to the reception band. The hybrid coupler **19** connects the reception filters **15**A and **15**B to the reception terminal **9**. The port **19**a is connected to the reception filter **15**A. The port **19**b is connected to the reception filter **15**B. The port **19**d is connected to the reception terminal **9**. The transmission filter system **202**T (more specifically, the hybrid coupler **17** shared with the reception filter system **202**R) electrically connects the port **17**c and the port **17**d to the transmission terminal **7** (i.e., the port **17**b from another viewpoint) such that the phase of a signal flowing from the port **17**c to the transmission terminal **7** is relatively shifted by 90° relative to the phase of a signal flowing from the port **17**d to the transmission terminal **7** and that the phase difference between the two signals changes by 90°.

(105) Therefore, it is clear from the operation described above that effects identical or similar to those in the first embodiment are exhibited. For example, a nonlinear distortion occurring in the transmission filter **13** and having a frequency within the reception band is distributed to the two reception filters **15**A and **15**B, and the nonlinear distortions cancel each other out in the hybrid coupler **19**. In other words, the nonlinear distortions to be input to the reception terminal **9** are reduced (i.e., eliminated in theory). As a result, the splitter **1** can have improved reception sensitivity.

(106) In the second embodiment described above, the splitter **201** is an example of a composite filter. The antenna terminal **5** is an example of a common terminal. The reception terminal **9** is an example of a first terminal. The transmission terminal **7** is an example of a second terminal. The reception filter system **202**R is an example of a first filter system. The transmission filter system **202**T is an example of a second filter system. The reception filter **15**A is an example of a first filter. The reception filter **15**B is an example of a second filter. The transmission filter **13** is an example of a third filter. The reception band is an example of a first passband. The transmission band is an example of a second passband. As in the first embodiment, the various types of ports of the hybrid couplers **17** and **19** are examples of a first port to an eighth port.

Third Embodiment

(107) (Configuration of Splitter)

(108) FIG. **6** is a circuit diagram illustrating the configuration of a splitter **301** serving as a composite filter according to a third embodiment.

(109) Briefly speaking, the splitter **301** is a combination of the first embodiment and the second embodiment. It is clear from a comparison between FIG. **1** and FIG. **6** that, in the splitter **301**, the transmission filter system **2**T may be the same as that in the first embodiment. It is clear from a comparison between FIG. **5** and FIG. **6** that, in the splitter **301**, the reception filter system **202**R may be the same as that in the second embodiment.

(110) As mentioned above, the reception filter system **202**R may be the same as that in the second embodiment. However, for the sake of convenience, a hybrid coupler and a termination resistor included in the reception filter system **202**R are given different reference signs from the second embodiment. In detail, in FIG. **6**, a hybrid coupler **21** and ports **21**a to **21**d correspond to the hybrid coupler **19** and the ports **19**a to **19**d in FIG. **5**. In FIG. **6**, a termination resistor **27** corresponds to the termination resistor **23** in FIG. **5**.

(111) The port **17**b of the hybrid coupler **17** may be connected to a termination resistor **25**. The above description of the termination resistor **23** may be applied to the termination resistor **25**.

(112) (Operation of Splitter)

(113) The operation of the splitter **301** is as follows.

(114) The operation of the splitter **301** when a signal (e.g., a transmission signal) is input to the transmission terminal **7** is substantially the same as and/or similar to the operation of the splitter **1** when a signal is input to the transmission terminal **7** in the first embodiment. For example, the signal input to the transmission terminal **7** is output to the antenna terminal **5** from the port **17**a of the hybrid coupler **17**, and is not output from the port **17**b. Unlike the first embodiment, a signal flowing toward the hybrid coupler **17** from each transmission filter **13** also flows through the corresponding reception filter **15** in this embodiment. In this case, a signal (e.g., a transmission signal) outside the reception band is reflected by each reception filter **15**.

(115) The operation of the splitter **301** when a signal (e.g., a reception signal) is input to the antenna terminal **5** is substantially the same as and/or similar to the operation of the splitter **201** when a signal is input to the antenna terminal **5** in the second embodiment. In other words, the signal input to the antenna terminal **5** passes through each reception filter **15** (reception terminal **9**) and is subsequently output to the reception terminal **9** from the port **21**d of the hybrid coupler **21**, but is not output from the port **21**c of the hybrid coupler **21**. Unlike the second embodiment, a signal flowing toward each reception filter **15** from the hybrid coupler **17** also flows through the corresponding transmission filter **13** in this embodiment. In this case, a signal (e.g., a reception signal) outside the transmission band is reflected by each transmission filter **13**. In order to match a transmission filter and a reception filter with each other, a wire to which the transmission filter and the reception filter are connected normally requires a matching circuit (not illustrated). Examples of the matching circuit include a delay line inserted to an intermediate location of the wire at the reception filter side and an inductor having one terminal connected to the wire and another terminal connected to a reference potential section.

(116) The operation of the splitter **301** when two signals (e.g., transmission signals) are input to the transmission terminal **7** and nonlinear distortions (e.g., PIM) occur in the transmission filters **13** will now be described.

(117) The operation from when the two signals are input to the transmission terminal **7** to when the nonlinear distortions occur in the transmission filters **13** is the same as and/or similar to the operation in the first embodiment described with reference to FIG. **4**A. In other words, nonlinear distortions with phases shifted from each other by 90° occur in the transmission filters **13**A and **13**B. In detail, assuming that the phase of the nonlinear distortion occurring in the transmission filter **13**B is 0°, the nonlinear distortion occurring in the transmission filter **13**A has a phase of 90°. As in the first embodiment, at least a portion of each of these nonlinear distortions flows to the hybrid coupler **17** and flows toward the antenna terminal **5** from the port **17**a.

(118) Unlike the first embodiment, the nonlinear distortion having the phase of 90° occurring in the transmission filter **13**A also flows to the reception filter **15**A in this embodiment. The nonlinear

distortion having the phase of 0° occurring in the transmission filter **13**B also flows to the reception filter **15**B. The situation in this case is the same as the situation when the nonlinear distortions occurring in the transmission filters **13** are distributed to the reception filters **15**A and **15**B by the hybrid coupler **17** in the second embodiment. Therefore, as in the second embodiment, the nonlinear distortion (i.e., the nonlinear distortion having the frequency within the reception band) passing through each reception filter **15** is output from the port **21***c* of the hybrid coupler **21**, and is not output to the reception terminal **9** from the port **21***d*.

(119) Accordingly, in this embodiment, the composite filter (splitter **301**) includes a first filter system (transmission filter system **2**T) that is the same as and/or similar to that in the first embodiment. The second filter system (i.e., the reception filter system **202**R, more specifically, the hybrid coupler **21**) electrically connects the port **17***c* and the port **17***d* to the reception terminal **9** (i.e., the port **21***d* from another viewpoint) such that the phase of a signal flowing from the port **17***c* to the reception terminal **9** is relatively shifted by 90° relative to the phase of a signal flowing from the port **17***d* to the reception terminal **9** and that the phase difference between the two signals changes by 90°.

(120) Therefore, it is clear from the operation described above that effects identical or similar to those in the first embodiment are exhibited. For example, a nonlinear distortion occurring in each transmission filter **13** and having a frequency within the reception band is distributed to the two reception filters **15**A and **15**B, and the nonlinear distortions cancel each other out in the hybrid coupler **21**. In other words, the nonlinear distortions to be input to the reception terminal **9** are reduced (i.e., eliminated in theory). As a result, the splitter **1** can have improved reception sensitivity.

(121) The second filter system (reception filter system **202**R) may include a third filter (reception filter **15**A), a fourth filter (reception filter **15**B), and a third 90° hybrid coupler (e.g., the hybrid coupler **21**). The reception filter **15**A may be connected to a third port (port **17***c*) and may correspond to a second passband (reception band). The reception filter **15**B may be connected to a fourth port (port **17***d*) and may correspond to the reception band. A ninth port (port **21***a*) may be connected to the reception filter **15**A. A tenth port (port **21***b*) may be connected to the reception filter **15**B. A twelfth port (port **21***d*) may be connected to the reception terminal.

(122) In this case, for example, since there are two reception filters **15** in addition to the transmission filters **13**, as compared with the first embodiment, the reception filters **15** can also have enhanced power durability. For example, duplexers can be used as the transmission filter **13**A and the reception filter **15**A, and other duplexers can be used as the transmission filter **13**B and the reception filter **15**B.

(123) The splitter **301** may include three termination resistors **23**, **25**, and **27** that are respectively connected to a second port (port **17***b*), a seventh port (port **19***c*), and an eleventh port (port **21***c*).

(124) In this case, for example, unwanted reflection is reduced. More specifically, the termination resistor **23** has already been described. The termination resistor **25** exhibits effects that are the same as and/or similar to those of the termination resistor **23** with regard to a signal input to the antenna terminal **5** and reflected by the transmission filters **13**A and **13**B or the reception filters **15**A and **15**B. PIM caused by two signals input to the transmission terminal **7** is output to the termination resistor **27** from the port **21***c*. Therefore, reflection of PIM can be reduced by adjusting the impedance of the termination resistor **27**.

(125) In the third embodiment described above, the splitter **301** is an example of a composite filter. The antenna terminal **5** is an example of a common terminal. The transmission terminal **7** is an example of a first terminal. The reception terminal **9** is an example of a second terminal. The transmission filter system **2**T is an example of a first filter system. The reception filter system **202**R is an example of a second filter system. The transmission filter **13**A is an example of a first filter. The transmission filter **13**B is an example of a second filter. The reception filter **15**A is an example of a third filter. The reception filter **15**B is an example of a fourth filter. The transmission band is an

example of a first passband. The reception band is an example of a second passband. The hybrid coupler **19** is an example of a second hybrid coupler. The hybrid coupler **21** is an example of a third hybrid coupler. The port **21***a* is an example of a ninth port. The port **21***b* is an example of a tenth port. The port **21***c* is an example of an eleventh port. The port **21***d* is an example of a twelfth port.

(126) This embodiment is different from the first and second embodiments in that the configuration of the splitter **301** does not change even when the transmission filters **13** and the reception filters **15** are interchanged with each other in FIG. **6**. From another viewpoint, the aforementioned correspondence relationship may be inverted, such that the reception terminal **9** may be regarded as an example of a first terminal and the transmission terminal **7** may be regarded as an example of a second terminal. The same applies to the first and second filter systems, the first to fourth filters, the first and second passbands, and the fifth to twelfth ports.

(127) [Configuration Example of Elements in Splitter and Usage Example of Splitter]

(128) The configuration example of elements in the splitter according to each embodiment and the usage example of the splitter will be described below. The configuration example and the usage example to be described below may be applied to any of the embodiments described above, unless otherwise noted. However, for the sake of convenience, splitters according to multiple embodiments may sometimes be represented by a reference sign used in any of the embodiments (mainly the first embodiment). A description may sometimes be provided assuming that the configuration of the splitter **1** according to the first embodiment is used.

(129) (Example of Elastic Wave Filter)

(130) As described above, each transmission filter **13** and/or each reception filter **15** may be an elastic wave filter that utilizes an elastic wave. An example of the configuration of an elastic wave filter will be described below.

(131) (Example of Elastic Wave Element)

(132) FIG. **7** is a plan view schematically illustrating the configuration of an elastic wave resonator **29** (sometimes simply referred to as "resonator **29**" hereinafter) as an example of an elastic wave element included in the elastic wave filter. In the following description, the term "resonator **29**" may be replaced with the term "elastic wave element" so long as there is no contradiction and/or the like.

(133) The resonator **29** may have any of the directions oriented upward or downward. However, for the sake of convenience, an orthogonal coordinate system constituted of a D**1** axis, a D**2** axis, and a D**3** axis is added to the drawing, and a term, such as an upper surface or a lower surface, may be used with the positive side of the D**3** axis being the upper side. The D**1** axis is defined such as to be parallel to the propagation direction of an elastic wave propagating along the upper surface of a piezoelectric member to be described later. The D**2** axis is defined such as to be parallel to the upper surface of the piezoelectric member and orthogonal to the D**1** axis. The D**3** axis is defined such as to be orthogonal to the upper surface of the piezoelectric member.

(134) The resonator **29** is a so-called one-port elastic wave resonator. The resonator **29** outputs a signal input from one of two terminals **28** schematically illustrated at opposite sides of the drawing from the other one of the two terminals **28**. In this case, the resonator **29** converts an electric signal into an elastic wave and converts an elastic wave into an electric signal. It is clear from a description of FIG. **8** to be provided later that each of the terminals **28** may correspond to, for example, any of the antenna terminal **5**, the transmission terminal **7**, the reception terminal **9**, and a reference potential section **11** (to be described later).

(135) The resonator **29** includes, for example, a substrate **31** (i.e., a part of at least an upper surface **31***a* thereof), an excitation electrode **33** located on the upper surface **31***a*, and a pair of reflectors **35** located at opposite sides of the excitation electrode **33**. Multiple resonators **29** may be formed on a single substrate **31**. In other words, the substrate **31** may be shared by multiple resonators **29**. For the sake of convenience, in order to differentiate the multiple resonators **29** sharing the same substrate **31** from each other, a combination (i.e., an electrode section of each resonator **29**) of the

excitation electrode **33** and the pair of reflectors **35** may be expressed as if the combination is a resonator **29** (i.e., as if the resonator **29** does not include the substrate **31**) in the following description.

(136) The substrate **31** has piezoelectricity at least in a region of the upper surface **31***a* provided with the resonator **29**. An example of the substrate **31** is a substrate (i.e., a piezoelectric substrate) entirely made of a piezoelectric member. Another example is a so-called laminated substrate. The laminated substrate includes a substrate (piezoelectric substrate) made of a piezoelectric member having the upper surface **31***a* and a support substrate directly bonded to a surface of the piezoelectric substrate opposite the upper surface **31***a* by using an adhesive or without using an adhesive. The support substrate may have or does not need to have a cavity below the piezoelectric substrate. An example of the substrate **31** having piezoelectricity in the region provided with the resonator **29** is a substrate including a support substrate and a film (piezoelectric film) made of a piezoelectric member or a multilayer film including a piezoelectric film formed partially or entirely over a main surface at the +D**3** side of the support substrate.

(137) A piezoelectric member **31***b* forming the region of the substrate **31** at least provided with the resonator **29** is made of, for example, a mono-crystal having piezoelectricity. Examples of a material forming such a mono-crystal include lithium tantalate (LiTaO.sub.3), lithium niobate (LiNbO.sub.3), and quartz (SiO.sub.2). The cut angle, the planar shape, and various dimensions may be set as appropriate.

(138) The excitation electrode **33** and the reflectors **35** are made of layered conductors provided on the substrate **31**. For example, the excitation electrode **33** and the reflectors **35** are composed of the same material and have the same thickness. The layered conductors are, for example, metal. The metal is, for example, Al or an alloy (Al alloy) with Al as the main component. The Al alloy is, for example, an Al—Cu alloy. Each layered conductor may be made of multiple metallic layers. The thickness of each layered conductor is appropriately set in accordance with the electrical properties and/or the like required in the resonator **29**. For example, the thickness of each layered conductor ranges from 50 nm to 600 nm inclusive.

(139) The excitation electrode **33** is a so-called IDT (interdigital transducer) electrode and includes a pair of comb electrodes **37** (one of which is hatched for better visibility). Each comb electrode **37** includes a bus bar **39**, multiple electrode fingers **41** extending parallel to each other from the bus bar **39**, and multiple dummy electrodes **43** protruding from the bus bar **39** between the multiple electrode fingers **41**. The pair of comb electrodes **37** is disposed such that the electrode fingers **41** engage with each other (in an alternating fashion).

(140) For example, each bus bar **39** substantially has a long shape with a fixed width and extending linearly in the propagation direction (D**1** direction) of the elastic wave. The pair of bus bars **39** is disposed facing each other in a direction (D**2** direction) orthogonal to the propagation direction of the elastic wave. Each bus bar **39** may have varying widths or may be inclined relative to the propagation direction of the elastic wave.

(141) For example, each electrode finger **41** substantially has a long shape with a fixed width and extending linearly in the direction (D**2** direction) orthogonal to the propagation direction of the elastic wave. Each electrode finger **41** may have varying widths. In each comb electrode **37**, the multiple electrode fingers **41** are arranged in the propagation direction of the elastic wave. The multiple electrode fingers **41** of one of the comb electrodes **37** and the multiple electrode fingers **41** of the other comb electrode **37** are basically arranged in an alternating fashion.

(142) A pitch p (e.g., a center-to-center distance between two neighboring electrode fingers **41**) of the multiple electrode fingers **41** is basically fixed within the excitation electrode **33**. The excitation electrode **33** may partially have a unique section with respect to the pitch p. Examples of the unique section include a narrow pitch section where the pitch p is narrower than the majority (e.g., 80 percent or higher), a wide pitch section where the pitch p is wider than the majority, and a thinned-out section where a small number of electrode fingers **41** are substantially thinned out.

(143) In the following, the term "pitch p" refers to the pitch in a section (i.e., the majority of the multiple electrode fingers **41**) excluding the aforementioned unique section, unless otherwise noted. If the pitch varies in the majority of electrode fingers **41** excluding the unique section, an average value of the pitches of the majority of electrode fingers **41** may be used as the value of the pitch p.

(144) The number of electrode fingers **41** may be appropriately set in accordance with the electrical properties and/or the like required in the resonator **29**. Since FIG. **7** is a schematic view, the number of electrode fingers **41** illustrated is small. In actuality, the number of electrode fingers **41** arranged may be larger than the number illustrated. The same applies to strip electrodes **47** of the reflectors **35** to be described later.

(145) The multiple electrode fingers **41** have, for example, the same length. The excitation electrode **33** may be given a so-called apodization treatment in which the length of the multiple electrode fingers **41** (i.e., an engagement width W from another viewpoint) varies depending on the location in the propagation direction. The length and the width of each electrode finger **41** may be appropriately set in accordance with the required electrical properties and/or the like.

(146) For example, the dummy electrodes **43** substantially have a fixed width and protrude in the direction orthogonal to the propagation direction of the elastic wave. The width is, for example, equal to the width of each electrode finger **41**. The multiple dummy electrodes **43** are arranged at a pitch equal to that of the multiple electrode fingers **41**. The tip of each dummy electrode **43** of one of the comb electrodes **37** faces the tip of the corresponding electrode finger **41** of the other comb electrode **37** with a gap therebetween. The excitation electrode **33** does not need to include the dummy electrodes **43**.

(147) The pair of reflectors **35** is located at the opposite sides of the excitation electrode **33** in the propagation direction of the elastic wave. For example, each reflector **35** may be in an electrically floating state or may be supplied with a reference potential. Each reflector **35** is, for example, lattice-shaped. In other words, each reflector **35** includes a pair of bus bars **45** facing each other and multiple strip electrodes **47** extending between the pair of bus bars **45**. The pitch between the multiple strip electrodes **47** and the pitch between the electrode finger **41** and the strip electrode **47** that are adjacent to each other are basically equal to the pitch between the multiple electrode fingers **41**.

(148) When a voltage is applied to the pair of comb electrodes **37**, the multiple electrode fingers **41** apply the voltage to the upper surface **31**a having piezoelectricity, thereby causing the upper surface **31**a to vibrate. Accordingly, an elastic wave (e.g., SAW) propagating in the D**1** direction is excited. The elastic wave is reflected by the multiple electrode fingers **41**. Then, a standing wave substantially having a half wavelength ($\lambda/2$) defined by the pitch p between the multiple electrode fingers **41** occurs. An electric signal occurring in the piezoelectric member **31**b due to the standing wave is extracted by the multiple electrode fingers **41**. In accordance with this principle, the resonator **29** functions as a resonator with a resonant frequency defined by the frequency of the elastic wave having the pitch p as the half wavelength.

(149) Although not particularly illustrated, the resonator **29** may include a protective film (not illustrated) that covers the upper surface **31**a of the substrate **31** from above the excitation electrode **33** and the reflectors **35**. For example, such a protective film is composed of an insulative material, such as SiO.sub.2, and contributes to reducing the probability of corrosion of the excitation electrode **33** and/or the like and/or compensating for a property change occurring due to a temperature change in the resonator **29**. The resonator **29** may also include an additional film overlying the upper surface or the lower surface of the excitation electrode **33** and the reflectors **35** and basically having a shape that is within the excitation electrode **33** and the reflectors **35** in plan view. Such an additional film is composed of an insulative material or a metallic material having acoustic properties different from the material of the excitation electrode **33** and/or the like and contributes to an improved elastic-wave reflection coefficient.

(150) In one representative configuration example, the resonator **29** includes one excitation electrode **33**, as described above. Alternatively, one resonator **29** may include multiple excitation electrodes **33** connected in series. In other words, one resonator **29** may be divided into multiple pieces. In this case, for example, a voltage applied to the resonator **29** is distributed to the multiple excitation electrodes **33**, so that the resonator **29** can have enhanced power durability. Since the vibration of the elastic wave is reduced, a nonlinear distortion is reduced.

(151) (Configuration Example of Splitter Unit Equipped with Elastic Wave Filters)

(152) FIG. **8** is a circuit diagram schematically illustrating the configuration of the splitter unit **3** (i.e., a section including a transmission filter **13** and a reception filter **15** and directly contributing to filtering). In this drawing, only the splitter unit **3** and the terminals of the splitter **1** are illustrated. In other words, the hybrid couplers **17** and **19** and/or the like are not illustrated. Only one of the transmission filters **13**A and **13**B is illustrated.

(153) It is clear from reference signs indicated at the upper left corner of this drawing that each of the comb electrodes **37** is schematically illustrated using a bifurcated fork shape, and that each of the reflectors **35** is expressed with a single line with bent opposite ends. In the following description, the term "splitter unit **3**" may be replaced with the term "splitter **1**" so long as there is no contradiction and/or the like.

(154) As mentioned above, the splitter unit **3** includes the antenna terminal **5**, the transmission terminal **7**, the reception terminal **9**, the transmission filter **13**, and the reception filter **15**. The splitter unit **3** also includes the reference potential section **11**. The reference potential section **11** is a section (conductor) to be supplied with a reference potential, and more specifically, may be a terminal to be supplied with a reference potential or a component (e.g., a shield) other than a terminal.

(155) The antenna terminal **5** and each of the filters (**13** and **15**) are connected to each other via the hybrid coupler **17**. In FIG. **8**, the connection between the antenna terminal **5** and each filter is indicated by a dotted line without the hybrid coupler **17** for the sake of convenience. The transmission terminal **7** and the transmission filter **13** are connected to each other via the hybrid coupler **19**. For the sake of convenience, in the following description, the connection relationship may sometimes be described as if the hybrid couplers **17** and **19** are not provided.

(156) Unlike FIG. **1**, two reception terminals **9** are illustrated in FIG. **8**. This is because, in the configuration illustrated in FIG. **8**, the reception filter **15** is configured to output a balanced signal including two signals with opposite phases. However, the reception filter **15** may output an unbalanced signal including one signal whose signal level changes relative to the reference potential (i.e., only one reception terminal **9** may be provided). In the splitter **1** according to the first embodiment, it is apparent that two reception terminals **9** may be used. In the splitter **201** according to the second embodiment, for example, each reception terminal **9** may be provided with a hybrid coupler **19** (i.e., a total of two hybrid couplers **19** may be provided), so that two reception terminals **9** may be used. The same applies to the splitter **301** according to the third embodiment.

(157) The transmission filter **13** is, for example, a ladder filter constituted by connecting multiple resonators **29** (**29**S and **29**P) into a ladder shape. In other words, the transmission filter **13** includes multiple (or may be one) series resonators **29**S connected in series between the transmission terminal **7** and the antenna terminal **5** and multiple (or may be one) parallel resonators **29**P (parallel arm) that connect the series line (series arm) of the series resonators **29**S to the reference potential section **11**.

(158) The reception filter **15** includes, for example, a resonator **29** and a multi-mode filter **49** (including a double-mode filter, and sometimes referred to as "MM filter **49**" hereinafter). The MM filter **49** includes multiple (i.e., three in the illustrated example) excitation electrodes **33** arranged in the propagation direction of the elastic wave and a pair of reflectors **35** disposed at the opposite sides of the multiple excitation electrodes **33**.

(159) The configuration of the transmission filter **13** and the reception filter **15** described above is

merely an example and may be modified as appropriate. For example, the reception filter **15** may be a ladder filter, similarly to the transmission filter **13**, or the transmission filter **13** may include the MM filter **49**.

(160) In the configuration described above, the multiple resonators **29** (**29**S, **29**P, and the resonator **29** of the reception filter **15**) and the MM filter **49** may be regarded as elastic wave elements. These multiple elastic wave elements may be provided on one substrate **31**, or may be provided distributively on two or more substrates **31**. For example, the multiple resonators **29** constituting the transmission filter **13** may be provided on the same substrate **31**. Likewise, the resonator **29** and the MM filter **49** constituting the reception filter **15** may be provided on the same substrate **31**. The transmission filters **13**A and **13**B may be provided on the same substrate **31** or may be provided on different substrates **31**. Likewise, the reception filters **15**A and **15**B may be provided on the same substrate **31** or may be provided on different substrates **31**. The transmission filter **13** (one or two) and the reception filter **15** (one or two) may be provided on the same substrate **31** or may be provided on different substrates **31**. With respect to one filter, the multiple series resonators **29**S may be provided on a single substrate **31**, and the multiple parallel resonators **29**P may be provided on another single substrate **31**.

(161) (Example of Sharing of Substrate by Elastic Wave Elements)

(162) As mentioned above, the multiple elastic wave elements (such as the elastic wave resonators **29**) may be appropriately disposed on one or more substrates **31**. The following is an example.

(163) FIG. **9** is a plan view illustrating an example of a chip **51** included in the splitter unit **3**. It is clear from the orthogonal coordinate system D**1**-D**2**-D**3** that this drawing illustrates the upper surface **31**a of the substrate **31**. Moreover, this drawing is a schematic diagram expressing each of the resonators **29** (**29**S and **29**P) with a rectangle.

(164) The chip **51** includes the transmission filters **13**A and **13**B made of ladder filters on the same substrate **31**. The chip **51** also includes multiple terminals (**53**I, **53**O, **53**G, and **53**E) electrically connected to a circuit substrate on which the chip **51** is mounted. Two terminals **53**I receive transmission signals. For example, in the splitter **1**, the two terminals **53**I are connected to the ports **19**a and **19**b of the hybrid coupler **19**, and by extension, to the transmission terminal **7**. Two terminals **53**O output filtered transmission signals. For example, in the splitter **1**, the two terminals **53**O are connected to the ports **17**c and **17**d of the hybrid coupler **17**, and by extension, to the antenna terminal **5**. Multiple (three in the illustrated example) terminals **53**G are supplied with a reference potential. A terminal **53**e will be described later.

(165) As mentioned above, the transmission filters **13**A and **13**B may substantially have the same configuration. For example, the transmission filters **13**A and **13**B may have the same number of series resonators **29**S and parallel resonators **29**P, and the resonators **29** corresponding to each other may have the same configuration. For example, the resonators **29** having the same configuration may have the same shape and size, may be composed of the same material, and may have the same crystal orientation of the substrate **31** in the electrode section (i.e., the excitation electrode **33** and the reflectors **35**). However, sections not essential for the filters may be different between the transmission filters **13**A and **13**B. For example, the relative position between the multiple resonators **29** in the orthogonal coordinate system D**1**-D**2**-D**3**, the shape and the length of the wire that connects the resonators **29** to each other, and/or the like may be different between the transmission filters **13**A and **13**B.

(166) Accordingly, the first filter and the second filter (i.e., the transmission filters **13**A and **13**B) may be located in the same piezoelectric member **31**b.

(167) In this case, for example, the aforementioned effect of reducing a nonlinear distortion is enhanced. Details are as follows. In a mode where the transmission filters **13**A and **13**B are provided in different piezoelectric members **31**b (i.e., this mode is also included in the technology according to the present disclosure), the transmission filters **13**A and **13**B may have the same configuration in design but may have different properties due to patterning of the electrodes and/or

a manufacturing error of the piezoelectric member **31***b* and/or the like. As a result, a nonlinear distortion that has occurred in the transmission filter **13**A and a nonlinear distortion that has occurred in the transmission filter **13**B have different intensities and/or different phases. This may possibly reduce the effect of cancelling out the nonlinear distortions. By providing the transmission filters **13**A and **13**B in the same piezoelectric member **31***b*, the probability of an occurrence of such a problem can be reduced.

(168) The transmission filters **13**A and **13**B (according to the first embodiment and/or the like) are described as an example of the first filter and the second filter located in the same piezoelectric member **31***b*. Alternatively, the first filter and the second filter located in the same piezoelectric member **31***b* may be the reception filters **15**A and **15**B (according to the second embodiment and/or the like). As another alternative, the third filter and the fourth filter (i.e., the reception filters **15**A and **15**B according to the third embodiment) may be located in the same piezoelectric member **31***b*.

(169) FIG. **10** is a schematic diagram illustrating an example of sharing of the piezoelectric member **31***b* in the third embodiment.

(170) As illustrated in this drawing, the transmission filters **13**A and **13**B may share a piezoelectric member **31***b* (i.e., a substrate **31** from another viewpoint). In addition, the reception filters **15**A and **15**B may share a piezoelectric member **31***b* (substrate **31**). Accordingly, the transmission filters **13** and the reception filters **15** share the respective piezoelectric members **31***b*, so that the effect of cancelling out nonlinear distortions is enhanced, as mentioned above.

(171) In the illustrated example, the piezoelectric member **31***b* shared by the transmission filters **13**A and **13**B and the piezoelectric member **31***b* shared by the reception filters **15**A and **15**B are different piezoelectric members **31***b* (i.e., different substrates **31**). In this case, for example, the probability of an increase in size of each substrate **31** (i.e., each chip component from another viewpoint) is reduced. Although the following description is redundant with the above description, the four filters may all be provided on a single substrate **31** (piezoelectric member **31***b*), unlike the illustrated example. Of the four filters, only the transmission filters **13**A and **13**B may share a piezoelectric member **31***b*, or only the reception filters **15**A and **15**B may share a piezoelectric member **31***b*.

(172) (Example of Termination Resistor)

(173) Referring back to FIG. **9**, the termination resistor **23** may be a conductive pattern formed on a circuit substrate, as mentioned above. FIG. **9** illustrates an example. In this example, the termination resistor **23** is a conductive pattern formed on the upper surface **31***a* of the substrate **31**. However, a specific shape of the conductive pattern is omitted from the drawing, and an example of a region where the conductive pattern is disposed is schematically expressed with a rectangle. The conductive pattern may have an appropriate shape and extend in, for example, a meandering manner. The termination resistor **23** is connected to the terminal **53***e* and the terminals **53**G that are to be supplied with a reference potential. The terminal **53***e* is connected to the port **19***c* of the hybrid coupler **19**.

(174) Accordingly, the termination resistor **23** may be located in the piezoelectric member **31***b* where at least one of the first filter, the second filter, and the third filter (as well as the fourth filter) (i.e., the transmission filters **13**A and **13**B as the first and second filters in the illustrated example) is located.

(175) In this case, for example, the termination resistor **23** can be formed at the same time as when the electrode section of the filter is formed, so that cost reduction can be expected. By utilizing photolithography, the accuracy for forming the electrode section increases, thereby achieving enhanced filter properties.

(176) FIG. **9** illustrates a mode where the piezoelectric member **31***b* provided with the termination resistor **23** is provided with the transmission filters **13**A and **13**B. However, it is clear from the previous description that the piezoelectric member **31***b* provided with the termination resistor **23** may be the piezoelectric member **31***b* where the reception filter **15** according to the first

embodiment (or the reception filters **15**A and/or **15**B according to the third embodiment) is located in addition to or in place of the transmission filters **13**A and **13**B, the piezoelectric member **31**b where only one of the transmission filters **13**A and **13**B is located, the piezoelectric member **31**b where only one of the transmission filters **13** according to the second embodiment is located, or the piezoelectric member **31**b where one of or each of the two reception filters **15**A and **15**B according to the second embodiment is located in place of or in addition to the one transmission filter **13**.

(177) Although the above description is provided with reference to the termination resistor **23** as an example, the above description may be applied to the termination resistors **25** and **27** according to the third embodiment so long as there is no contradiction and/or the like. For example, in the third embodiment, at least one of the termination resistors **23**, **25**, and **27** may be located in the piezoelectric member **31**b where at least one of the first to fourth filters (i.e., the transmission filters **13**A and **13**B and the reception filters **15**A and **15**B) is located.

(178) (Structural Example of Splitter)

(179) The splitter may have an appropriate structure. Three examples are described below. For the sake of convenience, the reference sign for the splitter **201** according to the second embodiment is given. However, the structural example described below may be applied to the other embodiments.

(180) FIG. **11**A is a plan view illustrating an example of the structure of the splitter **201**.

(181) In this example, each of the elements (**13**, **15**A, **15**B, **17**, **19**, and **23**) constituting the splitter **201** is a packaged electronic component. These electronic components are mounted on a circuit substrate **61** and are connected to one another by a wire **63** of the circuit substrate **61**. Although not particularly illustrated, the circuit substrate **61** may have mounted thereon another electronic component connected to the splitter **201** and/or an electronic component not connected to the splitter **201**. In other words, the splitter **201** may be a part of a printed circuit board (i.e., a printed wiring board and an electronic component mounted on the printed wiring board). Accordingly, in the splitter **201**, the elements other than the splitter unit **3** may be external electronic components of the splitter unit **3** instead of being packaged together with the splitter unit **3**.

(182) FIG. **11**B is a plan view illustrating another example of the structure of the splitter **201**.

(183) In this example, the elements (**13**, **15**A, **15**B, **17**, **19**, and **23**) constituting the splitter **201** are packaged together into a single electronic component. For example, the splitter **201** includes a circuit substrate **65** having the elements mounted thereon. The transmission filter **13** and the reception filters **15**A and **15**B may be in, for example, a bare chip state or a wafer level packaged state. The other elements may be in a packaged state or may be in a non-packaged state. The multiple elements constituting the splitter **201** are sealed together by using resin (not illustrated) covering the upper surface of the circuit substrate **65**. The circuit substrate **65** is provided with the antenna terminal **5**, the transmission terminal **7**, and the reception terminal **9** at appropriate locations.

(184) FIG. **11**C is a plan view illustrating yet another example of the structure of the splitter **201**.

(185) In this example, the elements (**13**, **15**A, **15**B, **17**, **19**, and **23**) constituting the splitter **201** are packaged together into a single electronic component, similarly to the example in FIG. **11**B. For example, the splitter **201** includes a circuit substrate **67** having the elements mounted thereon. However, one or more of the elements (i.e., all of the elements other than the splitter unit **3** in the illustrated example) are contained within the circuit substrate **67**. In other words, each element is formed by providing a conductor inside the circuit substrate **67** or on the surface thereof.

(186) Each of the circuit substrates **61**, **65**, and **67** may be of any of known various types. For example, each of these substrates may be an LTCC (low temperature co-fired ceramic) substrate, an HTCC (high temperature co-fired ceramic) substrate, or an organic substrate.

(187) The structural examples in FIG. **11**A to FIG. **11**C may be combined. For example, of multiple elements (**17**, **19**, and **23**) other than the splitter unit **3**, one or more elements may be packaged together with the splitter unit **3**, and the remaining one or more elements may be external elements. If the multiple elements (**17**, **19**, and **23**) other than the splitter unit **3** are entirely or partially

packaged together with the splitter unit **3**, the packaged one or more of the multiple elements may be mounted on the circuit substrate, whereas the remaining one or more elements may be contained within the circuit substrate. Furthermore, for example, one or more of the elements may be contained within the circuit substrate **61** having an external element mounted thereon.

(188) (Communication Device)

(189) FIG. **12** is a block diagram illustrating a relevant part of a communication device **151** as a usage example of the splitter **1**. The communication device **151** performs wireless communication by using a radio wave, and includes, for example, the splitter **1**. In this case, only the transmission filters **13** and the reception filter **15** of the splitter **1** are illustrated. The two transmission filters **13**A and **13**B are expressed as a single transmission filter **13**.

(190) In the communication device **151**, a transmission information signal TIS containing information to be transmitted undergoes modulation and frequency raise (i.e., conversion to a high frequency signal having a carrier frequency) by an RF-IC (radio frequency integrated circuit) **153**, so as to become a transmission signal TS. The transmission signal TS undergoes removal of an unwanted component outside the transmission passband therefrom by a bandpass filter **155**, is amplified by an amplifier **157**, and is input to the splitter **1** (transmission terminal **7**). Then, the splitter **1** (transmission filter **13**) removes an unwanted component outside the transmission passband from the input transmission signal TS and outputs the transmission signal TS having undergone the removal to an antenna **159** from the antenna terminal **5**. The antenna **159** converts the input electric signal (transmission signal TS) into a wireless signal (radio wave) and transmits the wireless signal.

(191) In the communication device **151**, the wireless signal (radio wave) received by the antenna **159** is converted into an electric signal (reception signal RS) by the antenna **159**, and the electric signal (reception signal RS) is input to the splitter **1** (antenna terminal **5**). The splitter **1** (reception filter **15**) removes an unwanted component outside the reception passband from the input reception signal RS and outputs the reception signal RS from the reception terminal **9** to an amplifier **161**. The output reception signal RS is amplified by the amplifier **161**, and undergoes removal of an unwanted component outside the reception passband by a bandpass filter **163**. Then, the reception signal RS undergoes frequency reduction and demodulation by the RF-IC **153**, so as to become a reception information signal RIS.

(192) Each of the transmission information signal TIS and the reception information signal RIS may be a low frequency signal (baseband signal) containing appropriate information, and is, for example, an analog audio signal or a digitalized signal. The passband for the wireless signal may be set as appropriate, and may be a relatively high frequency passband (e.g., equal to or higher than 5 GHz). The modulation method may be phase modulation, amplitude modulation, frequency modulation, or a combination of two or more of these methods. Although a direct conversion system is illustrated in FIG. **12** as a circuit system, the circuit system may be an appropriate system other than the direct conversion system and may be, for example, a double super-heterodyne system. FIG. **12** schematically illustrates the relevant part alone and may have a low-pass filter, an isolator, and/or the like added to an appropriate location or locations or may have the amplifiers and/or the like at modified locations.

(193) The technology according to the present disclosure is not limited to the above embodiments and may be implemented in various modes.

(194) The composite filter is not limited to a duplexer. For example, the composite filter may include two transmission filter systems with different passbands as the first filter system and the second filter system. From another viewpoint, a process of simultaneously inputting two signals having different frequencies within the first passband to the first terminal and a process of simultaneously inputting two signals having different frequencies within the second passband different from the first passband to the second terminal may both be performed. The composite filter may include another filter system in addition to the first filter system and the second filter

system. For example, the composite filter may be a triplexer including three filter systems or may be a quadplexer including four filter systems.

REFERENCE SIGNS

(195) **1** splitter (composite filter) **2**T transmission filter system (first filter system) **2**R reception filter system (second filter system) **5** antenna terminal (common terminal) **7** transmission terminal (first terminal or second terminal) **9** reception terminal (second terminal or first terminal) **13** transmission filter (first filter, second filter, third filter, or fourth filter) **13**A transmission filter (first filter or third filter) **13**B transmission filter (second filter or fourth filter) **15** reception filter (first filter, second filter, third filter, or fourth filter) **15**A reception filter (first filter or third filter) **15**B reception filter (second filter or fourth filter) **17** 90° hybrid coupler **17***a* port (first port) **17***b* port (second port) **17***c* port (third port) **17***d* port (fourth port) **19** 90° hybrid coupler **19***a* port (fifth port) **19***b* port (sixth port) **19***c* port (seventh port) **19***d* port (eighth port) **21** 90° hybrid coupler **21***a* port (ninth port) **21***b* port (tenth port) **21***c* port (eleventh port) **21***d* port (twelfth port)

Claims

1. A composite filter that performs at least one of a process of simultaneously inputting two signals having different frequencies within a first passband to a first terminal and a process of simultaneously inputting two signals having different frequencies within a second passband to a second terminal, the composite filter comprising: a common terminal; the first terminal; the second terminal; a first filter system connecting the common terminal and the first terminal to each other; a second filter system connecting the common terminal and the second terminal to each other, wherein the second filter system comprises: a third filter corresponding to the second passband and connecting a second port and the second terminal to each other; and a first 90° hybrid coupler connected to the common terminal that is shared by the first filter system and the second filter system, wherein the first 90° hybrid coupler comprises a first port that is connected to the common terminal, the second port, a third port electrically connected to the first port and the second port, and a fourth port electrically connected to the first port and the second port, the fourth port being a port to which a signal with a phase shifted by 90° relative to a phase of a signal distributed from the first port to the third port is distributed from the first port, and wherein the first filter system comprises: a first filter connected to the third port and corresponding to the first passband; a second filter connected to the fourth port and corresponding to the first passband; and a second 90° hybrid coupler connecting the first filter and the second filter to the first terminal, wherein the second 90° hybrid coupler comprises: a fifth port, a sixth port, a seventh port electrically connected to the fifth port that is connected to the first filter and the sixth port that is connected to the second filter, an eighth port electrically connected to the fifth port, the sixth port and the first terminal, the eighth port being a port to which a signal with a phase shifted by 90° relative to a phase of a signal distributed from the fifth port to the seventh port is distributed from the fifth port, and a termination resistor connected to the seventh port, wherein the termination resistor is located at a piezoelectric member where at least one of the first filter, the second filter, and the third filter is located wherein the second filter system electrically connects the third port and the fourth port to the second terminal and relatively shifts a phase of a signal flowing from the third port toward the second terminal by 90° relative to a phase of a signal flowing from the fourth port toward the second terminal to change a phase difference between the two signals by 90°.

2. The composite filter according to claim 1, wherein each of the first filter and the second filter is a piezoelectric filter, the first filter and the second filter being located at a single piezoelectric member.

3. A communication device comprising: the composite filter according to claim 1; an antenna connected to the common terminal; and an integrated circuit element connecting the first terminal and the second terminal to each other and performing at least one of the process of simultaneously

inputting two signals having different frequencies within the first passband to the first terminal and the process of simultaneously inputting two signals having different frequencies within the second passband to the second terminal.

4. A composite filter that performs at least one of a process of simultaneously inputting two signals having different frequencies within a first passband to a first terminal and a process of simultaneously inputting two signals having different frequencies within a second passband to a second terminal, the composite filter comprising: a common terminal; the first terminal; the second terminal; a first filter system connecting the common terminal and the first terminal to each other; a second filter system connecting the common terminal and the second terminal to each other; and a first 90° hybrid coupler connected to the common terminal that is shared by the first filter system and the second filter system, wherein the first 90° hybrid coupler comprises a first port that is connected to the common terminal, a second port, a third port electrically connected to the first port and the second port, and a fourth port electrically connected to the first port and the second port, the fourth port being a port to which a signal with a phase shifted by 90° relative to a phase of a signal distributed from the first port to the third port is distributed from the first port, wherein the first filter system comprises: a first filter connected to the third port and corresponding to the first passband; a second filter connected to the fourth port and corresponding to the first passband; and a second 90° hybrid coupler connecting the first filter and the second filter to the first terminal, wherein the second 90° hybrid coupler comprises: a fifth port, a sixth port, a seventh port electrically connected to the fifth port that is connected to the first filter and the sixth port that is connected to the second filter, and an eighth port electrically connected to the fifth port, the sixth port and the first terminal, the eighth port being a port to which a signal with a phase shifted by 90° relative to a phase of a signal distributed from the fifth port to the seventh port is distributed from the fifth port, wherein the second filter system electrically connects the third port and the fourth port to the second terminal and relatively shifts a phase of a signal flowing from the third port toward the second terminal by 90° relative to a phase of a signal flowing from the fourth port toward the second terminal to change a phase difference between the two signals by 90° wherein the second filter system comprises: a third filter connected to the third port and corresponding to the second passband, a fourth filter connected to the fourth port and corresponding to the second passband, and a third 90° hybrid coupler connecting the third filter and the fourth filter to the second terminal, wherein third 90° hybrid coupler comprises: a ninth port that is connected to the third filter, a tenth port that is connected to the fourth filter, an eleventh port electrically connected to the ninth port and the tenth port, and a twelfth port electrically connected to the ninth port, the tenth port and the second terminal, the twelfth port being a port to which a signal with a phase shifted by 90° relative to a phase of a signal distributed from the ninth port to the eleventh port is distributed from the ninth port.

5. The composite filter according to claim 4, wherein at least one of conditions is satisfied, the conditions comprising: a condition in which each of the first filter and the second filter is a piezoelectric filter, the first filter and the second filter being located at a single piezoelectric member; and a condition in which each of the third filter and the fourth filter is a piezoelectric filter, the third filter and the fourth filter being located at a single piezoelectric member.

6. The composite filter according to claim 4, further comprising: three termination resistors respectively connected to the second port, the seventh port, and the eleventh port.

7. The composite filter according to claim 6, wherein at least one of the three termination resistors is located at a piezoelectric member where at least one of the first filter, the second filter, the third filter, and the fourth filter is located.

8. A communication device comprising: the composite filter according to claim 4; an antenna connected to the common terminal; and an integrated circuit element connecting the first terminal and the second terminal to each other and performing at least one of the process of simultaneously inputting two signals having different frequencies within the first passband to the first terminal and

the process of simultaneously inputting two signals having different frequencies within the second passband to the second terminal.