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(54) **HIGH-FREQUENCY AMPLIFIER CIRCUIT**

(52) **U.S. Cl.**

(71) Applicant: **Murata Manufacturing Co., Ltd.**,
Kyoto (JP)

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(72) Inventor: **Hiroyuki HIROOKA**, Kyoto (JP)

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(57) **ABSTRACT**

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A high-frequency amplifier circuit (10) includes a high-frequency amplifier (101) and a bias circuit (20). The bias circuit (20) includes bias control elements (102, 103). An emitter of the bias control element (102) is connected to a base of the amplifier (101) via a resistor (201). An emitter of the bias control element (103) is connected to a collector of a switch element (104) via a resistor (203). The switch element (104) is a common emitter. A resistor (204) is connected between the emitter of the bias control element (102) and the emitter of the bias control element (103). A control voltage (V_{CTL}) is applied to bases of the bias control elements (102, 103). A bias current adjustment voltage (V_{LIN}) corresponding to an operation mode is applied to a base of the switch element (104).

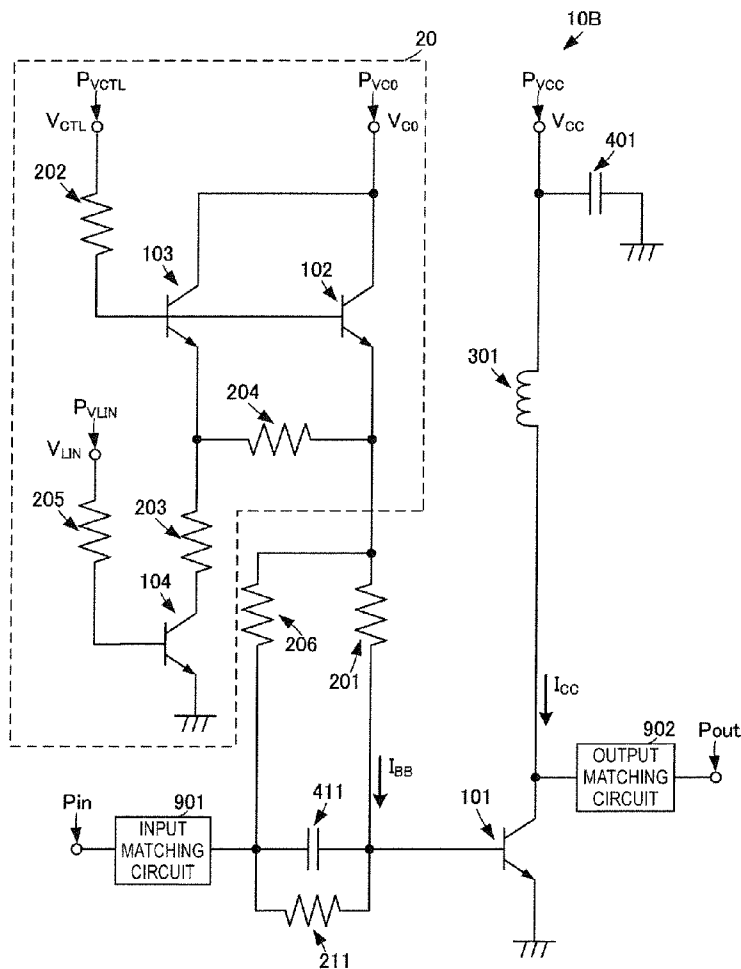


FIG. 1

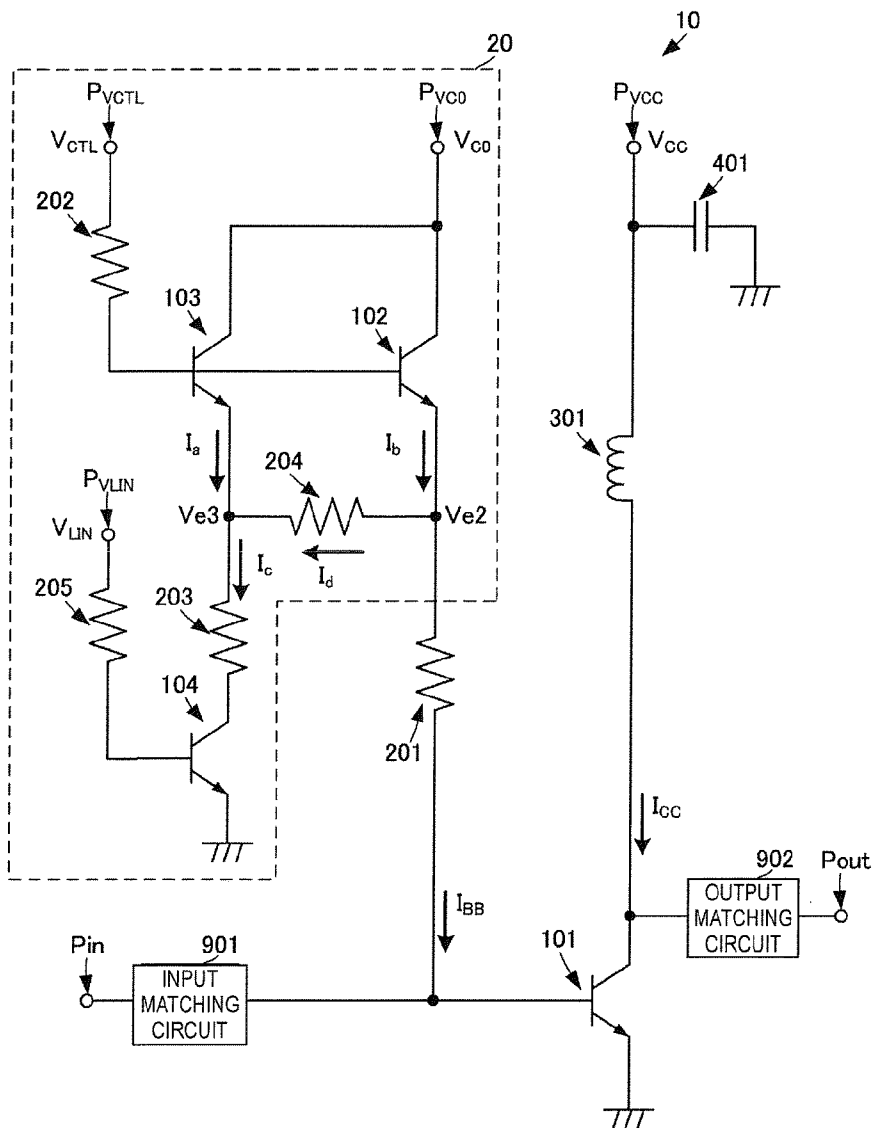


FIG. 2

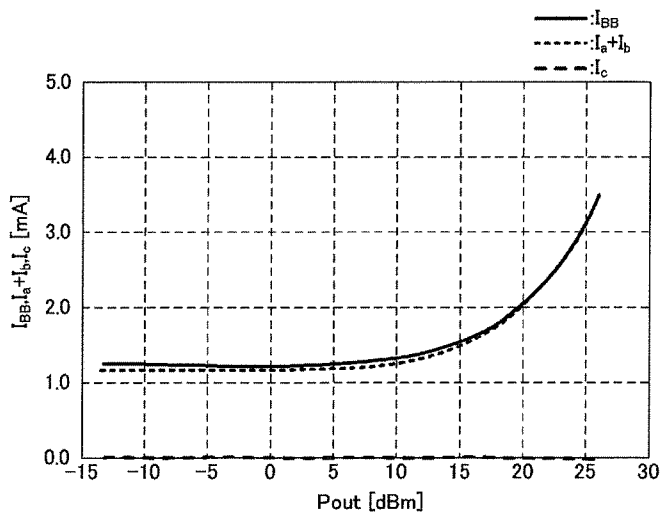
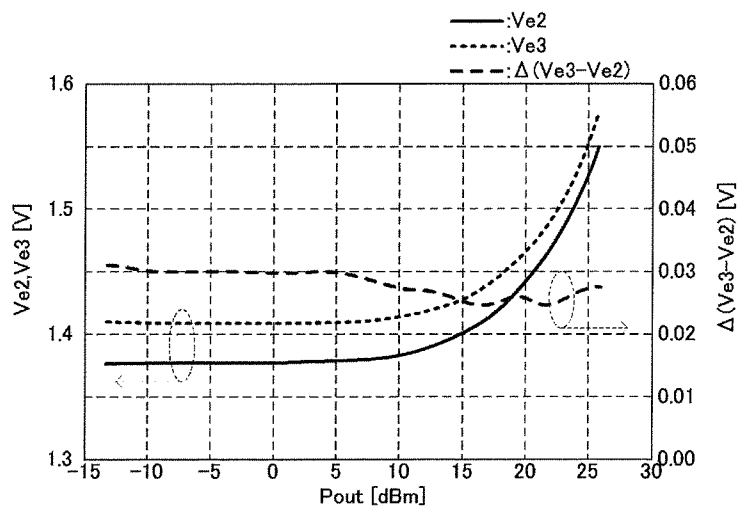


FIG. 3

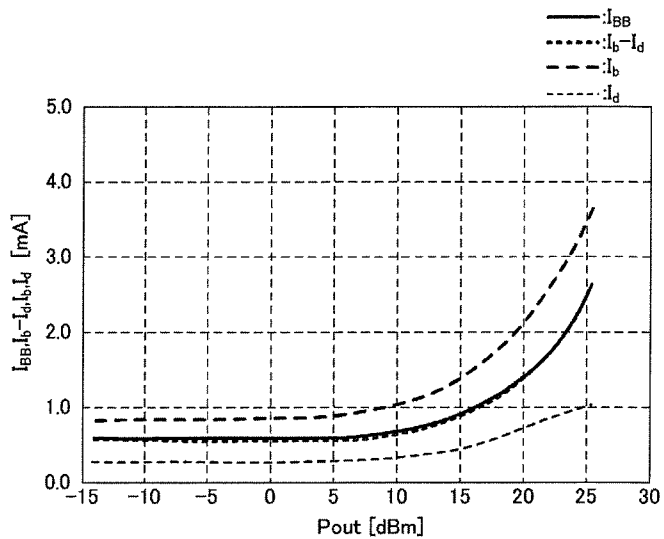
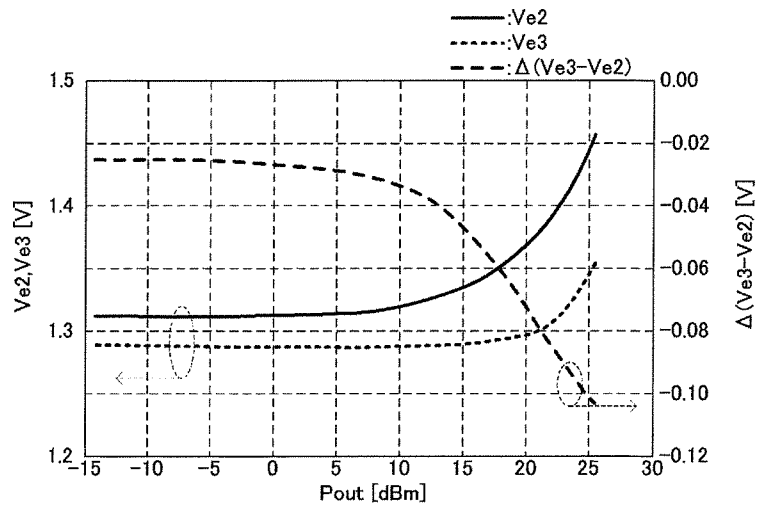


FIG. 4

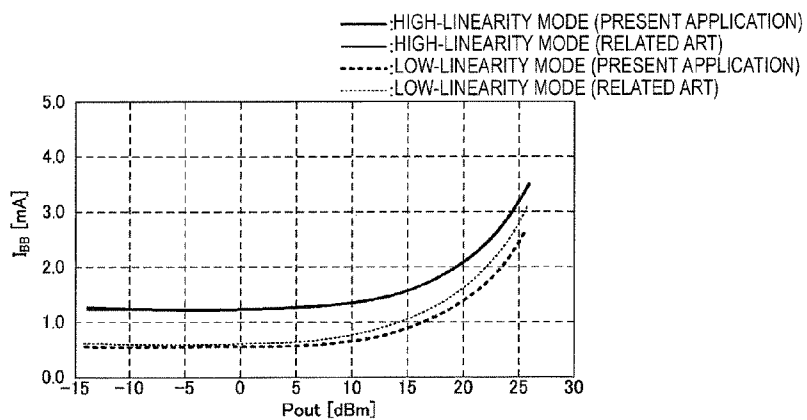


FIG. 5

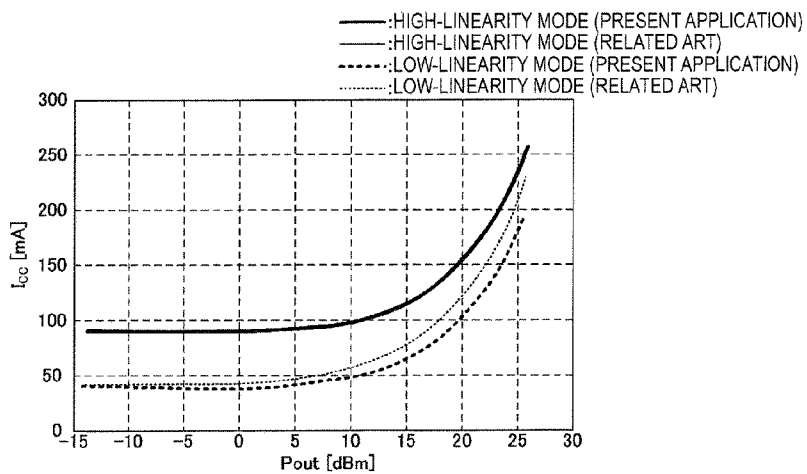


FIG. 6

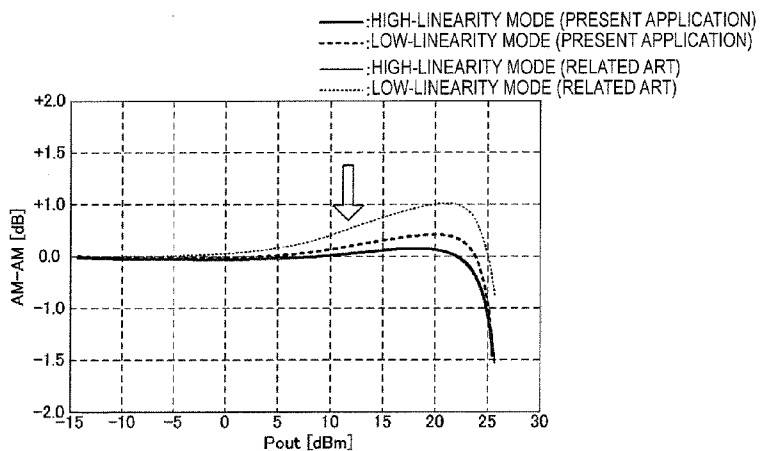


FIG. 7

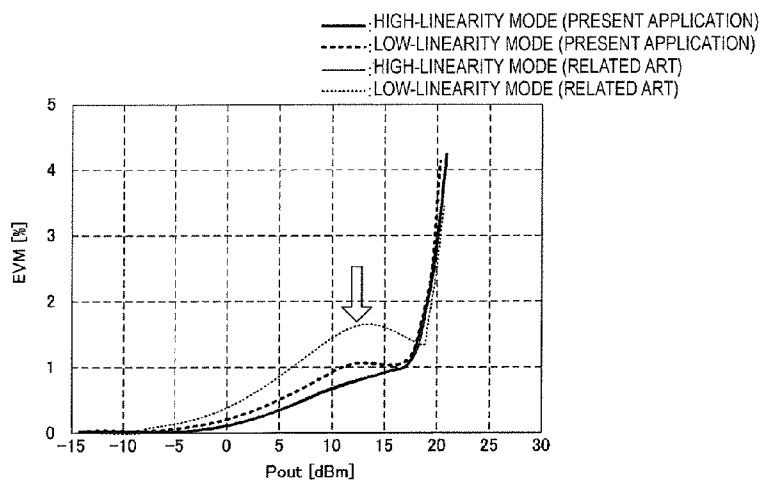


FIG. 8

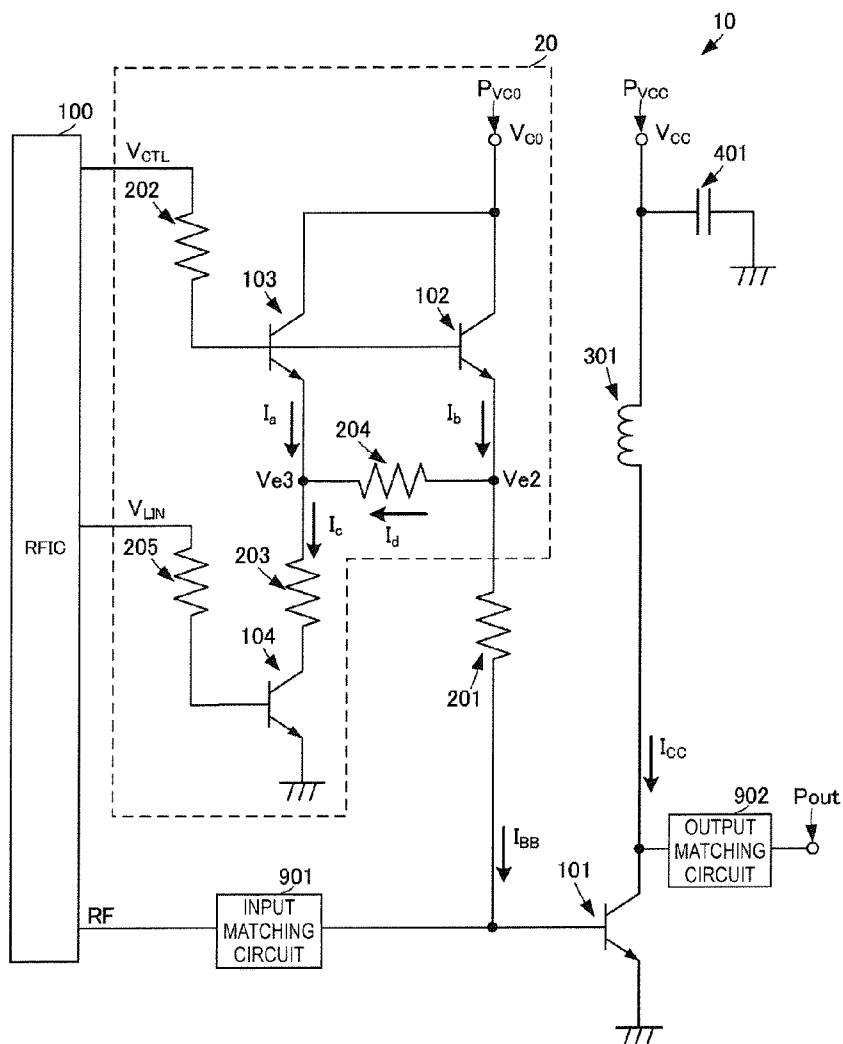


FIG. 9

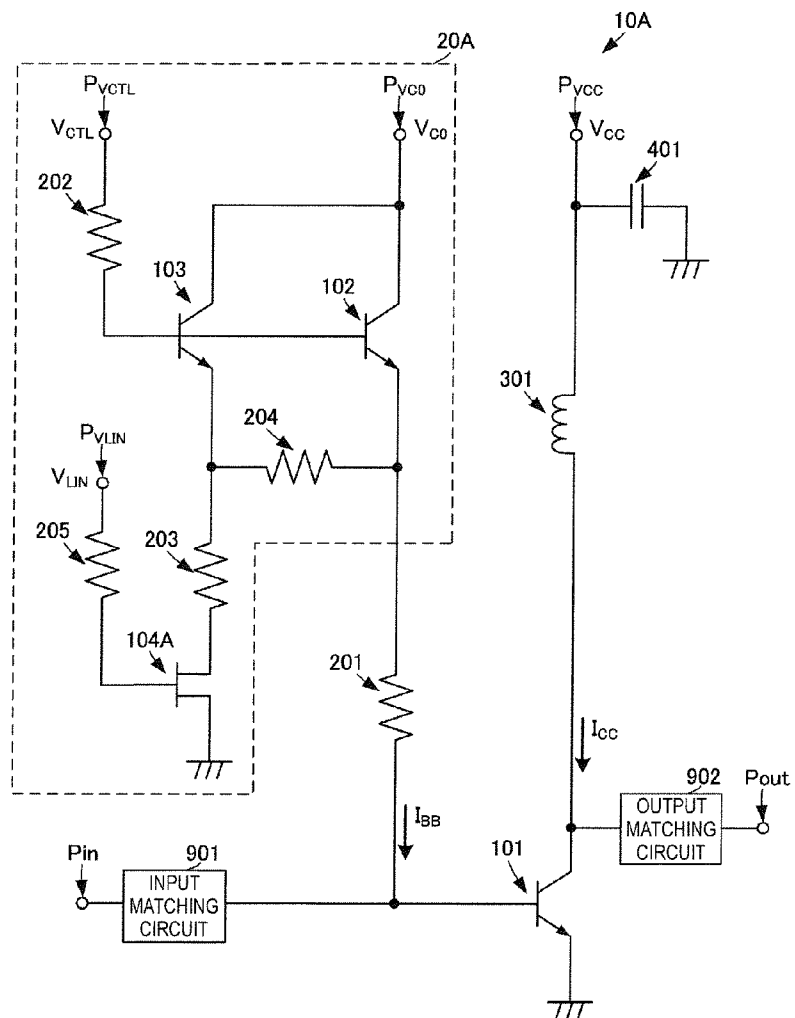


FIG. 10

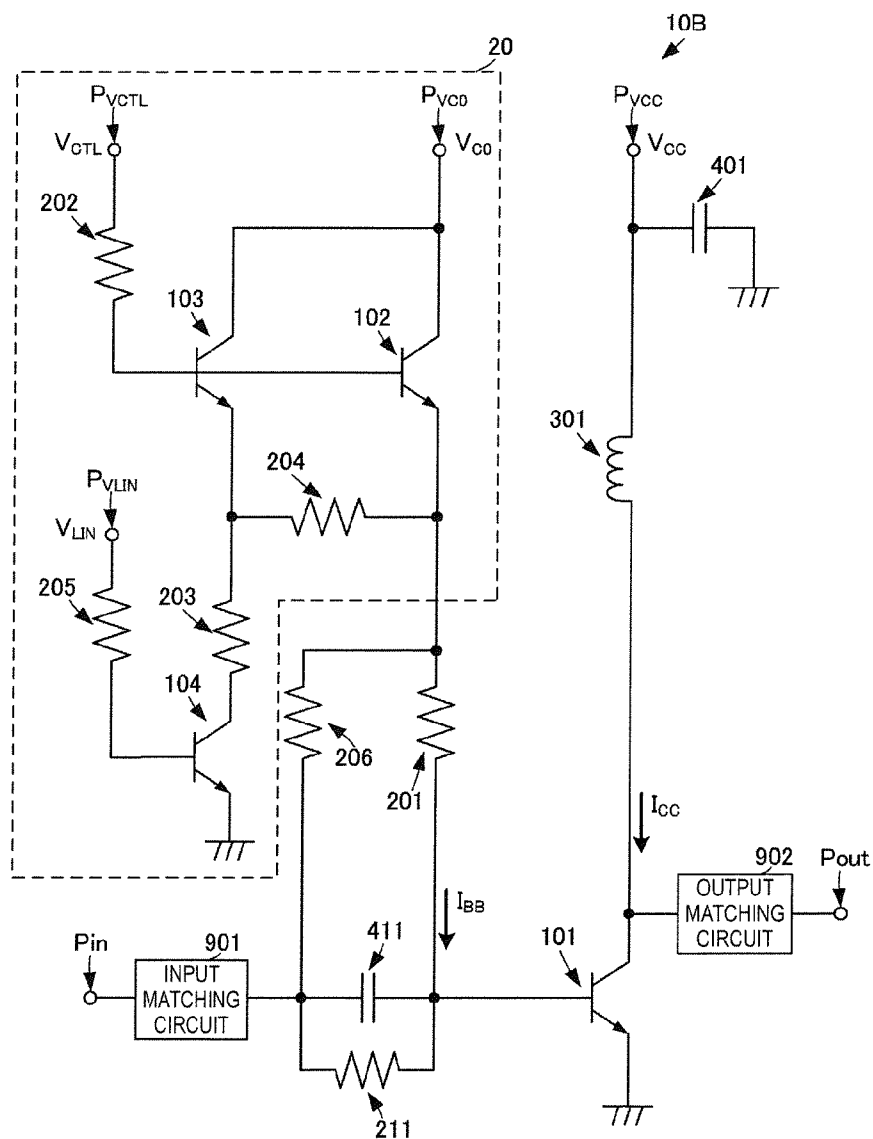


FIG. 11

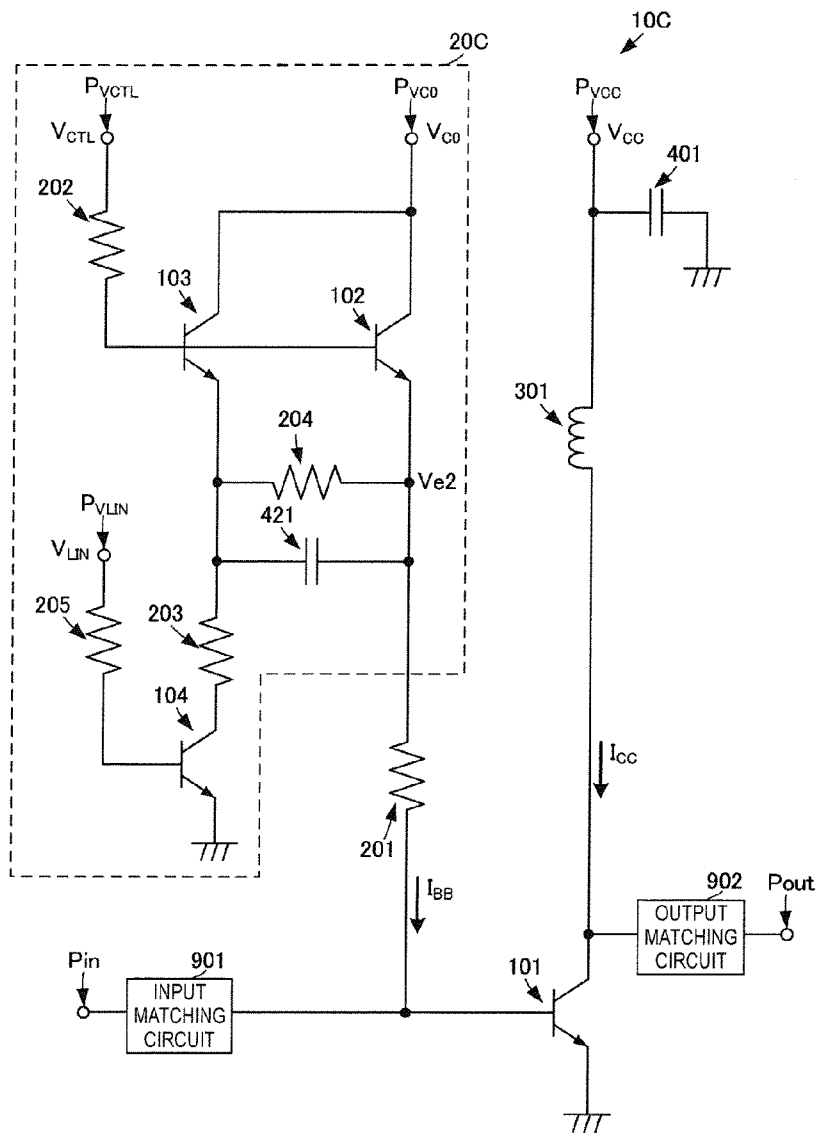


FIG. 12

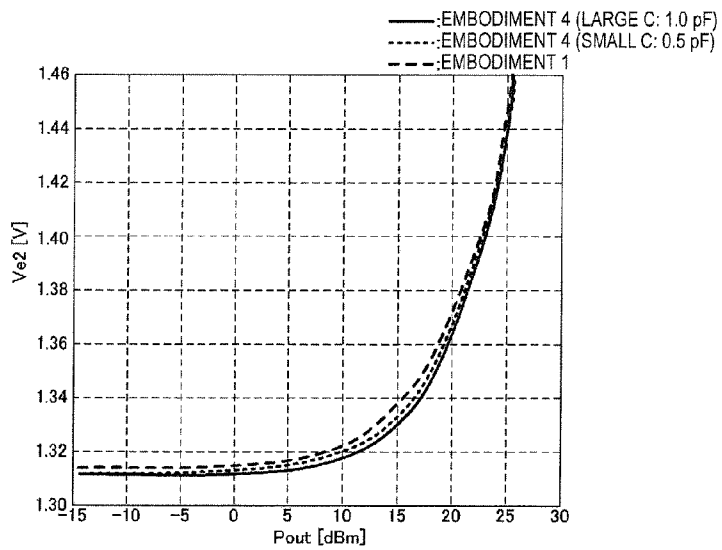


FIG. 13

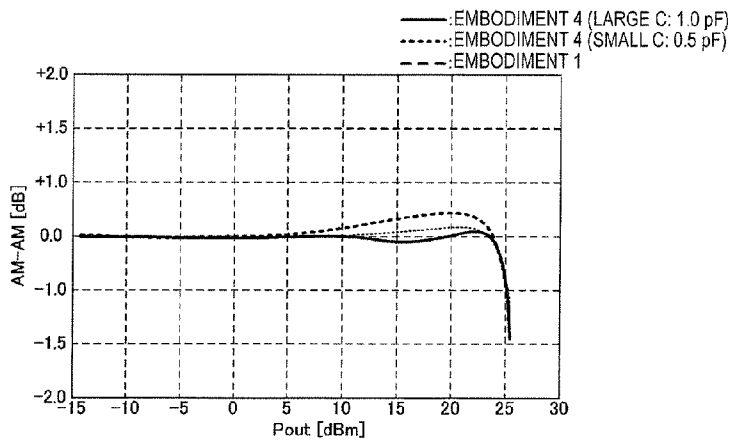


FIG. 14

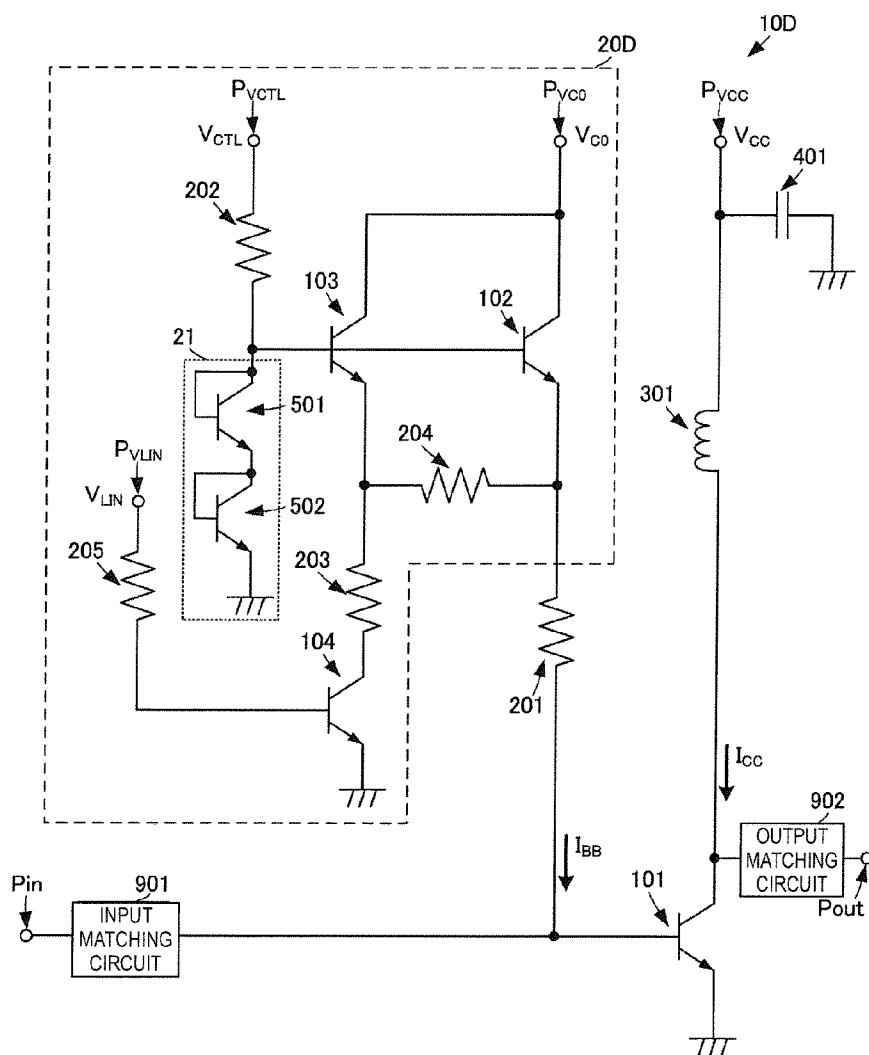
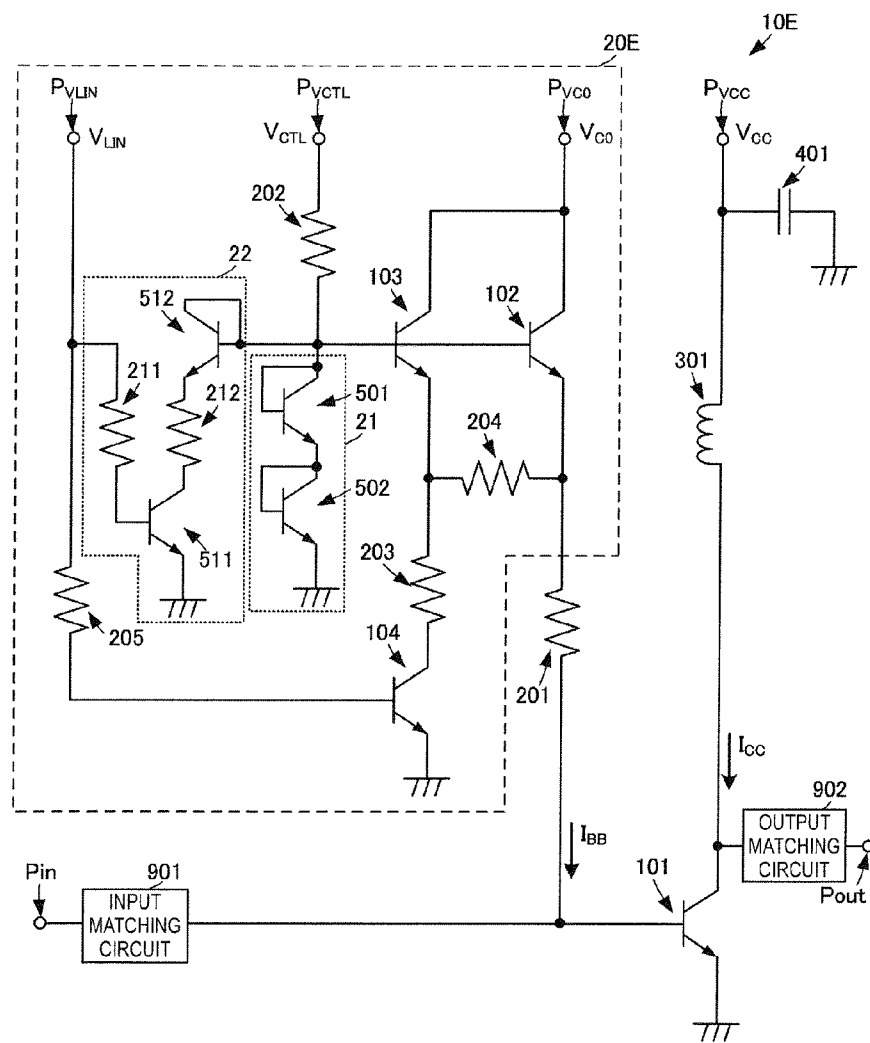


FIG. 15



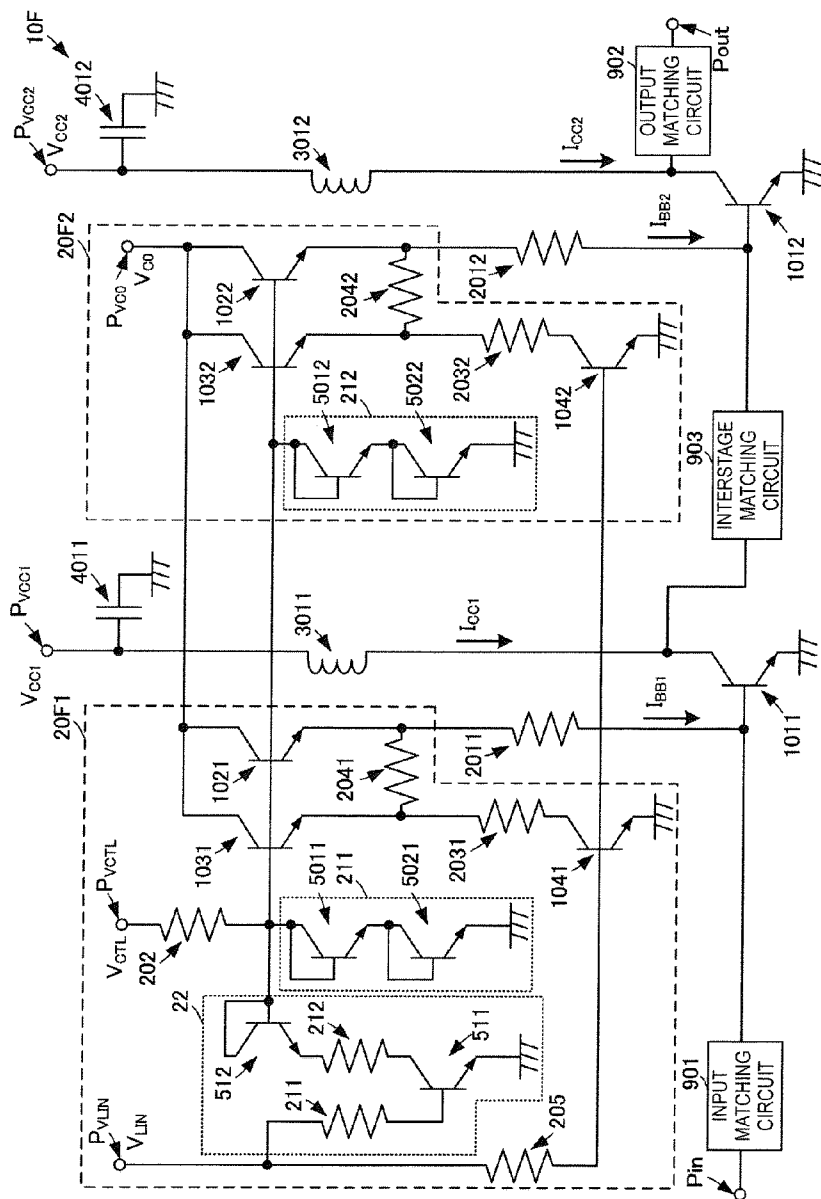


FIG. 16

FIG. 17

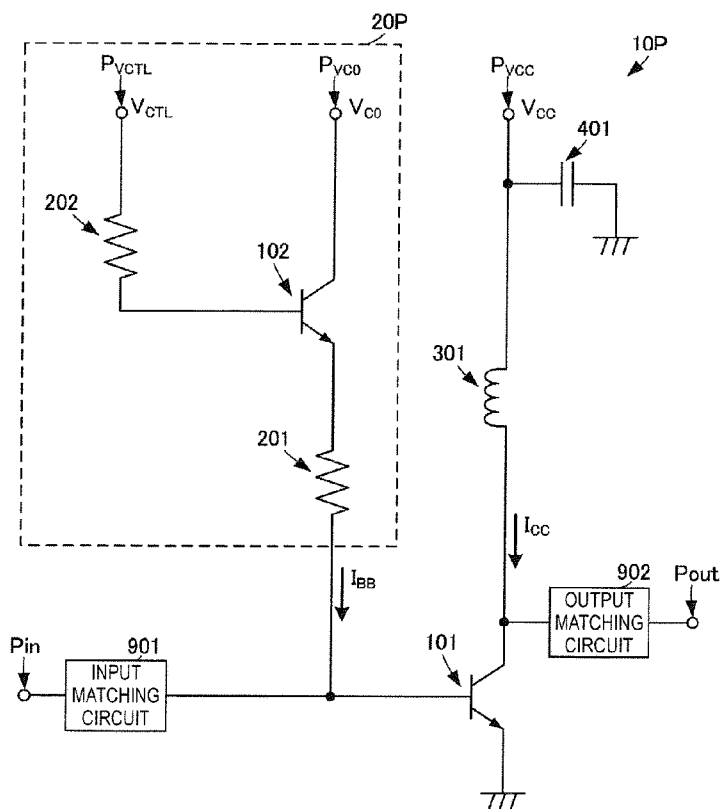


FIG. 18

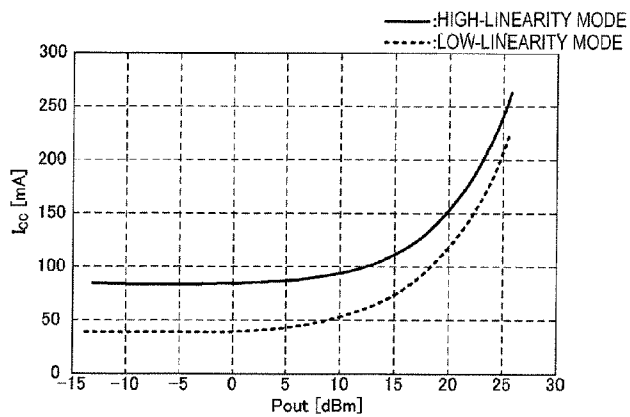


FIG. 19

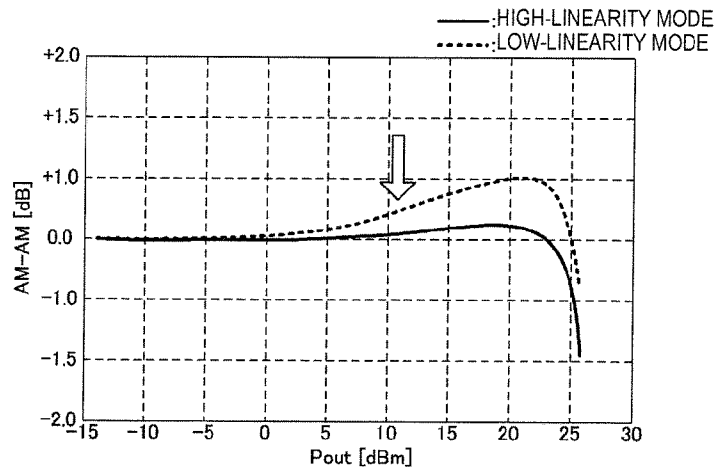
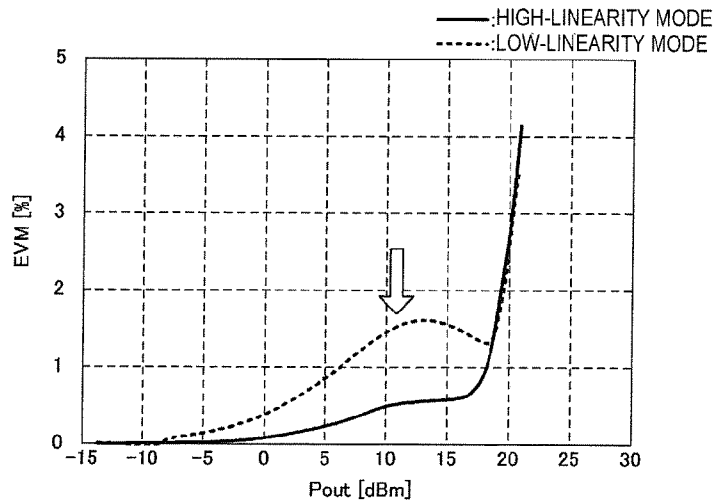


FIG. 20



HIGH-FREQUENCY AMPLIFIER CIRCUIT

BRIEF SUMMARY

BACKGROUND

[0001] 1. Technical Field

[0002] The present disclosure relates to high-frequency amplifier circuits that amplify and then output an input high-frequency signal.

[0003] 2. Background Art

[0004] A variety of high-frequency amplifier circuits are used in wireless communication terminals. Among such high-frequency amplifier circuits, there are high-frequency amplifier circuits configured to be able to change among a plurality of operation modes. For example, a high-frequency amplifier circuit as described in Patent Document 1 is used. FIG. 17 is a circuit diagram of a typical high-frequency amplifier circuit as described in Patent Document 1.

[0005] A high-frequency amplifier circuit 10P of the related art includes an amplifier 101 composed of an npn transistor and a bias determiner 20P. An emitter of the amplifier 101 is grounded. A base of the amplifier 101 is connected via an input matching circuit 901 to an RF input terminal Pin through which a high-frequency signal is input. A collector of the amplifier 101 is connected via an output matching circuit 902 to an RF output terminal Pout through which an amplified high-frequency signal is output.

[0006] The collector of the amplifier 101 is connected to a driving voltage application terminal P_{VCC} via a coil 301 and a direct-current driving voltage V_{CC} is applied to the collector of the amplifier 101 from the driving voltage application terminal P_{VCC} . A connection point between the driving voltage application terminal P_{VCC} and the coil 301 is grounded by a capacitor 401.

[0007] The bias determiner 20P includes a bias control element 102 composed of an npn transistor. An emitter of the bias control element 102 is connected via a resistor 201 to the base of the amplifier 101 used for high-frequency amplification. A bias driving voltage application terminal P_{VCO} is connected to a collector of the bias control element 102 and a direct-current bias driving voltage V_{CO} is applied to the collector of the bias control element 102 from the bias driving voltage application terminal P_{VCO} .

[0008] A control voltage input terminal P_{VCTL} is connected via a resistor 202 to a base of the bias control element 102 and a direct-current control voltage V_{CTL} is applied to the base of the bias control element 102 from the control voltage input terminal P_{VCTL} .

[0009] In this high-frequency amplifier circuit 10P of the related art, a control voltage V_{CTL} corresponding to an operation mode is applied to the base of the bias control element 102. In a low linearity mode, the control voltage V_{CTL} is made low. As a result, a base current I_{BB} supplied to the amplifier 101 used for high-frequency amplification from the bias control element 102 becomes low, the level of an output high-frequency signal can be lowered and power consumption can be suppressed. In a high linearity mode, the control voltage V_{CTL} is made high. As a result, the base current I_{BB} supplied to the amplifier 101 used for high-frequency amplification from the bias control element 102 can be made high and the level of an output high-frequency signal can be made high.

[0010] Patent Document 1: Japanese Unexamined Patent Application Publication No. 11-330866

[0011] However, in the high-frequency amplifier circuit 10P of the related art, when the base current I_{BB} is lowered in the low linearity mode as described above, the level of the high-frequency signal is high compared to the base current I_{BB} and the effect of the high-frequency signal on the bias control element 102 is increased. Therefore, the base current I_{BB} supplied to the amplifier 101 used for high-frequency amplification is also affected by the high-frequency signal. As a result, an AM-AM characteristic and an EVM characteristic of the high-frequency amplifier circuit are degraded.

[0012] FIG. 18 illustrates a collector current characteristic with respect to output power of the high-frequency amplifier circuit of the related art. FIG. 19 illustrates an AM-AM characteristic with respect to output power of the high-frequency amplifier circuit of the related art. FIG. 20 illustrates an EVM characteristic with respect to output power of the high-frequency amplifier circuit of the related art. The AM-AM characteristic is an index indicating a phase change between input power and output power. EVM characteristic is an abbreviation of error vector magnitude characteristic and is an index indicating the performance of a demodulator under conditions where there is a problem.

[0013] As illustrated in FIG. 18, in the case of the low linearity mode, the collector current I_{CC} is suppressed to be low compared with that in the high linearity mode.

[0014] However, as illustrated in FIG. 19 (referring to the portion indicated by the large arrow), the AM-AM characteristic deviates from 0 and the AM-AM characteristic is degraded in a medium power region of over 5 dBm. In accordance with this, as illustrated in FIG. 20 (refer to the portion indicated by the large arrow), the EVM characteristic also becomes higher than in the high linearity mode and is degraded.

[0015] Currently, in wireless communication, along with increasing amounts of data being transferred, many multi-value modulation methods are employed. However, as described above, in the case of the configuration of the high-frequency amplifier circuit 10P of the related art, the AM-AM characteristic and the EVM characteristic are degraded in the low linearity mode and a sufficient demodulation performance is not obtained.

[0016] The present disclosure provides a high-frequency amplifier circuit that suppresses degradation of an AM-AM characteristic and an EVM characteristic in a low linearity mode.

[0017] The present disclosure relates to a high-frequency amplifier circuit including a high-frequency amplifier that amplifies a high-frequency signal, a bias circuit that supplies a bias current to the high-frequency amplifier and a control voltage input terminal that determines the bias current. The bias circuit of the high-frequency amplifier circuit includes a 1st bias control element that supplies a 1st bias current to the high-frequency amplifier in accordance with the control voltage, a 2nd bias control element that supplies a 2nd bias current to the high-frequency amplifier in accordance with the control voltage, and a bias adjustment circuit that adjusts a potential difference between a 1st bias current output terminal of the 1st bias control element and a 2nd bias current output terminal of the 2nd bias control element.

[0018] With this configuration, the sizes of the 1st bias current and the 2nd bias current supplied to the high-frequency amplifier are adjusted by the bias adjustment circuit. Thus, a bias current corresponding to an operation mode can

be supplied to the high-frequency amplifier. For example, in the case where a bias current is caused to increase to a certain extent in the low linearity mode, an unwanted increase in the bias current can be suppressed. Thus, an unwanted increase in a collector current I_{CC} of the high-frequency amplifier can be suppressed and degradation of an AM-AM characteristic and an EVM characteristic can be suppressed.

[0019] Furthermore, the bias adjustment circuit of the high-frequency amplifier circuit of the present disclosure may have the following configuration. The bias adjustment circuit includes an impedance element, a switch circuit and a bias current adjustment voltage application terminal. The impedance element is connected between the 1st bias current output terminal of the 1st bias control element and the 2nd bias current output terminal of the 2nd bias control element. The switch circuit sets the 2nd bias current output terminal to either of a 1st potential and a 2nd potential, which are different from each other. The bias current adjustment voltage application terminal applies a bias current adjustment voltage to the switch circuit.

[0020] With this configuration, the switch circuit adjusts the potential of the 2nd bias current output terminal to the 1st potential or the 2nd potential in accordance with the bias current adjustment voltage. As a result of the potential of the output terminal of the 2nd bias current being adjusted, the potential difference between the 1st bias current output terminal and the 2nd bias current output terminal is changed and the bias current supplied to the high-frequency amplifier circuit is adjusted. Thus, the bias current can be adjusted with certainty and easily.

[0021] In addition, the switch circuit of the high-frequency amplifier circuit of the present disclosure may include a switch element that is controlled to be on or off in accordance with the bias current adjustment voltage from the bias current adjustment voltage application terminal.

[0022] With this configuration, the 1st potential and the 2nd potential are selectively set via the switch element being turned on and off. The bias current can be adjusted using a simpler circuit configuration.

[0023] Furthermore, the high-frequency amplifier circuit of the present disclosure may further include a control voltage synchronous adjustment circuit. The control voltage synchronous adjustment circuit adjusts an application voltage, which is based on the control voltage, applied to the 1st bias control element and the 2nd bias control element by using the bias current adjustment voltage.

[0024] With this configuration, biases of the 1st bias control element and the 2nd bias control element are also adjusted. Thus, the 1st bias current and the 2nd bias current are also adjusted and an unwanted increase in the bias currents can be suppressed with more certainty.

[0025] In addition, in the high-frequency amplifier circuit of the present disclosure, the high-frequency amplifier, the 1st bias control element, the 2nd bias control element and the switch element may be npn transistors.

[0026] In this configuration, each of the active elements is realized using the same type of semiconductor element. Thus, the high-frequency amplifier circuit can be realized using a simple structure while obtaining the above-described operational effect.

[0027] In addition, in the high-frequency amplifier circuit of the present disclosure, the high-frequency amplifier, the 1st

bias control element and the 2nd bias control element may be npn transistors and the switch element may be a field effect transistor.

[0028] With this configuration as well, the high-frequency amplifier circuit can be realized using a comparatively simple structure while obtaining the above-described operational effect.

[0029] In addition, the impedance element of the high-frequency amplifier circuit of the present disclosure may be a resistor.

[0030] With this configuration, the high-frequency amplifier circuit can be realized with a simple configuration.

[0031] In addition, the impedance element of the high-frequency amplifier circuit of the present disclosure may be a parallel circuit composed of a resistor and a capacitor.

[0032] With this configuration, the size of the bias current flowing to the high-frequency amplifier can be further reduced and degradation of the AM-AM characteristic and the EVM characteristic can be further suppressed.

[0033] In addition, the high-frequency amplifier circuit of the present disclosure may further include a voltage compensation circuit that compensates an application voltage, which is based on the control voltage, applied to the 1st bias control element and the 2nd bias control element.

[0034] With this configuration, variation of the control voltage, temperature characteristics of the 1st and 2nd bias control elements and a temperature characteristic of the high-frequency amplifier can be compensated for. Thus, a high-frequency amplification characteristic is improved.

[0035] Furthermore, the voltage compensation circuit of the high-frequency amplifier circuit of the present disclosure may be composed of a plurality of compensation control elements cascade connected with each other between an application point of the control voltage of the 1st bias control element and the 2nd bias control element, and the ground.

[0036] With this configuration, voltage compensation can be realized with high accuracy and with a simple circuit configuration.

[0037] In addition, in the high-frequency amplifier circuit of the present disclosure, a parallel circuit composed of a capacitor and a resistor is connected to a side of a connection point between the high-frequency amplifier and the bias circuit from which a high-frequency signal is input.

[0038] With this configuration, the stability of the high-frequency amplifier circuit can be improved.

[0039] Furthermore, in the high-frequency amplifier circuit of the present disclosure, the high-frequency amplifier may be connected in a plurality of stages and the bias circuit may be formed for each of the plurality of stages of the high-frequency amplifier.

[0040] With this configuration, the above-described operational effect is obtained by each stage and therefore the effect of reducing power consumption can be more effectively exhibited without necessarily causing high-frequency characteristics such as the EVM characteristic to be degraded.

[0041] According to the present disclosure, degradation of the AM-AM characteristic and the EVM characteristic in the low linearity mode can be suppressed without necessarily affecting the characteristics of the high linearity mode.

BRIEF DESCRIPTION OF THE SEVERAL
VIEWS OF THE DRAWINGS

[0042] FIG. 1 is a circuit diagram of a high-frequency amplifier circuit according to a 1st embodiment of the present disclosure.

[0043] FIG. 2 illustrates characteristics of emitter voltages V_{e2} and V_{e3} and an emitter potential difference $\Delta(V_{e3}-V_{e2})$ with respect to output power P_{out} at the time of a high linearity mode and illustrates characteristics of a bias current I_{BB} and partial currents I_a+I_b and I_c with respect to output power P_{out} .

[0044] FIG. 3 illustrates characteristics of the emitter voltages V_{e2} and V_{e3} and the emitter potential difference $\Delta(V_{e3}-V_{e2})$ with respect to output power P_{out} at the time of a low linearity mode and illustrates characteristics of the bias current I_{BB} and the partial currents I_b-I_d , I_b and I_d with respect to output power P_{out} .

[0045] FIG. 4 illustrates a characteristic of a bias current I_{BB} with respect to output power P_{out} for a configuration of the related art and a configuration of the 1st embodiment.

[0046] FIG. 5 illustrates a characteristic of a collector current I_{CC} of a high-frequency amplifier with respect to output power P_{out} for the configuration of the related art and the configuration of the 1st embodiment.

[0047] FIG. 6 illustrates an AM-AM characteristic with respect to output power P_{out} for the configuration of the related art and the configuration of the 1st embodiment.

[0048] FIG. 7 illustrates an EVM characteristic with respect to output power P_{out} for the configuration of the related art and the configuration of the 1st embodiment.

[0049] FIG. 8 is a circuit diagram of a composite module composed of an RFIC and a high-frequency amplifier circuit.

[0050] FIG. 9 is a circuit diagram of a high-frequency amplifier circuit according to a 2nd embodiment of the present disclosure.

[0051] FIG. 10 is a circuit diagram of a high-frequency amplifier circuit according to a 3rd embodiment of the present disclosure.

[0052] FIG. 11 is a circuit diagram of a high-frequency amplifier circuit according to a 4th embodiment of the present disclosure.

[0053] FIG. 12 compares an emitter voltage V_{e2} with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 4th embodiment with an emitter voltage V_{e2} with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 1st embodiment.

[0054] FIG. 13 compares an AM-AM characteristic with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 4th embodiment with an AM-AM characteristic with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 1st embodiment.

[0055] FIG. 14 is a circuit diagram of a high-frequency amplifier circuit according to a 5th embodiment of the present disclosure.

[0056] FIG. 15 is a circuit diagram of a high-frequency amplifier circuit according to a 6th embodiment of the present disclosure.

[0057] FIG. 16 is a circuit diagram of a high-frequency amplifier circuit according to a 7th embodiment of the present disclosure.

[0058] FIG. 17 is a circuit diagram of a typical high-frequency amplifier circuit of the related art.

[0059] FIG. 18 illustrates a characteristic of a collector current with respect to output power of the high-frequency amplifier circuit of the related art.

[0060] FIG. 19 illustrates an AM-AM characteristic with respect to output power of the high-frequency amplifier circuit of the related art.

[0061] FIG. 20 illustrates an EVM characteristic with respect to output power of the high-frequency amplifier circuit of the related art.

[0062] A high-frequency amplifier circuit according to a 1st embodiment of the present disclosure will be described with reference to the drawings. FIG. 1 is a circuit diagram of a high-frequency amplifier circuit according to the 1st embodiment of the present disclosure.

[0063] A high-frequency amplifier circuit 10 includes an amplifier 101 (corresponding to a high-frequency amplifier of the present disclosure) and a bias circuit 20. The amplifier 101 is composed of an npn transistor and is a common emitter. A base of the amplifier 101 is connected to an RF input terminal P_{in} via an input matching circuit 901. A collector of the amplifier 101 is connected to an RF output terminal P_{out} via an output matching circuit 902. A connection point between the collector of the amplifier 101 and the output matching circuit 902 is connected to a driving voltage application terminal P_{VCC} via a coil 301. A connection point between the driving voltage application terminal P_{VCC} and the coil 301 is grounded via a capacitor 401. A direct-current driving voltage V_{CC} is applied to the collector of the amplifier 101 from the driving voltage application terminal P_{VCC} .

[0064] The bias determiner 20 includes bias control elements 102 and 103 and a switch element 104. The bias control elements 102 and 103 and the switch element 104 are each composed of an npn transistor. The bias control element 102 corresponds to a "1st bias control element" of the present disclosure and the bias control element 103 corresponds to a "2nd bias control element" of the present disclosure.

[0065] An emitter of the bias control element 102 is connected to the base of the amplifier 101 via a resistor 201. The emitter of the bias control element 102 corresponds to a "1st bias current output terminal" of the present disclosure.

[0066] A collector of the bias control element 102 is connected to a bias driving voltage application terminal P_{VCO} . A direct-current bias driving voltage V_{CO} is applied to the collector of the bias control element 102 from the bias driving voltage application terminal P_{VCO} .

[0067] In addition, the bias driving voltage application terminal P_{VCO} is also connected to a collector of the bias control element 103 and the direct-current bias driving voltage V_{CO} is also applied to the collector of the bias control element 103 from the bias driving voltage application terminal P_{VCO} .

[0068] Bases of the bias control elements 102 and 103 are connected to a control voltage input terminal P_{VCTL} via a resistor 202. A direct-current control voltage V_{CTL} is applied to the bases of the bias control elements 102 and 103 from the control voltage input terminal P_{VCTL} .

[0069] An emitter of the bias control element 103 is connected to a collector of the switch element 104 via a resistor 203. In addition, the emitter of the bias control element 103 is connected to the emitter of the bias control element 102 via a resistor 204. The emitter of the bias control element 103 corresponds to a "2nd bias current output terminal" of the present disclosure.

[0070] The switch element 104 is a common emitter. A base of the switch element 104 is connected to a bias current

adjustment voltage application terminal P_{VLIN} via a resistor **205**. A direct-current bias current adjustment voltage V_{LIN} is applied to the base of the switch element **104** from the bias current adjustment voltage application terminal P_{VLIN} . A circuit composed of the switch element **104** and the resistors **203** and **205** corresponds to a “switch circuit” of the present disclosure. A circuit composed of the switch element **104** and the resistors **203**, **204** and **205** corresponds to a “bias adjustment circuit” of the present disclosure.

[0071] In the high-frequency amplifier configured as described above, a high-frequency signal input from the RF input terminal P_{in} is amplified by the amplifier **101** and output from the RF output terminal P_{out} . At this time, the output of the amplifier **101** corresponds to the bias current I_{BB} supplied from the bias circuit **20**. Therefore, by adjusting the bias current I_{BB} , amplification processing, that is, an operation mode of the amplifier **101** can be switched.

(i) High Linearity Mode

[0072] FIG. 2 illustrates characteristics of an emitter voltage V_{e2} of the bias control element **102**, an emitter voltage V_{e3} of the bias control element **103** and an emitter potential difference $\Delta (V_{e3}-V_{e2})$ with respect to output power P_{out} at the time of a high linearity mode and illustrates characteristics of the bias current I_{BB} and partial currents I_a+I_b and I_c with respect to output power P_{out} .

[0073] In the case of the high linearity mode, the bias current adjustment voltage V_{LIN} is set to be a voltage that is less than an operation threshold of the switch element **104**. In this case, the switch element **104** is in an off state and an end of the resistor **203** on the switch element **104** side is in a state of not being connected to ground. In this state, the control voltage V_{CTL} is applied to the bases of the bias control elements **102** and **103** from the control voltage input terminal P_{VCTL} and the bias driving voltage V_{CO} is applied to the collectors of the bias control elements **102** and **103** from the bias driving voltage application terminal P_{VCO} . Thus, an emitter current I_b corresponding to the control voltage V_{CTL} flows through the emitter of the bias control element **102** and an emitter current I_a corresponding to the control voltage V_{CTL} flows through the emitter of the bias control element **103**.

[0074] Here, as described above, the end of the resistor **203** on the switch element **104** side is disconnected from ground and therefore a partial current I_c is approximately 0 and the emitter voltage V_{e3} of the bias control element **103** is maintained higher than the emitter voltage V_{e2} of the bias control element **102**. On the other hand, since the emitter of the bias control element **102** is grounded via the resistor **201** and the amplifier **101**, the emitter voltage V_{e2} is a voltage corresponding to the voltages dropped across these elements. Therefore, as illustrated in FIG. 2, an emitter potential difference $\Delta (V_{e3}-V_{e2})$ between the bias control element **103** and the bias control element **102** has a positive value regardless of the output power P_{out} at the time of the high linearity mode.

[0075] Since the emitter of the bias control element **103** is open, the emitter current I_a thereof flows through the resistor **204** but does not flow through the resistor **203**. That is, as illustrated in FIG. 2, the partial current I_c flowing to the resistor **203** is approximately 0.

[0076] Thus, the emitter current I_a flows toward the bias control element **102** side from the bias control element **103** side via the resistor **204**. For example, as illustrated in FIG. 1,

if a current flowing from the emitter of the bias control element **102** toward the emitter of the bias control element **103** is set to be I_d , $I_a=-I_d$.

[0077] Therefore, the bias current I_{BB} flowing through the resistor **201** connected between the emitter of the bias control element **102** and the base of the amplifier **101** is $I_b-(I_d)=I_b+I_a$ (refer to bottom part of FIG. 2). Consequently, the emitter current I_b from the bias control element **102** and the emitter current I_a from the bias control element **103** are added together and supplied to the base of the amplifier **101** as the bias current I_{BB} .

[0078] Thus, at the time of the high linearity mode, the bias current I_{BB} is supplied to the amplifier **101** without necessarily being suppressed.

(ii) Low Linearity Mode

[0079] FIG. 3 illustrates characteristics of the emitter voltages V_{e2} and V_{e3} and the emitter potential difference $\Delta (V_{e3}-V_{e2})$ with respect to output power P_{out} at the time of a low linearity mode and illustrates characteristics of the bias current I_{BB} and the partial currents I_b-I_d , I_b and I_d with respect to output power P_{out} .

[0080] In the case of the low linearity mode, the bias current adjustment voltage V_{LIN} is set to be a voltage that is equal to or greater than the operation threshold of the switch element **104**. In this case, the switch element **104** is in an on state and the end of the resistor **203** on the switch element **104** side is connected to ground. In this state, the control voltage V_{CTL} is applied to the bases of the bias control elements **102** and **103** from the control voltage input terminal P_{VCTL} and the bias driving voltage V_{CO} is applied to the collectors of the bias control elements **102** and **103** from the bias driving voltage application terminal P_{VCO} . Thus, an emitter current I_b corresponding to the control voltage V_{CTL} flows through the emitter of the bias control element **102** and an emitter current I_a corresponding to the control voltage V_{CTL} flows through the emitter of the bias control element **103**.

[0081] Here, as described above, an end portion on the switch element **104** side connected to the resistor **203** is short circuited with the ground and therefore the emitter voltage V_{e3} of the bias control element **103** drops so as to approach the ground potential. On the other hand, since the emitter of the bias control element **102** is grounded via the resistor **201** and the amplifier **101**, the emitter voltage V_{e2} is a voltage corresponding to the voltages dropped across these elements. Consequently, the emitter voltage V_{e3} is lower than the emitter voltage V_{e2} . Therefore, as illustrated in FIG. 3, an emitter potential difference $\Delta (V_{e3}-V_{e2})$ between the bias control element **103** and the bias control element **102** has a negative value regardless of the output power P_{out} at the time of the low linearity mode.

[0082] Therefore, the emitter current I_a flows through the resistor **203** and does not flow through the resistor **204**. In addition, part of the emitter current I_b also flows toward the bias control element **103** side from the bias control element **102** side via the resistor **204**. That is, the emitter current I_b branches between the resistor **201** and the resistor **204**. If this branch current component is denoted I_{db} , $I_d=I_{db}$.

[0083] Therefore, the bias current I_{BB} flowing through the resistor **201** connected between the emitter of the bias control element **102** and the base of the amplifier **101** is $I_b-(I_d)=I_b-I_{db}$. Thus, a current obtained by subtracting the current I_{db} branching to the resistor **204** from the emitter current I_b from

the bias control element **102** is supplied as the bias current I_{BB} to the base of the amplifier **101**.

[0084] At this time, part of the high-frequency signal (RF signal) input from the RF input terminal Pin is input to the bias circuit **20** via the resistor **201**. Here, the emitter potential difference Δ ($V_{e3} - V_{e2}$) between the bias control element **103** and the bias control element **102** has a negative value and the emitter voltage V_{e2} is higher than the emitter voltage V_{e3} .

[0085] Consequently, the high-frequency signal flows to ground via the resistor **204**, the resistor **203** and the switch element **104**. Thus, the high-frequency signal flowing into the bias control elements **102** and **103** can be suppressed and an adverse effect of the high-frequency signal on the bias current I_{BB} can be suppressed. Therefore, the AM-AM characteristic and the EVM characteristic of the high-frequency amplifier circuit **10** are improved.

[0086] In addition, with the above-described configuration, at the time of the low linearity mode, the bias current I_{BB} is suppressed compared with that in the configuration of the related art and then supplied to the amplifier **101**.

(Comparison of Characteristics Between Configuration of Related Art and Configuration of this Embodiment)

[0087] FIG. **4** illustrates a characteristic of a bias current I_{BB} with respect to output power P_{out} for the configuration of the related art and the configuration of the 1st embodiment. In the high linearity mode, as illustrated in FIG. **4**, the same bias current I_{BB} as in the configuration of the related art can be supplied to the amplifier **101** by using the configuration of this embodiment. In addition, in the low linearity mode, as illustrated in FIG. **4**, the bias current I_{BB} can be reduced from that in the configuration of the related art by using the configuration of this embodiment.

[0088] FIG. **5** illustrates a characteristic of a collector current I_{CC} of a high-frequency amplifier with respect to output power P_{out} for the configuration of the related art and the configuration of the 1st embodiment. In the high linearity mode, since the same bias current I_{BB} as in the configuration of the related art is supplied by using the configuration of this embodiment, as illustrated in FIG. **5**, the same collector current I_{CC} as in the configuration of the related art can be obtained. In addition, in the low linearity mode, since a bias current I_{BB} that has been suppressed compared with that in the configuration of the related art is supplied by using the configuration of this embodiment, as illustrated in FIG. **5**, the collector current I_{CC} can be reduced compared with that in the configuration of the related art.

[0089] FIG. **6** illustrates an AM-AM characteristic with respect to output power P_{out} for the configuration of the related art and the configuration of the 1st embodiment. In the high linearity mode, since the same collector current I_{CC} as in the configuration of the related art is obtained by using the configuration of this embodiment, as illustrated in FIG. **6**, an excellent AM-AM characteristic can be obtained similarly to as in the configuration of the related art. In addition, in the low linearity mode, by using the configuration of this embodiment, the collector current I_{CC} can be suppressed compared with that in the configuration of the related art, in particular, the collector current I_{CC} in a power region of 5 dBm or more can be suppressed, and a high-frequency signal that has entered the bias circuit **20** flows toward the resistor **203** side and as a result the effect of the high-frequency signal on the bias circuit **20** can be suppressed, and therefore, as illustrated in FIG. **6**, the AM-AM characteristic can be improved com-

pared with that in the configuration of the related art. In particular, the AM-AM characteristic in the medium power region can be improved.

[0090] FIG. **7** illustrates an EVM characteristic with respect to output power P_{out} for the configuration of the related art and the configuration of the 1st embodiment. In the high linearity mode, since the same collector current I_{CC} as in the configuration of the related art is obtained by using the configuration of this embodiment, as illustrated in FIG. **7**, an excellent EVM characteristic can be obtained similarly to as in the configuration of the related art. In addition, in the low linearity mode, by using the configuration of this embodiment, the collector current I_{CC} can be suppressed compared with that in the configuration of the related art, in particular, the collector current I_{CC} in a power region of 5 dBm or more can be suppressed, and a high-frequency signal that has entered the bias circuit **20** flows toward the resistor **203** side and as a result the effect of the high-frequency signal on the bias circuit **20** can be suppressed and therefore, as illustrated in FIG. **7**, the EVM characteristic can be improved compared with that in the configuration of the related art. In particular, the EVM characteristic can be improved in the medium power region.

[0091] As described above, by using the high-frequency amplifier circuit of this embodiment, degradation of the AM-AM characteristic and the EVM characteristic in the low linearity mode can be suppressed thereby improving the characteristics without necessarily affecting the characteristics of the high linearity mode.

[0092] In the above-described FIG. **1**, an example in which the RF input terminal Pin, the control voltage input terminal P_{VCTL} and the bias current adjustment voltage application terminal P_{VLLN} are provided is illustrated, but the configuration illustrated in FIG. **8** may be instead employed. FIG. **8** is a circuit diagram of a composite module composed of an RFIC and a high-frequency amplifier circuit.

[0093] The RF input terminal Pin, the control voltage input terminal P_{VCTL} and the bias current adjustment voltage application terminal P_{VLLN} of the high-frequency amplifier circuit **10** become output terminals of an RFIC **100**.

[0094] The RFIC **100** generates the control voltage V_{CTL} , the bias current adjustment voltage V_{LLN} and the high-frequency signal RF. The RFIC **100** applies the control voltage V_{CTL} to the bias control elements **102** and **103** via the resistor **202**. The RFIC **100** applies the bias current adjustment voltage V_{LLN} to the switch element **104** via the resistor **205**. At this time, the RFIC **100** sets and then applies the bias current adjustment voltage V_{LLN} in accordance with the operation mode. The RFIC **100** inputs the high-frequency signal RF to the amplifier **101** via the input matching circuit **901**.

[0095] Next, a high-frequency amplifier circuit according to a 2nd embodiment will be described with reference to the drawings. FIG. **9** is a circuit diagram of the high-frequency amplifier circuit according to the 2nd embodiment of the present disclosure. A switch element of a bias circuit **20A** of a high-frequency amplifier circuit **10A** of this embodiment differs from that of the high-frequency amplifier circuit **10** according to the 1st embodiment, but the rest of the configuration of the high-frequency amplifier circuit **10A** is the same as that of the high-frequency amplifier circuit **10** according to the 1st embodiment. In this embodiment and the following embodiments, only places that are different to the embodiment that is the target of comparison will be described.

[0096] A switch element 14A of the bias circuit 20A of this embodiment is composed of a field effect transistor (FET). The bias current adjustment voltage application terminal P_{VLIN} is set based on a threshold voltage of the FET. Therefore, an operational effect the same as that of the high-frequency amplifier circuit 10 of the 1st embodiment can be obtained when the high-frequency amplifier circuit 10A of this embodiment is used.

[0097] Next, a high-frequency amplifier circuit according to a 3rd embodiment will be described with reference to the drawings. FIG. 10 is a circuit diagram of the high-frequency amplifier circuit according to the 3rd embodiment of the present disclosure. The connection configuration between the input matching circuit 901 and the amplifier 101 and the connection configuration with respect to the bias circuit 20 of the high-frequency amplifier circuit 10A of this embodiment differ from those of the high-frequency amplifier circuit 10 according to the 1st embodiment but the rest of the configuration of the high-frequency amplifier circuit 10A is the same as that of the high-frequency amplifier circuit 10 according to the 1st embodiment.

[0098] A parallel circuit composed of a capacitor 411 and a resistor 211 is connected between the input matching circuit 901 and the amplifier 101 of the high-frequency amplifier circuit 10B. The amplifier 101 side of the parallel circuit is connected to the resistor 201 connected to the bias circuit 20. In addition, the input matching circuit 901 side of the parallel circuit is connected to the emitter of the bias control element 102 of the bias circuit 20 via a resistor 206.

[0099] With this configuration, the same operational effect as with the above-described embodiments is obtained, and in addition the high-frequency amplifier circuit 10B can be prevented from oscillating with more certainty since a stability coefficient of the high-frequency amplifier circuit 10B can be adjusted by using the added circuit. Thus, the stability of the high-frequency amplifier circuit 10B can be improved.

[0100] Next, a high-frequency amplifier circuit according to a 4th embodiment will be described with reference to the drawings. FIG. 11 is a circuit diagram of the high-frequency amplifier circuit according to the 4th embodiment of the present disclosure. The configuration of a bias circuit 20C of a high-frequency amplifier circuit 10C of this embodiment differs from that of the high-frequency amplifier circuit 10 according to the 1st embodiment, but the rest of the configuration of the high-frequency amplifier circuit 10C is the same as that of the high-frequency amplifier circuit 10 according to the 1st embodiment.

[0101] The bias circuit 20C is obtained by adding a capacitor 421 to the bias circuit 20 according to the 1st embodiment. The capacitor 421 is connected in parallel with the resistor 204. That is, the emitter of the bias control element 103 and the emitter of the bias control element 102 are connected to each other by a parallel circuit composed of the resistor 204 and the capacitor 421.

[0102] FIG. 12 compares the emitter voltage V_{e2} with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 4th embodiment with the emitter voltage V_{e2} with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 1st embodiment. In FIG. 12 and the later-mentioned FIG. 13, a case of a large capacitance of 10 pF and a case of a small capacitance of 0.5 pF are illustrated.

[0103] By providing the capacitor 421 as in this embodiment, the emitter voltage V_{e2} of the bias control element 102 at the time of the low linearity mode can be reduced. At this time, the amount of reduction of the emitter voltage V_{e2} can be adjusted by adjusting the capacitance of the capacitor 421. Specifically, as illustrated in FIG. 12, the emitter voltage V_{e2} can be reduced by a greater amount by making the capacitance of the capacitor 421 larger.

[0104] FIG. 13 compares an AM-AM characteristic with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 4th embodiment with an AM-AM characteristic with respect to output voltage P_{out} at the time of a low linearity mode of the high-frequency amplifier circuit of the 1st embodiment.

[0105] By providing the capacitor 421 as in this embodiment, the AM-AM characteristic of the bias control element 102 at the time of the low linearity mode can be adjusted. Specifically, as illustrated in FIG. 13, by making the capacitance of the capacitor 421 large, the AM-AM characteristic in a medium power region can be shifted toward the negative value side and therefore the AM-AM characteristic can be appropriately adjusted by adjusting the capacitance of the capacitor 421.

[0106] Thus, by using the configuration of this embodiment, a more optimum AM-AM characteristic can be obtained by appropriately adjusting the AM-AM characteristic. Thus, the EVM characteristic can be further improved.

[0107] Next, a high-frequency amplifier circuit according to a 5th embodiment will be described with reference to the drawings. FIG. 14 is a circuit diagram of the high-frequency amplifier circuit according to the 5th embodiment of the present disclosure. The configuration of a bias circuit 20D of a high-frequency amplifier circuit 10D of this embodiment differs from that of the high-frequency amplifier circuit 10 according to the 1st embodiment, but the rest of the configuration of the high-frequency amplifier circuit 10D is the same as that of the high-frequency amplifier circuit 10 according to the 1st embodiment.

[0108] The bias circuit 20D of the high-frequency amplifier circuit 10D is obtained by adding a voltage compensation circuit 21 to the bias circuit 20. The voltage compensation circuit 21 is composed of compensation control elements 501 and 502, which are cascade connected with each other. The compensation control elements 501 and 502 are composed of npn transistors, the same the amplifier 101 and the bias control elements 102 and 103. As a more specific configuration of the control voltage adjustment circuit 21, a collector of the compensation control element 501 is connected to the bases of the bias control elements 102 and 103. The compensation control element 501 has its collector connected to its own base (that of compensation control element 501). An emitter of the compensation control element 501 is connected to a collector of the compensation control element 502. The compensation control element 502 has its collector connected to its own base (that of compensation control element 502). The compensation control element 502 is a common emitter.

[0109] When a voltage value of the control voltage V_{CTL} from the control voltage input terminal P_{VCTL} becomes high and the base voltages of the bias control elements 102 and 103 attempt to rise, a current that simultaneously flows into the voltage compensation circuit 21 configured as described above increases. Thus, a voltage dropped across the resistor 202 increases and therefore the increases of the base voltages are compensated for and the base voltages are maintained

constant. On the other hand, when the voltage value of the control voltage V_{CTL} from the control voltage input terminal P_{VCTL} becomes low and the base voltages of the bias control elements **102** and **103** attempt to fall, a current simultaneously flowing into the voltage compensation circuit **21** decreases. Thus, a voltage dropped across the resistor **202** decreases and therefore the decreases of the base voltages are compensated for and the base voltages are maintained constant. In addition, there is an effect from the temperature characteristics of the amplifier **101** and the bias control elements **102** and **103**, and it is considered that even though the control voltage V_{CTL} is constant, an amplification characteristic changes. However, temperature compensation can be performed by providing the voltage compensation circuit **21**.

[0110] Next, a high-frequency amplifier circuit according to a 6th embodiment will be described with reference to the drawings. FIG. 15 is a circuit diagram of the high-frequency amplifier circuit according to the 6th embodiment of the present disclosure. The configuration of a bias circuit **20E** of a high-frequency amplifier circuit **10E** of this embodiment differs from that of the high-frequency amplifier circuit **10D** according to the 5th embodiment, but the rest of the configuration of the high-frequency amplifier circuit **10E** is the same as that of the high-frequency amplifier circuit **10D** according to the 5th embodiment.

[0111] The control bias adjustment circuit **20E** of the high-frequency amplifier circuit **10E** is obtained by adding a control voltage synchronous adjustment circuit **22** to the bias circuit **20D** of the high-frequency amplifier circuit **10D**. The control voltage synchronous adjustment circuit **22** includes tuning control elements **511** and **512** and resistors **211** and **212**. The tuning control elements **511** and **512** are composed of npn transistors.

[0112] The tuning control element **511** is a common emitter and its base is connected to the bias current adjustment voltage V_{LIN} via the resistor **211**. A collector of the tuning control element **511** is connected to an emitter of the tuning control element **512** via the resistor **212**. The tuning control element **512** has its base connected to the bases of the bias control elements **102** and **103** and to its own collector (that of tuning control element **512**). The tuning control element **511** has the same characteristics as the switch element **104** and is arranged close thereto. With this configuration, the following operations occur at the times of the respective operation modes.

(At Time of High Linearity Mode)

[0113] At the time of the high linearity mode, the bias current adjustment voltage V_{LIN} is set to be less than a threshold voltage of the switch element **104**. Therefore, the bias current adjustment voltage V_{LIN} is less than a threshold voltage of the tuning control element **511** and the tuning control element **511** is in an off state. Thus, an emitter voltage of the tuning control element **512** is high and base voltages of the bias control elements **102** and **103** are also maintained high. Therefore, a current corresponding to the control voltage V_{CTL} is supplied to the bias control elements **102** and **103** and the bias current I_{BB} to the amplifier **101** can also be maintained high.

(At Time of Low Linearity Mode)

[0114] At the time of the low linearity mode, the bias current adjustment voltage V_{LIN} is set to be equal to or more than

the threshold voltage of the switch element **104**. Therefore, the bias current adjustment voltage V_{LIN} is equal to or more than the threshold voltage of the tuning control element **511** and the tuning control element **511** is in an on state. Thus, the emitter of the tuning control element **512** is connected to the ground via the resistor **212** and the emitter voltage becomes low. As a result of the emitter voltage of the tuning control element **512** decreasing, part of the current corresponding to the control voltage V_{CTL} flows into the control voltage synchronous adjustment circuit **22** and the base currents of the bias control elements **102** and **103** decrease. Therefore, the bias current I_{BB} to the amplifier **101** supplied from the bias control elements **102** and **103** is suppressed. Thus, power consumption is further decreased and compared with the configuration of the 1st embodiment the two necessary control terminals can be unified into a single control terminal.

[0115] Next, a high-frequency amplifier circuit according to a 7th embodiment will be described with reference to the drawings. FIG. 16 is a circuit diagram of the high-frequency amplifier circuit according to the 7th embodiment of the present disclosure. A high-frequency amplification amplifier of a high-frequency amplifier circuit **10F** of this embodiment has a two-stage configuration and the basic configuration of the bias circuit for each stage of the amplifier is the same as that described in the above-described embodiments.

[0116] The high-frequency amplifier circuit **10F** includes high-frequency amplification amplifiers **1011** and **1012**. The amplifiers **1011** and **1012** are composed of npn transistors. Emitters of the amplifiers **1011** and **1012** are grounded. A base of the amplifier **1011** is connected to the RF input terminal Pin via the input matching circuit **901**. A collector of the amplifier **1011** is connected to a base of the amplifier **1012** via an interstage matching circuit **903**. The collector of the bias control element **102** is connected to the RF output terminal Pout via the output matching circuit **902**.

[0117] A bias current I_{BB1} is supplied from a bias circuit **20F1** to the amplifier **1011**. A bias current I_{BB2} is supplied from a bias circuit **20F2** to the amplifier **1012**. The bias circuits **20F1** and **20F2** have the same basic configuration as the bias circuit **20E** according to the above-described 6th embodiment, but the bias driving voltage application terminal P_{VCO} , the control voltage input terminal P_{VCTL} , the bias current adjustment voltage application terminal P_{VLIN} , the resistor **205** and the control voltage synchronous adjustment circuit **22** are shared therebetween.

[0118] The same operational effect as in each of the above-described embodiments can also be obtained with this configuration. In addition, the amplification factor of the high-frequency amplifier circuit can be improved as a result of the high frequency amplification amplifier being connected in two stages. In particular, the amplification factor at the time of the high linearity mode can be improved. On the other hand, since the power consumption of each stage can be suppressed, the power consumption of the high-frequency amplifier circuit can be more effectively reduced.

[0119] An example of two stages is described in this embodiment, but a configuration with more stages may be adopted.

[0120] In addition, the configurations of the above-described embodiments may be combined with each other. For example, the configuration of the 2nd embodiment and the configuration of the 3rd embodiment may be combined with

each other and the configuration of the 3rd embodiment and the configuration of the 4th embodiment may be combined with each other.

REFERENCE SIGNS LIST

- [0121] 10, 10A, 10B, 10C, 10D, 10E, 10F, 10P: high-frequency amplifier circuit,
- [0122] 20, 20A, 20C, 20D, 20E, 20F1, 20F2, 20P: bias circuit,
- [0123] 21: voltage compensation circuit,
- [0124] 22: control voltage synchronous adjustment circuit
- [0125] 100: RFIC,
- [0126] 101, 1011, 1012: high-frequency amplifier,
- [0127] 102: bias control element (1st bias control element),
- [0128] 103: bias control element (2nd bias control element),
- [0129] 104, 104A: switch element,
- [0130] 501, 502: compensation control element,
- [0131] 511, 512: tuning control element,
- [0132] 201, 202, 203, 204, 205, 206, 211, 212: resistor,
- [0133] 301: coil,
- [0134] 401, 411, 421: capacitor,
- [0135] 901: input matching circuit,
- [0136] 902: output matching circuit,
- [0137] 903: interstage matching circuit,
- [0138] Pin: RF input terminal,
- [0139] Pout: RF output terminal,
- [0140] P_{VCC} : driving voltage application terminal,
- [0141] P_{VCO} : bias driving voltage application terminal,
- [0142] P_{CTL} : control voltage input terminal,
- [0143] P_{VLIN} : bias current adjustment voltage application terminal,
- [0144] V_{CC} : driving voltage,
- [0145] V_{CO} : bias driving voltage,
- [0146] V_{CTL} : control voltage,
- [0147] V_{LIN} : bias current adjustment voltage

1. A high-frequency amplifier circuit comprising:
 a high-frequency amplifier that amplifies a high-frequency signal;
 a bias circuit that supplies a bias current to the high-frequency amplifier; and
 a control voltage input terminal that determines the bias current;
 wherein the bias circuit includes
 a 1st bias control element that supplies a 1st bias current to the high-frequency amplifier in accordance with the control voltage,
 a 2nd bias control element that supplies a 2nd bias current to the high-frequency amplifier in accordance with the control voltage, and
 a bias adjustment circuit that adjusts a potential difference between a 1st bias current output terminal of the 1st bias control element and a 2nd bias current output terminal of the 2nd bias control element.

2. The high-frequency amplifier circuit according to claim 1,
 wherein the bias adjustment circuit includes
 an impedance element connected between the 1st bias current output terminal of the 1st bias control element and the 2nd bias current output terminal of the 2nd bias control element,

a switch circuit that sets the 2nd bias current output terminal to either of a 1st potential and a 2nd potential, which are different from each other, and
 a bias current adjustment voltage application terminal that applies a bias current adjustment voltage to the switch circuit.

3. The high-frequency amplifier circuit according to claim 2, wherein the switch circuit includes a switch element that is controlled to be on or off in accordance with the bias current adjustment voltage from the bias current adjustment voltage application terminal.

4. The high h-frequency amplifier circuit according to claim 3, further comprising a control voltage synchronous adjustment circuit that adjusts an application voltage, which is based on the control voltage, applied to the 1st bias control element and the 2nd bias control element by using the bias current adjustment voltage.

5. The high-frequency amplifier circuit according to claim 3, wherein the high-frequency amplifier, the 1st bias control element, the 2nd bias control element and the switch element are npn transistors.

6. The high-frequency amplifier circuit according to claim 3, wherein the high-frequency amplifier, the 1st bias control element and the 2nd bias control element are npn transistors and the switch element is a field effect transistor.

7. The high-frequency amplifier circuit according to claim 2, wherein the impedance element is a resistor.

8. The high-frequency amplifier circuit according to claim 2, wherein the impedance element is a parallel circuit composed of a resistor and a capacitor.

9. The high-frequency amplifier circuit according to claim 1, further comprising a voltage compensation circuit that compensates an application voltage, which is based on the control voltage, applied to the 1st bias control element and the 2nd bias control element.

10. The high-frequency amplifier circuit according to claim 1, wherein the voltage compensation circuit is composed of a plurality of compensation control elements cascade connected with each other between an application point of the control voltage of the 1st bias control element and the 2nd bias control element and the ground.

11. The high-frequency amplifier circuit according to claim 1, wherein a parallel circuit composed of a capacitor and a resistor is connected to a side of a connection point of the high-frequency amplifier and the bias circuit, a high-frequency signal being input at the side of the connection point.

12. The high-frequency amplifier circuit according to claim 1,
 wherein the high-frequency amplifier is connected in a plurality of stages, and
 each of the plurality of stages of the high-frequency amplifier comprises the bias circuit.

13. The high-frequency amplifier circuit according to claim 3, wherein the impedance element is a resistor.

14. The high-frequency amplifier circuit according to claim 4, wherein the impedance element is a resistor.

15. The high-frequency amplifier circuit according to claim 5, wherein the impedance element is a resistor.

16. The high-frequency amplifier circuit according to claim 6, wherein the impedance element is a resistor.

17. The high-frequency amplifier circuit according to claim 3, wherein the impedance element is a parallel circuit composed of a resistor and a capacitor.

18. The high-frequency amplifier circuit according to claim 4, wherein the impedance element is a parallel circuit composed of a resistor and a capacitor.

19. The high-frequency amplifier circuit according to claim 5, wherein the impedance element is a parallel circuit composed of a resistor and a capacitor.

20. The high-frequency amplifier circuit according to claim 6, wherein the impedance element is a parallel circuit composed of a resistor and a capacitor.

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