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(54) **METHODS AND APPARATUS FOR MATCHING AN ANTENNA**

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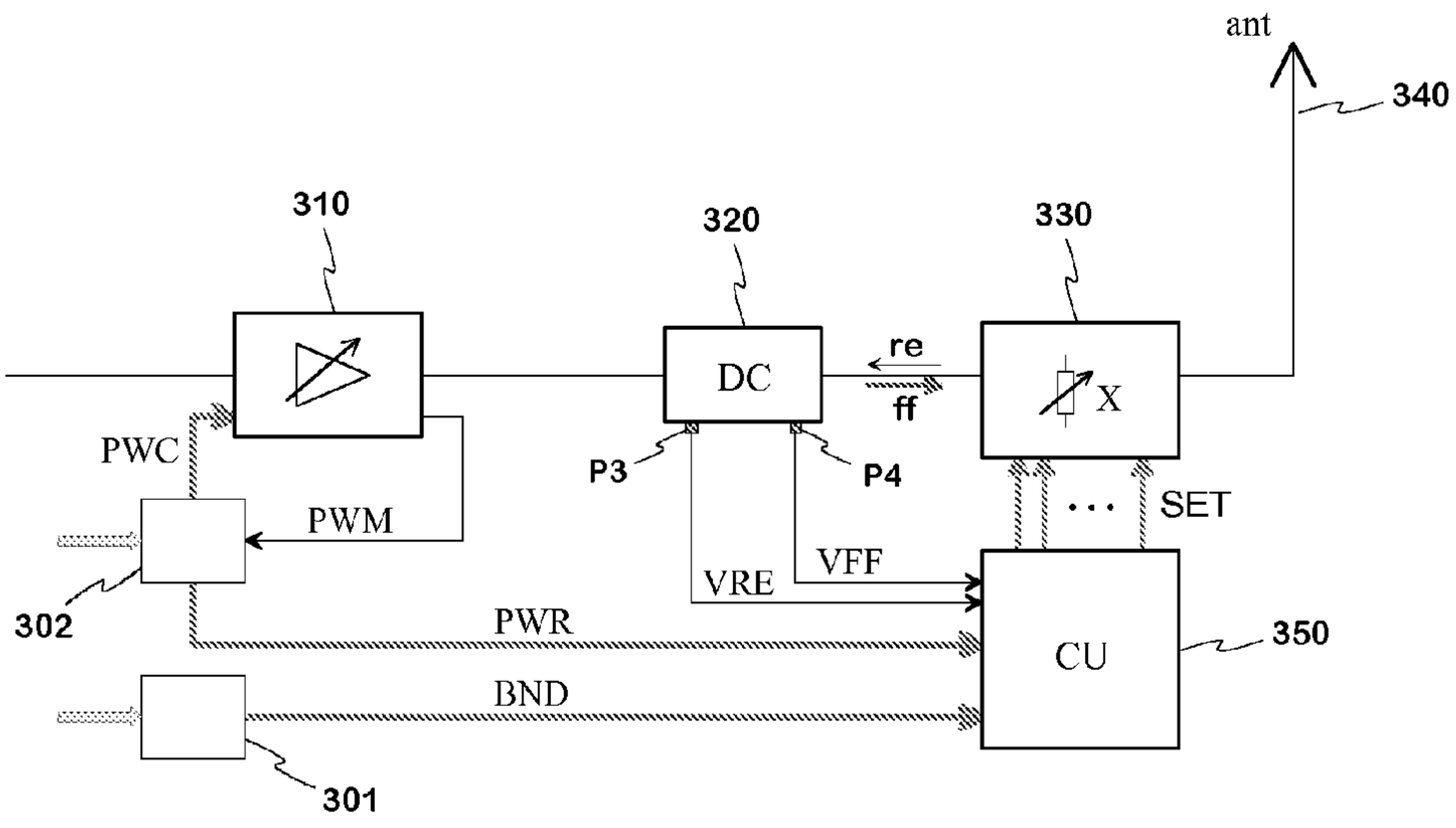
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(57) **ABSTRACT**

A method and an arrangement for matching the antenna of a radio device in transmitting condition. The antenna impedance in the output of the power amplifier of a transmitter is adjusted by means of a π-shaped reactive matching circuit, the component values of which can be selected from a relatively wide array of the alternatives. The component values are selected using multiple-way switches, which only are located in the transverse branches of the matching circuit. The switches are set by the control unit, input variables of which being the SWR value provided by the directional coupler, the operating band used each time and a value of the transmitting power. The matching is based on an adjusting process to be executed at regular intervals, in which process the control unit tries different combinations of the switch states and finally selects the combination, which brings the lowest SWR value.

20 Claims, 6 Drawing Sheets



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2012/0119955	A1	5/2012	Milosavljevic

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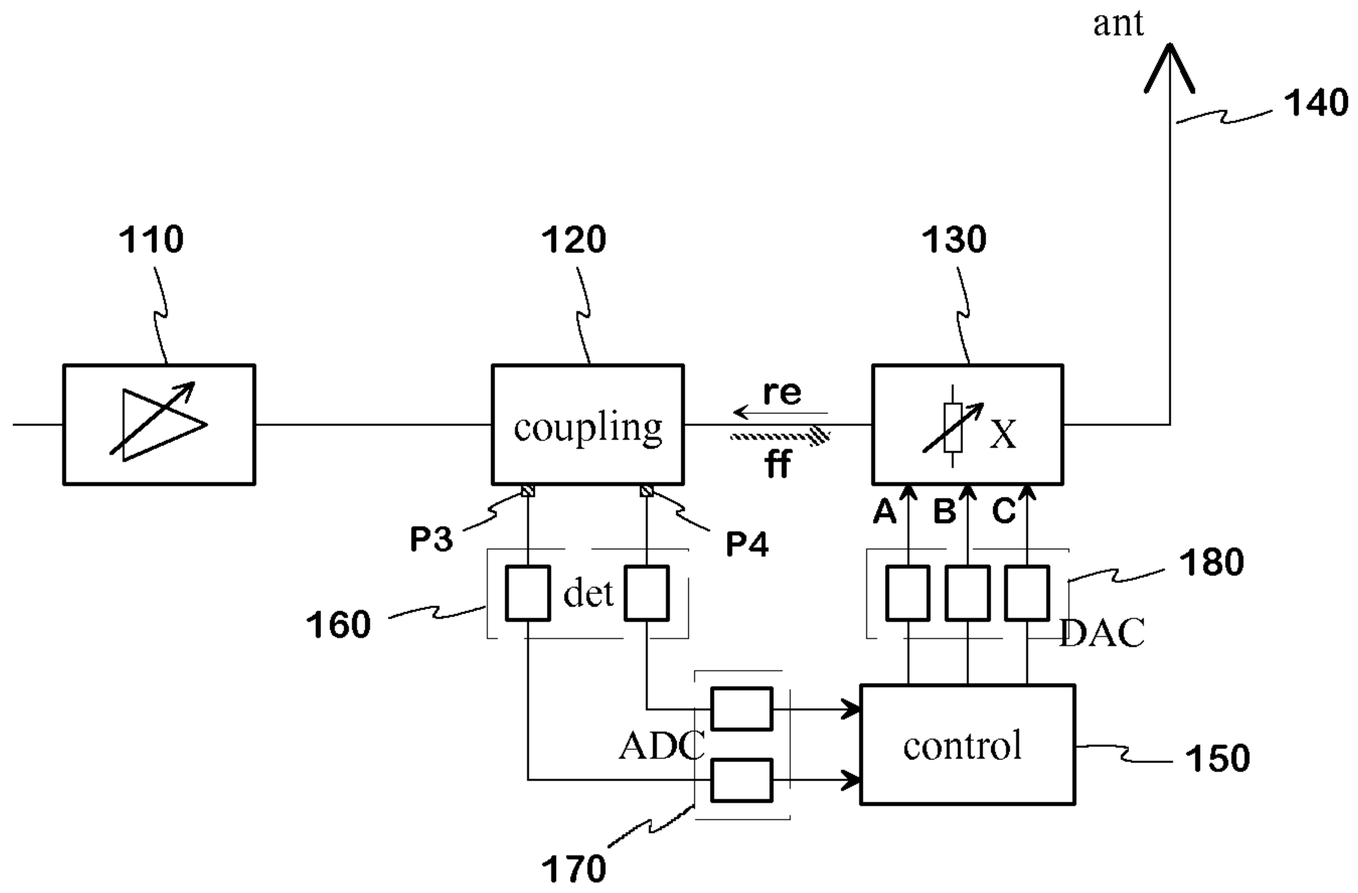


Fig. 1 PRIOR ART

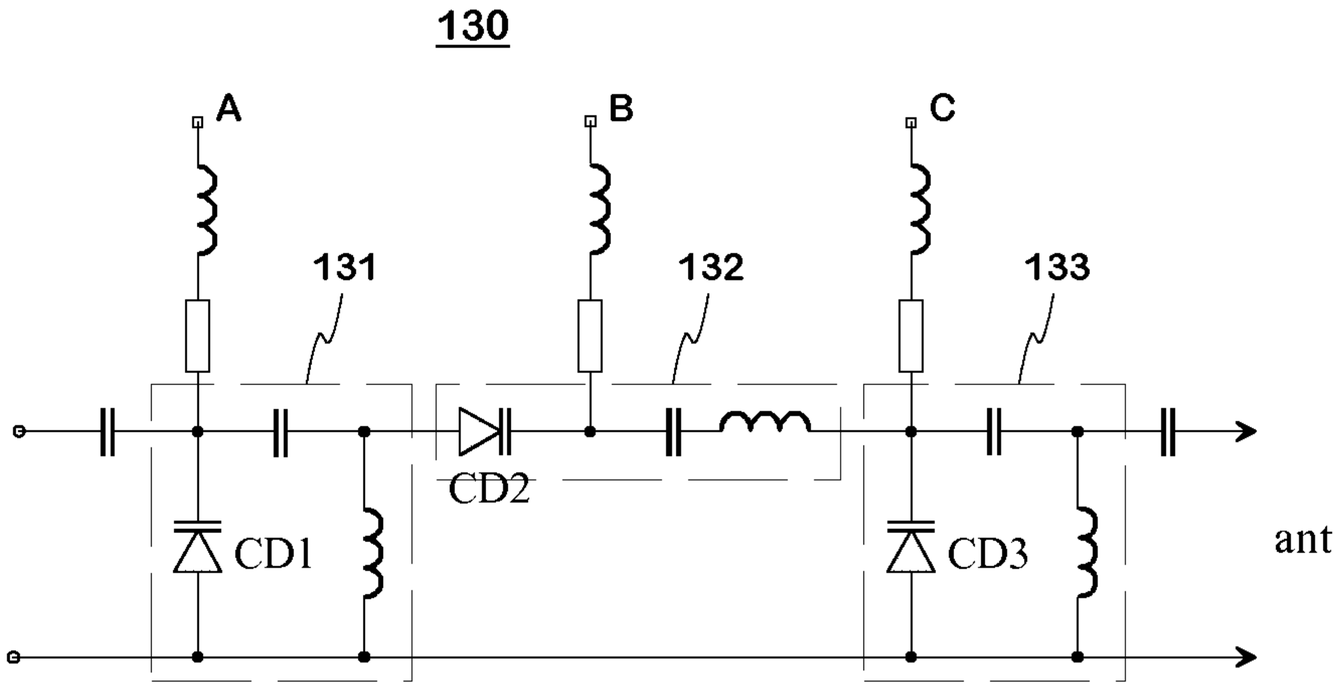


Fig. 2 PRIOR ART

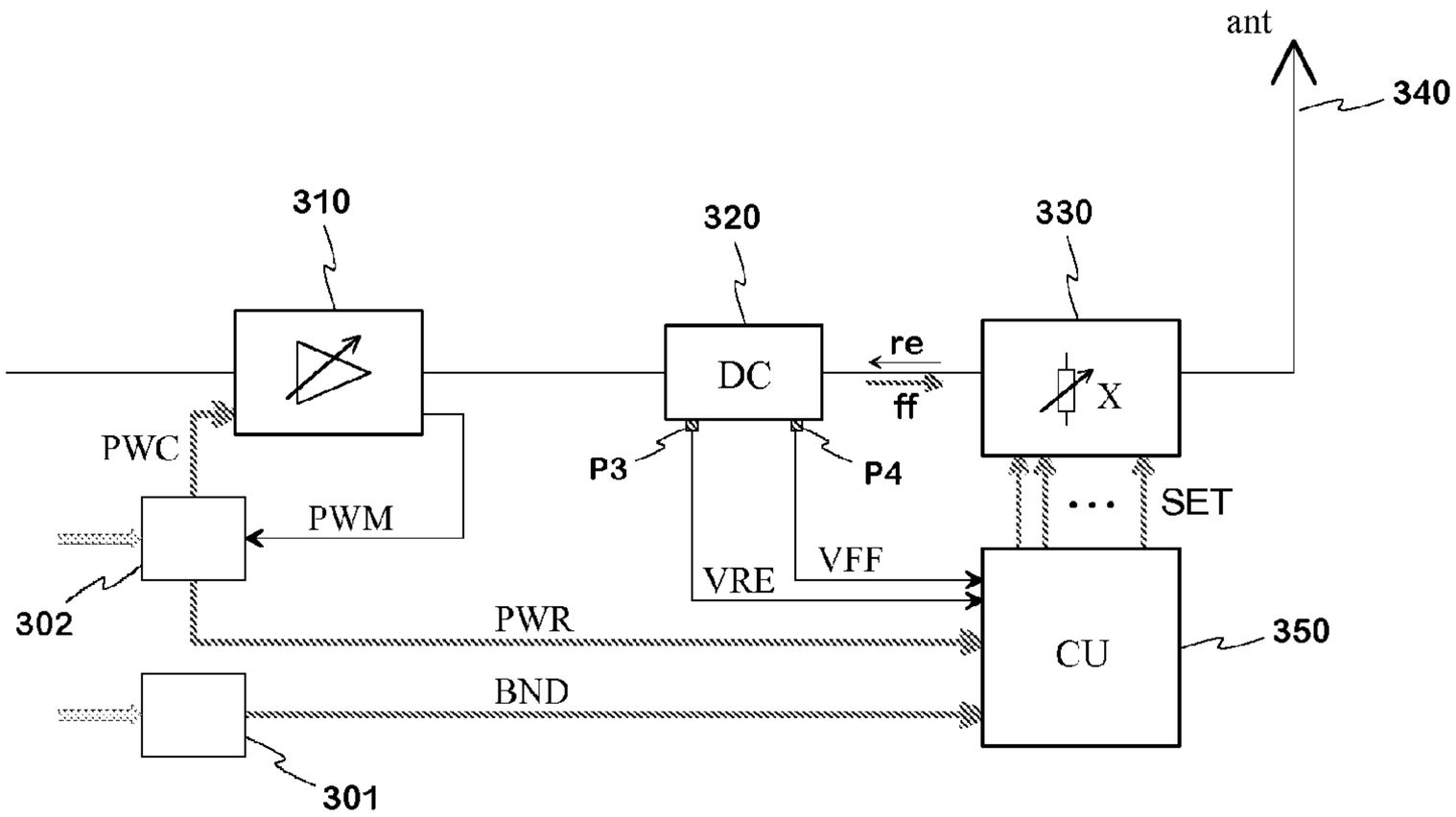

ant
340
310
320
330
DC
re
ff
X
PWC
P3
P4
SET
PWM
VRE
VFF
302
PWR
CU
350
BND
301

Fig. 3

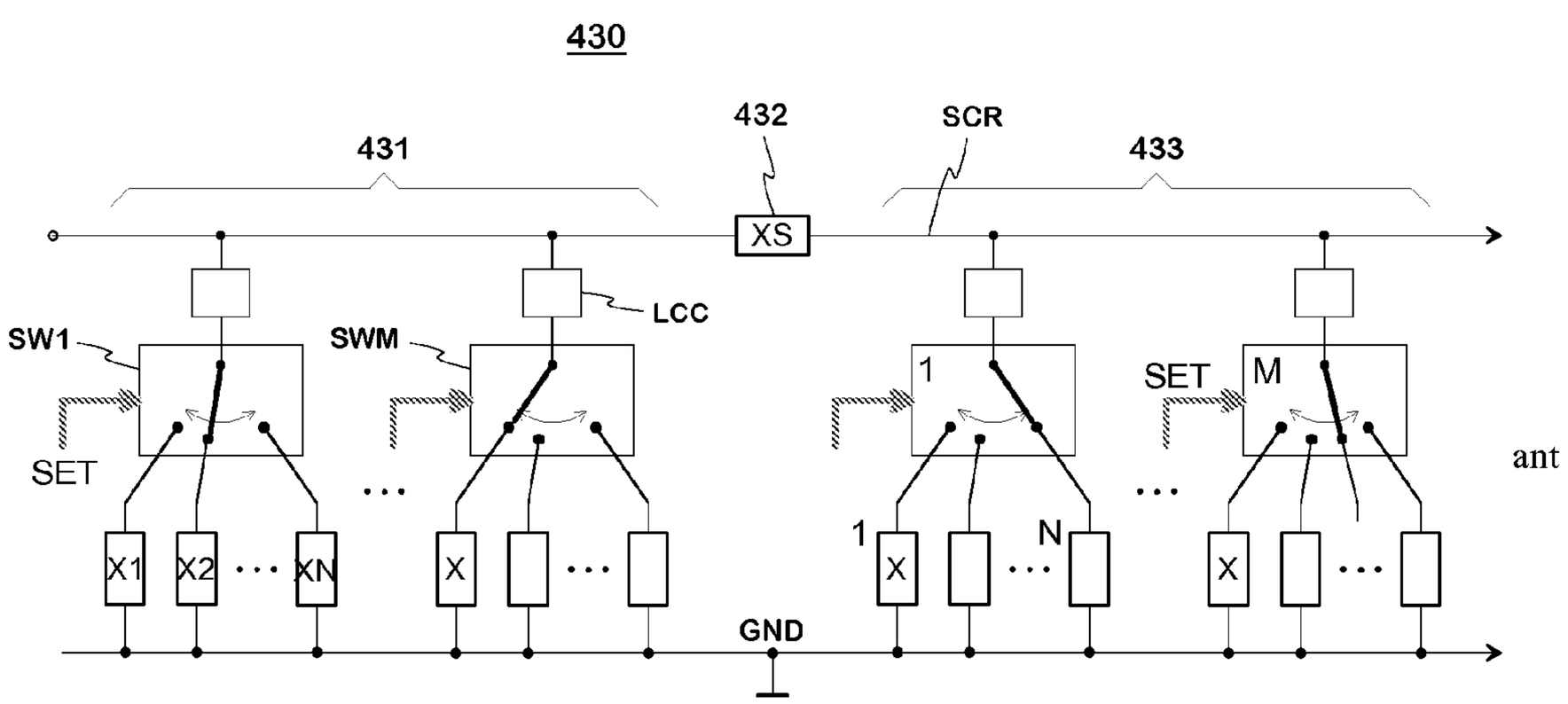
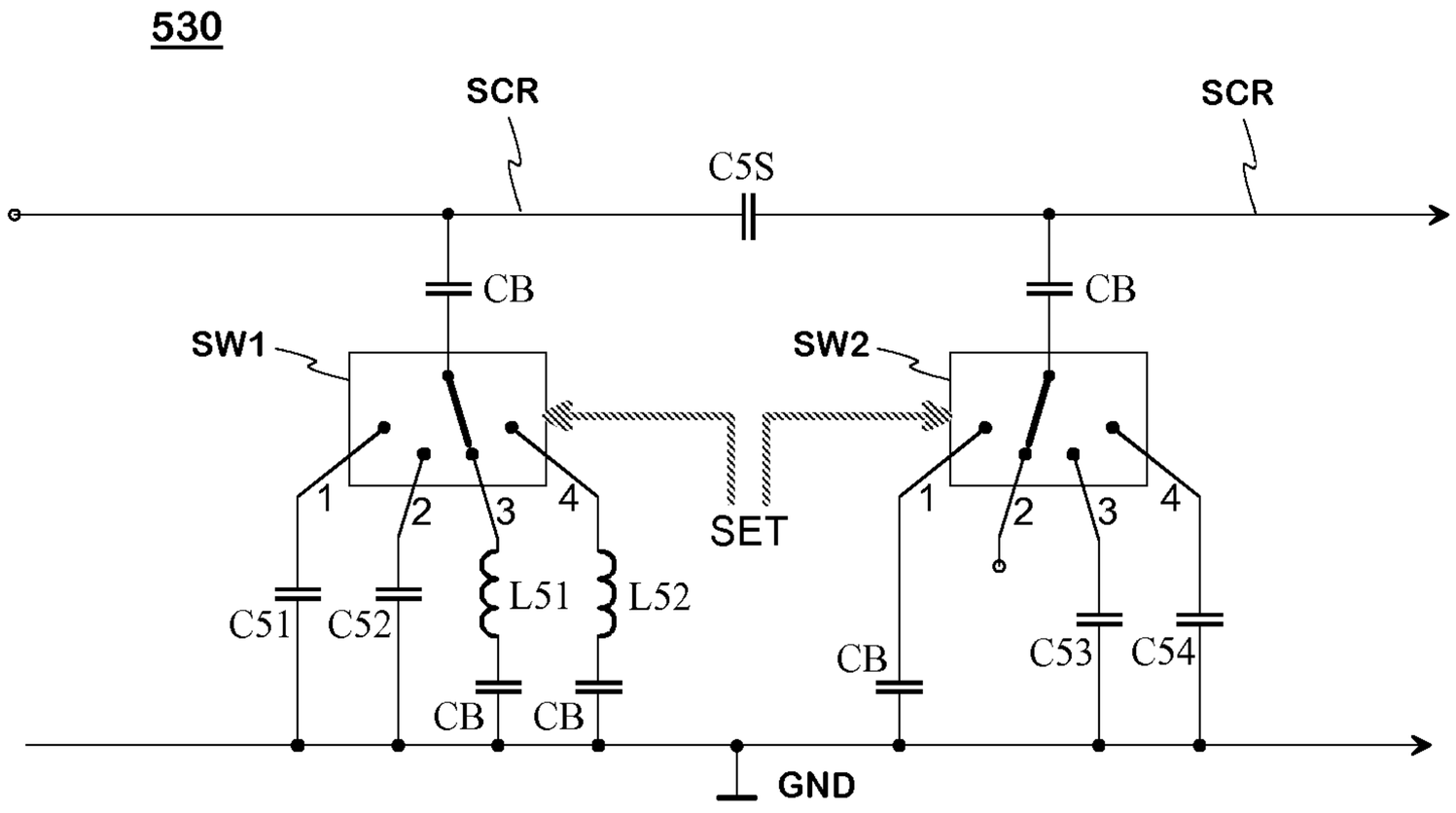

430
432
SCR
431
433
XS
LCC
SW1
SWM
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SET
M
SET
ant
X1
X2
XN
X
1
N
X
X
GND

Fig. 4



ant

Fig. 5

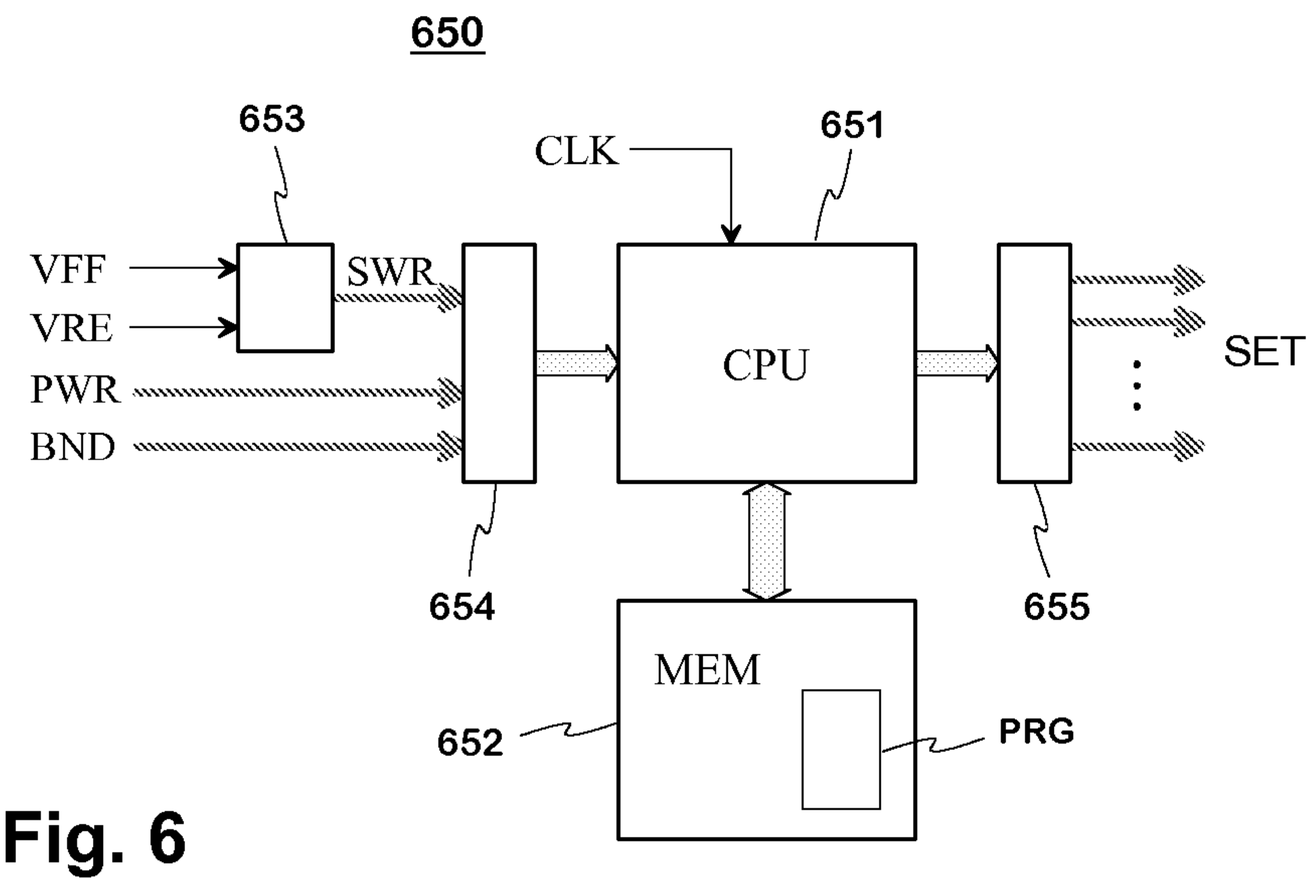


Fig. 6

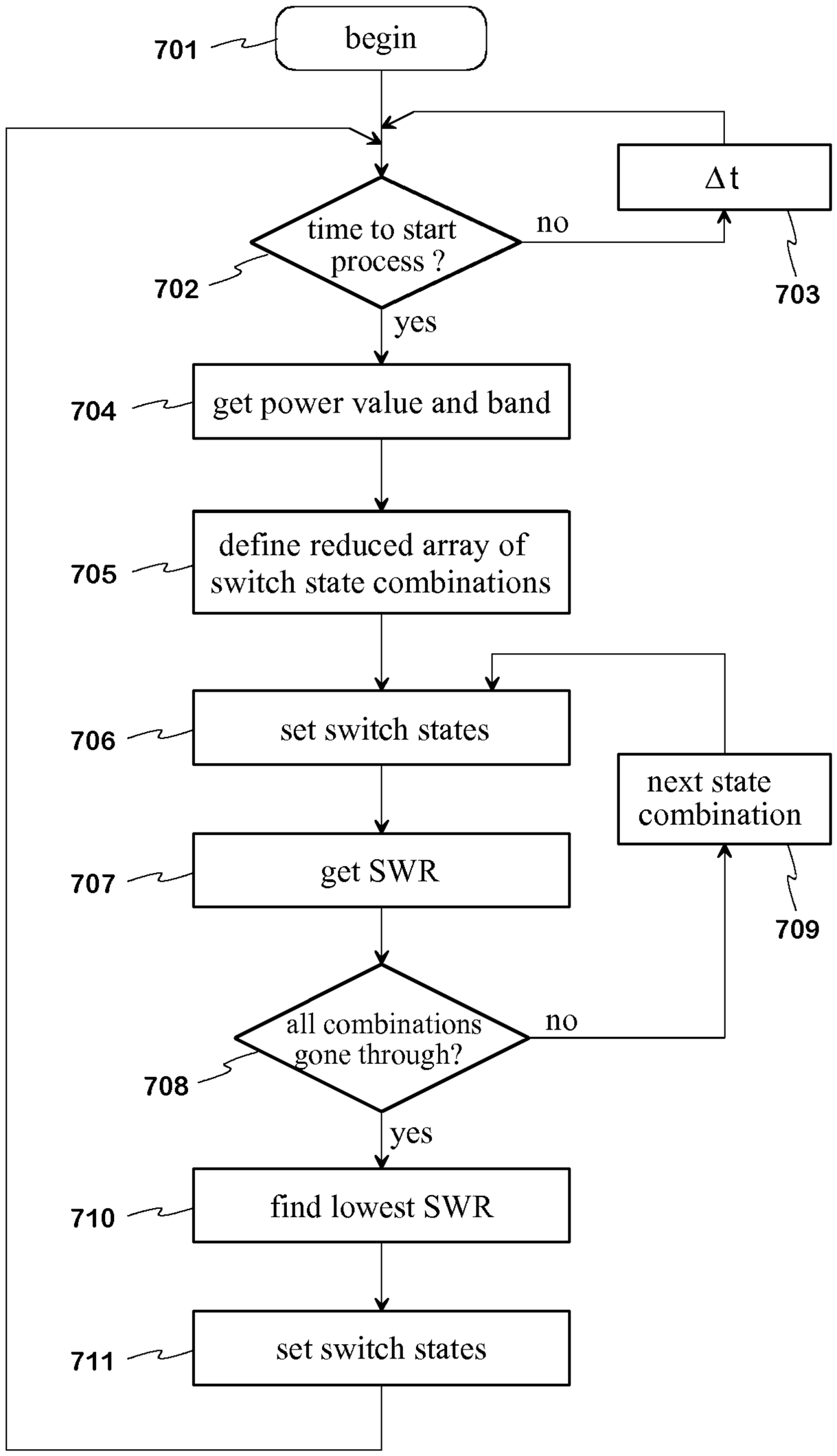

701
begin
Δt
time to start process ?
no
702
703
yes
704
get power value and band
705
define reduced array of switch state combinations
706
set switch states
707
get SWR
next state combination
709
all combinations gone through?
no
708
yes
710
find lowest SWR
711
set switch states

Fig. 7

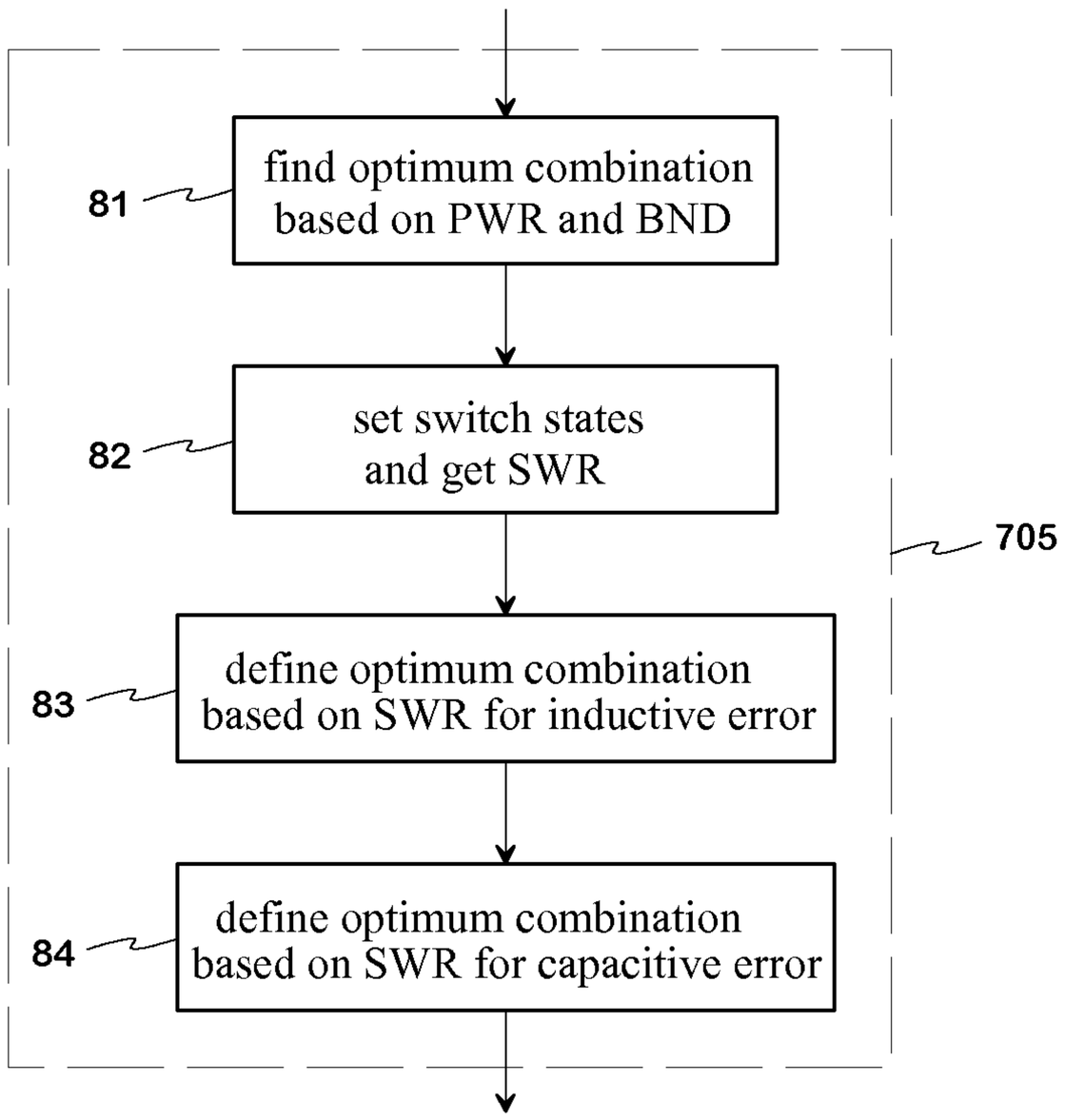

find optimum combination based on PWR and BND
81
set switch states and get SWR
82
define optimum combination based on SWR for inductive error
83
define optimum combination based on SWR for capacitive error
84
705

Fig. 8

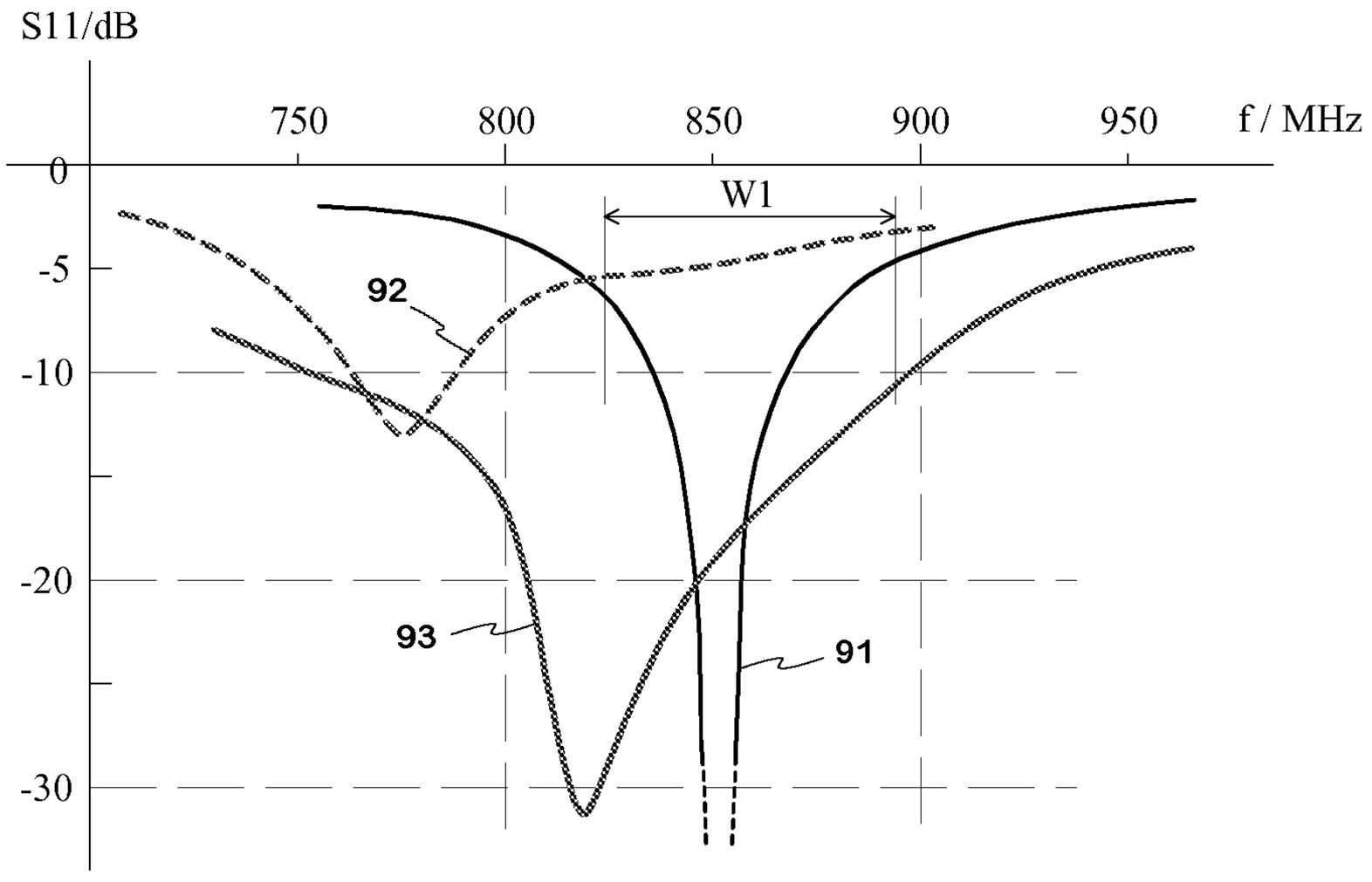

S11/dB
750
800
850
900
950
f / MHz
0
-5
-10
-20
-30
W1
92
93
91

Fig. 9

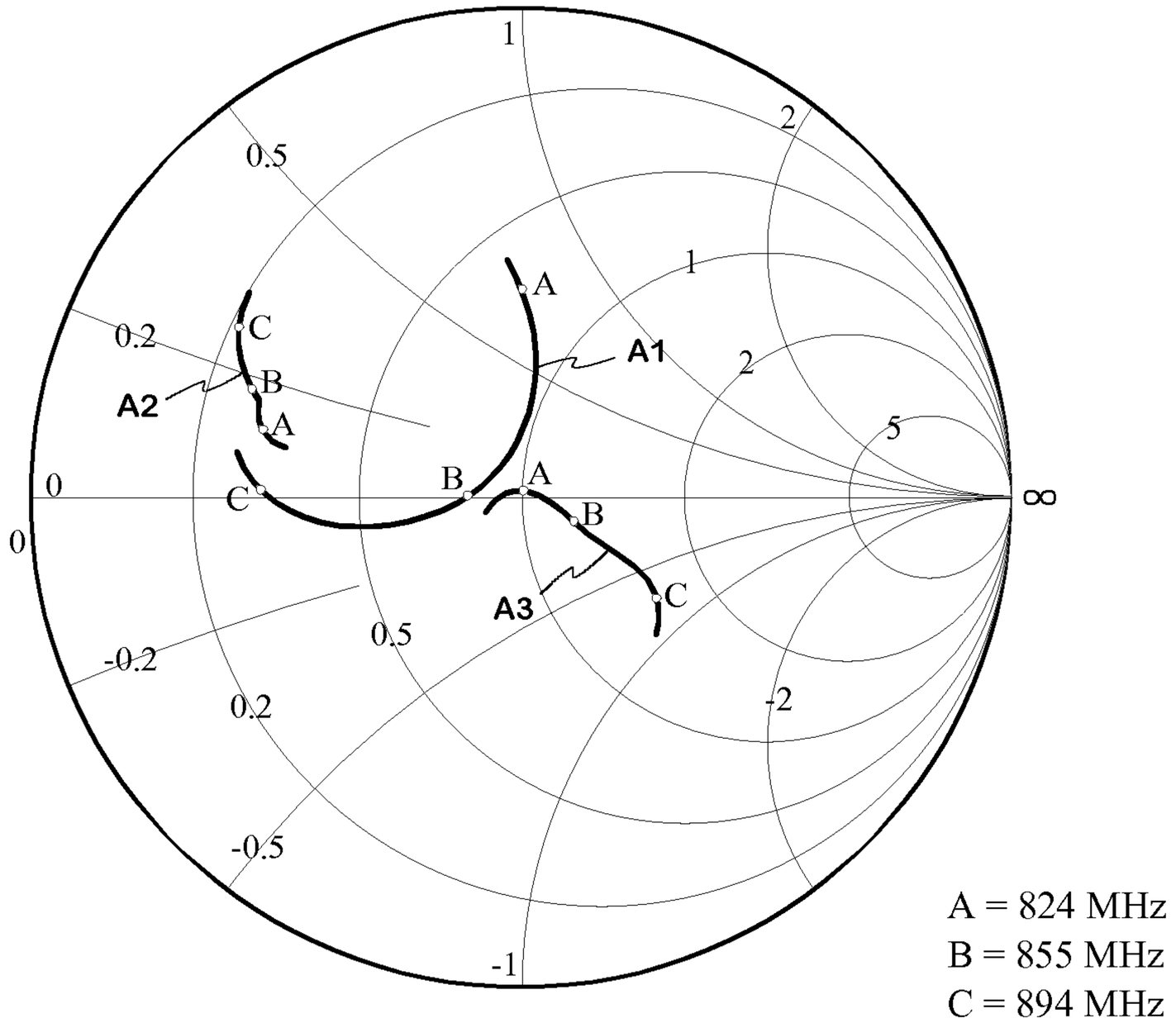

1
0.5
2
1
0.2
2
5
0
∞
0
-0.2
0.5
2
0.2
-0.5
-1
A
C
B
A
A1
A2
C
B
A
B
A
B
C
A3
C
A = 824 MHz
B = 855 MHz
C = 894 MHz

Fig. 10

METHODS AND APPARATUS FOR MATCHING AN ANTENNA

PRIORITY AND RELATED APPLICATIONS

This application is a National Stage Application of, and claims priority to, International Application No. PCT/FI2008/050200 under 35 U.S.C. 371, filed Apr. 17, 2008, which claims the benefit of priority to Finnish Patent Application Ser. No. 20075269, filed on Apr. 19, 2007, the priority benefit of which is also herein claimed, each of the foregoing being incorporated herein by reference in its entirety.

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BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates to the matching of the antenna of a radio device in transmitting condition, and it includes both a matching method and arrangement. The invention is intended especially for small-sized mobile terminals.

2. Description of Related Technology

Matching the impedance of the antenna of a radio device to the power amplifier of the transmitter feeding the antenna is a normal arrangement in transmission technology. By means of the matching, the radiation power of the antenna can be made as high as possible in proportion to the power of the power amplifier. The poorer the matching of the antenna, the higher the strength of the field reflected from the antenna towards the power amplifier in proportion to the strength of the field propagating towards the antenna. If a certain transmitting power is wanted even though the matching degrades, the gain of the power amplifier has to be raised, which will result in increased current consumption and possibly problems of heating up in the output stage.

The matching of an antenna can degrade for external and internal reasons. If the device approaches some conductive object, the impedance of the antenna changes. Similarly, already the head of a user and the hand, where the mobile terminal usually is during the connection, can cause a significant change in the impedance. Secondly, the internal output impedance of the power amplifier depends on the transmitting power: when the power is raised, the output impedance of the amplifier lowers and vice versa. This means that if the matching is good when the transmitting power has a certain value, a change in the power causes a degradation of the matching. For these facts it is favourable to make the antenna matching adaptable such that it varies to be each time conformable to the circumstances. In this case, the information of the strength of the field reflected from the antenna is used to control the matching circuit so that the antenna matching is all the time as good as possible.

In FIGS. **1** and **2** there is an example of the adaptable matching, known from the publication U.S. Pat. No. 5,778,308. The figure shows the transmission path of the transmitter as a simplified block diagram. There are, connected in series in the direction of the propagation of the signal, the power amplifier **110** of the transmitter, a directional coupler **120**, a reactive matching circuit **130** and the antenna **140**. The directional coupler and the matching circuit belong to the antenna's matching arrangement, which further comprises a control unit **150**, detectors **160**, analog-to-digital converters **170** and digital-to-analog converters **180**.

The antenna matching can never be perfect, so a certain part re of the propagating field ff is reflected back. The directional coupler provides two measuring signals: a radio frequency voltage proportional to the reflected field is received from its port P**3** and a radio frequency voltage proportional to the propagating field from its port P**4**. These measuring signals are converted to direct voltages by the detectors **160** and further to binary digits by said AD converters **170**. The digital signals provided by the AD converters are led to the control unit **150**. The control unit generates three control signals, which are converted to be analog by said DA converters **180**. The analog control signals are led to control inputs A, B and C of the matching circuit **130**. The control unit can be also analog, in which case the AD and DA converters are naturally not needed.

The principle of the adjustment in FIG. **1** is the following: The control unit **150** computes from the measuring signals provided by the directional coupler the ratio of the reflected and propagating signals, or the reflection coefficient of the antenna, and tries to keep it so low as possible. When the antenna matching degrades for some reason, the control unit searches for the control signals A, B and C such values that the reflection coefficient becomes lower and thus the antenna matching again improves. FIG. **2** shows an example of the structure of the matching circuit **130**. The matching circuit comprises three adjustable reactance circuits so that they form a network of π type. In the propagating direction of the transmitting signal there is first the first reactance circuit **131**, which is a transverse parallel resonance circuit. Then there is the second reactance circuit **132**, which is a longitudinal serial resonance circuit and lastly the third reactance circuit **133**, which is a transverse parallel resonance circuit. Each reactance circuit includes a capacitance diode as the adjusting element. The capacitance diode of the first reactance circuit, or the first capacitance diode CD**1**, is controlled through said control input A, the second capacitance diode CD**2** is controlled through the control input B and the third capacitance diode CD**3** is controlled through the control input C. Each control signal is led through a coil that the radio frequency signals would not reach the DA converters. In addition, there are blocking capacitors in the transmission path so that each control voltage can proceed only to the capacitance diode to be controlled.

As known, a parallel resonance circuit is inductive at the frequencies below the resonance frequency and capacitive at the frequencies above the resonance frequency. A serial resonance circuit again is capacitive at the frequencies below the resonance frequency and inductive at the frequencies above the resonance frequency. It has been programmed in the control unit **130** the values of the control voltage for each reactance circuit, which correspond to its resonance condition and to some capacitance and inductance values. Consequently the search process of the optimum matching in transmitting condition goes on as follows: First e.g. the first reactance circuit **131** is set to the resonance condition, in which case it represents a high impedance and therefore does not at all effect on the matching, and the second reactance circuit **132** is set to correspond a certain capacitance. The reactance of the third reacrance circuit **133** is changed step by step from a certain capacitive value to a certain inductive value, and the value of the reflection coefficient is calculated in each step. At second stage the second reactance circuit is set to correspond a cer-

tain inductance, the reactance of the third reactance circuit is again changed step by step from a certain capacitive value to a certain inductive value and the value of the reflection coefficient is calculated in each step. At third stage the third reactance circuit **133** is set to the resonance condition, in which case it represents a high impedance and therefore does not at all effect on the matching, and the second reactance circuit **132** is set to correspond a certain capacitance. The reactance of the first reactance circuit **131** is changed step by step from a certain capacitive value to a certain inductive value, and the value of the reflection coefficient is calculated in each step. At fourth stage the second reactance circuit is set to correspond a certain inductance, the reactance of the first reactance circuit is again changed step by step from a certain capacitive value to a certain inductive value and the value of the reflection coefficient is calculated in each step. From all reflection coefficient values thus obtained the lowest one is selected, and a respective control is inputted to the matching circuit. The process is started for example two times in a second. If the reflection coefficient is lower than a determined lower limit, the process is not executed. On the other hand, if the reflection coefficient is higher than a determined upper limit, the control unit again does not execute the process, but gives an alarm.

The capacitance diodes to be used in the solution described before result in drawbacks: The matching circuit according to the solution is poorly suitable for the transmitter, because its capacitance diodes do not function acceptably when the power is relatively high. In addition, the losses caused by them are remarkable also when the power is low. Moreover, a serial diode causes reflections in practice, because this kind of semiconductors are designed for the impedance level of 50Ω, and the output impedance of a power amplifier is normally remarkably lower. A drawback of the above-described solution is also that it includes a relatively complex adjusting algorithm.

An object of the invention is to implement the antenna matching in a new way so that the above-mentioned drawbacks are reduced.

In one aspect of the invention, the antenna impedance in the output of the power amplifier of a transmitter is adjusted by means of a π-shaped reactive matching circuit, the component values of which can be selected from a relatively wide array of the alternatives. In one embodiment, the component values are selected by means of the multiple-way switches, which only are located in the transverse branches of the matching circuit. The switches are set by the control unit, input variables of which being the SWR value provided by the directional coupler, the operating band used each time and a value of the transmitting power. The matching is based on an adjusting process to be executed at regular intervals, in which process the control unit tries different combinations of the switch states and finally selects the combination, which brings the lowest SWR value. In the beginning of the adjusting process the control unit reduces, on grounds of the current values of the input variables, the number of the combinations to be tried.

An advantage of the invention is that the mean efficiency of the transmitter in a certain period improves. This is due to the fact that in the arrangement according to the invention the antenna matching maintains relatively good, although the internal output impedance of the amplifier and the impedance from the output towards the antenna would strive to differ from each other for external reasons or a band changing. Also the impedance changes due to the changes in the transmitting power can be taken into account. The improvement of the efficiency results in that the current consumption of the radio device decreases and the power amplifier does not heat up so much. The efficiency remains relatively good also for the fact that the adjusting components are low-loss switches and no adjusting component is located in series in the transmission path. A further advantage of the invention is that the adjusting algorithm of the antenna impedance is relatively simple and fast. This is due to the fact that the most of the combinations of the switch states can be immediately removed on grounds of the input information of the control unit of the matching circuit.

In another aspect of the invention, a method for matching an antenna of a radio device is disclosed. In one embodiment, the antenna is associated with a radio device in which a standing wave ratio (SWR) value of a signal to be transmitted in a transmission path of the antenna is provided and a reactive pi-shaped matching circuit in the transmission path between a power amplifier of a transmitter and the antenna is adjusted to optimize a load impedance of the power amplifier, the matching circuit adjusted by a plurality of multiple-way switching elements located in transverse portions associated with the matching circuit, said method comprising: reading an information associated with an operating band that is in use; defining a trial array comprised of a subset of state combinations, said trial array being substantially smaller than a total array of a plurality of state combinations of said multiple-way switching elements, said act of defining utilizing at least a certain value of the transmitting power, said information associated with the operating band that is in use, and the SWR value; setting the switching elements of the matching circuit to each of the states associated with the subset of state combinations of the trial array; determining the SWR value of the signal to be transmitted in each state and determining the lowest one of the SWR values determined; setting the switches of the matching circuit to the state corresponding to the lowest one of the SWR values determined; and repeating the acts of reading, defining, determining and setting at a regular interval.

In one variant, said certain value of the transmitting power comprises a current set value of the transmitting power.

In another variant, said trial array is defined according to the method comprising: addressing a memory by means of at least the information associated with the operating band that is in use, the memory including a plurality of optimal state combinations for different operating bands and at least one transmitting power based on measurements made with the radio device; setting the states of the switching elements in the matching circuit in accordance with the state combination retrieved from said memory; reading the SWR value of the signal to be transmitted; defining based at least in part on the read SWR value and current switching element states a first state combination which is arranged to correct a matching error if it is inductive, and a second state combination, which is arranged to correct the matching error if it is capacitive; and determining the SWR values of the signal to be transmitted corresponding to the first and second state combinations.

The trial array comprises of e.g., the first state combination correcting an inductive matching error, and the second state combination correcting a capacitive matching error.

The adjustment of the matching circuit is made in another variant more accurate by defining at least two state combinations which are arranged to correct inductive or capacitive matching error based on the determination of which type of correction has been found to provide a better SWR value, said at least two state combinations comprising said trial array.

In a second embodiment of the method, the method comprises: adjusting an impedance value of a reactive matching circuit coupled to said antenna, said act of adjusting being

made based at least on: (1) an operating band signal indicative of the current operating band of a transmitter associated with the radio device; (2) a power level signal indicative of the current transmitting power of the transmitter; and/or (3) one or more impedance signals indicative of an impedance mismatch associated with a transmitted signal.

In one variant, said act of adjusting further comprises: defining a set of reactive matching circuit switching element combinations; setting said reactive matching circuit to each of said set of switching element combinations; determining a standing wave ratio (SWR) value for each of said combinations; choosing a lowest one of said SWR values; and adjusting the matching circuit based at least in part on said lowest one of said SWR value.

In another variant, the act of defining further comprises: selecting a first set of state combinations based on a defined operating band and a defined transmitting power of the radio device; setting the reactive matching circuit to each of the set of switching element combinations associated with the first set of state combinations; obtaining an SWR value for each of the switch combinations of the first set; defining a first state combination based at least in part on the obtained SWR value and current switching element states to correct a matching error if it is inductive; and defining a second state combination based at least in part on the obtained SWR value and current switching element states to correct a matching error if it is capacitive. The defined set of reactive matching circuit combinations comprises e.g., said first state combination and said second state combination.

In another aspect of the invention, an apparatus for matching an antenna of a radio device is disclosed. In one embodiment, a transmitter of the radio device comprises a power amplifier controllable by its output power and a transmission path from the power amplifier to the antenna, and the apparatus comprise: a directional coupler in said transmission path to measure a level of a signal transmitted to the antenna and of a signal reflected from the antenna; apparatus configured to determine a standing wave ratio (SWR) value of a signal in the transmission path of the antenna based at least in part on the measured signals provided with the directional coupler; a pi-shaped adjustable reactive matching circuit with a control unit, and further comprising a longitudinal portion of the matching circuit that has a constant capacitance or inductance, and a plurality of transverse portions comprising at least one multiple-way switch, a common terminal of which is coupled to a separate conductor of said transmission path and wherein each change-over terminal is coupled to a ground conductor of the transmission path through a reactive element, the control unit having a first input adapted for operative coupling to a setting unit of an operating band of the radio device, and the control unit being operatively coupled to said directional coupler from its input side, and to said at least one switch in the matching circuit from its output side so as to permit setting of the switches. The control unit comprises in one variant: apparatus configured to define a trial array of the state combinations of the switches in the matching circuit based at least in part on a certain value of the transmitting power, an information associated with the operating band and the SWR value; apparatus configured to set the switches of the matching circuit in turn to the states according to each state combination of the trial array to determine the SWR values correspond to these combinations; apparatus configured to compare the determined SWR values and for finding the lowest one of them; and apparatus configured to start an adjusting process of the antenna matching at regular intervals.

In another variant, each transverse portion of the matching circuit comprises two multiple-way switches, and each multiple-way switch comprises four change-over terminals.

In yet another variant, the control unit is based on a processor and comprises a central processing unit, a memory, input interfaces, output interfaces and a program in accordance with the adjusting process stored in the memory.

In yet another variant, said multiple-way switches are implemented by a pseudomorphic high electron mobility transistor (PHEMT) or a micro electro mechanical system (MEMS) technique.

In another embodiment, the apparatus comprises: a power amplifier comprising a power measuring signal output interface; a directional coupler comprising an impedance measuring signal output interface; a control unit coupled to said power measuring signal output interface and said impedance measuring signal interface; and a reactive matching circuit controlled at least in part by said control unit. The power amplifier, directional coupler and reactive matching circuit are positioned along a transmission path of said radio device.

In one variant, the reactive matching circuit comprises a plurality of multi-state switchable elements. Each of the multi-state switchable elements is coupled to said transmission path of said radio device.

In another variant, the transmission path within said reactive matching circuit comprises a plurality of transverse portions, each transverse portion of the matching circuit comprising two multi-state switchable elements with each multi-state element comprising four change-over terminals.

In still another variant, the control unit comprises: a central processing unit; a computer readable apparatus comprising a memory coupled to said central processing unit; an input interface; and an output interface. The computer readable apparatus has at least one computer program stored thereon, the at least one computer program comprising a plurality of computer executable instructions that when executed by the central processing unit: read a plurality of input signals received via said input interface; execute an algorithm based at least in part on said plurality of signals; and output a plurality of output signals via said output interface.

In another variant, said plurality of output signals adjust the impedance characteristics associated with said reactive matching circuit.

In yet another variant, said multi-state switchable elements are selected from the group consisting of: a pseudomorphic high electron mobility transistor (PHEMT), and a micro electro mechanical system (MEMS) technique.

Below, the invention is described in detail. Reference will be made to the accompanying drawings where

FIG. **1** presents as block diagram an example of the adaptable matching according to the prior art,

FIG. **2** presents an example of the structure of the matching circuit in FIG. **1**,

FIG. **3** presents as block diagram an example of the arrangement according to the invention,

FIG. **4** presents the principle of the structure of the matching circuit belonging to the arrangement according to the invention,

FIG. **5** presents an example of the implementation of the matching circuit according to FIG. **4**,

FIG. **6** presents as block diagram the principled structure of the control unit according to the invention,

FIG. **7** presents as flow chart an example of the method according to the invention,

FIG. **8** presents an example of the reducing the number of the state combinations to be tried of the switches of the matching circuit, the reducing belonging to the method according to the invention,

FIG. **9** presents by means of the reflection coefficient an example of the matching of an antenna provided with an arrangement according to the invention, and

FIG. **10** presents by means of the Smith diagram an example of the matching of an antenna provided with an arrangement according to the invention.

FIGS. **1** and **2** were already explained in conjunction with the description of the prior art.

FIG. **3** shows as block diagram an example of the arrangement according to the invention in the transmitter of a radio device. In the transmission path of the transmitter there are, named in the direction of the signal propagation, the power amplifier **310** of the transmitter, a directional coupler **320**, a reactive matching circuit **330** and an antenna **340**. In addition to the directional coupler and the matching circuit, a control unit **350** of the latter with its couplings belongs to the matching arrangement.

The transmitting power of the amplifier **310** can be changed by the power controlling signal PWC, which represents the set value of the power and is provided from the setting unit **302** of the transmitting power. A measuring signal PWM proportional to the true transmitting power is generated in the amplifier, which signal is used as a feedback signal to bring the transmitting power equal to its set value. The directional coupler **320** outputs two measuring signals: A radio frequency voltage VRE proportional to the reflected field re is received from its port P**3** and a radio frequency voltage VFF proportional to the propagating field ff from its port P**4**. The relative strength of the reflected field increases, when the antenna matching degrades for any reason.

The control unit **350** of the matching circuit has in this example four inputs. One input is connected to the setting unit **301** of the operating band of the radio device, from which unit it is received the band signal BND indicating the current operating band. The change of the band e.g. from the range of 900 MHz to the range of 1.8 GHz causes understandably an impedance change in the antenna, for which reason the matching has to be improved. The second input is connected to said setting unit **302** of the transmitting power, from which it is received the power signal PWR proportional to the set value of the transmitting power. It is specific to the power amplifier that its internal output impedance depends on the transmitting power: The higher the transmitting power, the lower in general the output impedance. A change in the power may cause a remarkable degradation in the matching, if the impedance change is not compensated for. Alternatively, the control unit can be programmed so that it uses as default value a certain value of the transmitting power, e.g. a value close to the maximum power, in which case the power signal PWR is not used and no second input is. The third and fourth input of the control unit are connected to the directional coupler for bringing said voltages VRE and VFF proportional to the reflected and propagating fields. The outputs SET of the control unit again are connected to the matching circuit **330** for selecting its component values.

The component values of the matching circuit are selected by means of the multiple-way switches, the number of which being at least two. The switches have a certain total number of state combinations. The control unit **350** executes at regular intervals an adjusting process. The standing wave ratio, or SWR, of the antenna is obtained from the measuring signals VRE and VFF provided by the directional coupler. SWR can be obtained by hardware with a converter, in which case the SWR value exists in the output of the converter all the time, or by software from the detected forms of the measuring signals. The higher SWR, the poorer matching. On grounds of the SWR value, the information of the operating band coming from the signal BND and the default value of the transmitting power or the set value of the transmitting power coming from the signal PWR the control unit chooses a substantially smaller array from the total array of the state combinations of the switches. The choice takes place in accordance with a certain algorithm, which again is based on the research information of the facts, how the antenna impedance has to be improved in different situations, the information being gathered in the design stage of the device. In the matching process the switches of the matching circuit are in turn set to each of the state combinations, which belong to said smaller array, and the SWR value of the transmitting signal is read in each setting. Finally in the process the control unit sets the switches to the states, the combination of which corresponds to the lowest of the obtained SWR values.

FIG. **4** shows the principled structure of the matching circuit according to the invention. The matching circuit **430** is a π-shaped network, which then comprises in order a first transverse portion **431**, a longitudinal portion **432** and a second transverse portion **433**. The longitudinal portion is simple. It is constituted by a reactive element XS in series with the separate conductor SCR of the antenna transmission path, which element has a certain constant capacitance or inductance. Generally, in FIG. **4** the symbol 'X' refers to an element/component, which has a certain capacitance or inductance. Naturally, the reactance of such a component then depends on the frequency. Each transverse portion comprises at least one change-over switch SW**1**, SWM with multiple states, the common terminal of which is coupled to the separate conductor SCR and each change-over terminal is coupled to the ground conductor of the transmission path, or the signal ground GND, through a reactive element X**1**, X**2**, XN. In FIG. **4** the number of the switches in the first transverse portion **431** is marked by the symbol M, and the number of the reactive elements to be selected by its first switch SW**1** is marked by the symbol N. The transverse portions then can consist of plurality of parallel transverse branches. The number of the switches in the first and second transverse portion can be unequal, and the number of the reactive elements to be selected by one switch is independent of the corresponding number of the other switches. The control SET of the matching circuit comes from the control unit belonging to the matching arrangement, by which control each switch can be separately set to a desired state.

Let us suppose the special case, in which both transverse portions comprise M switches, and the number of the reactive elements to be selected by each switch is N. Thus the total array of the state combinations of the matching circuits's switches includes $(M \cdot N)^2$ alternatives, or different combinations. If e.g. M is two and N is four, the total number of the state combinations becomes 64.

Between each switch and the separate conductor SCR of the transmission path there is in the example of FIG. **4** a LC circuit LCC, the object of which is to attenuate the harmonic frequency components being generated in the switch and to function as an ESD (ElectroStatic Discharge) protector for the switch. In addition, the serial capacitor belonging to the LC circuit functions, when needed, as a blocking capacitor preventing the forming of a direct current circuit from the switch control through the conductor SCR.

FIG. **5** shows a simple example of the matching circuit according to FIG. **4**. Each transverse portion of the matching circuit **530** comprise one switch, and the number of the reac-

tive elements to be selected by each switch is four. In this case the total number of the state combinations of the matching circuit becomes 16. The first reactive element of the first switch SW**1** is the capacitor C**51**, in other words the first change-over terminal of the switch SW**1** is connected to the signal ground through this capacitor. Correspondingly, the second reactive element of the first switch is the capacitor C**52**, the third reactive element is the coil L**51** and the fourth reactive element the coil L**52**. In series with both the coil L**51** and coil L**52** there is a blocking capacitor CB for breaking the direct current path from the switch control. The capacitance of the blocking capacitors is so high, for example 100 pF, that they constitute almost a short-circuit at the operating frequencies of the antenna. The first reactive element of the second switch SW**2** is intended to represent a very low reactance at the operating frequencies of the antenna. For this reason there is only a blocking capacitor between the first change-over terminal of the second switch and the signal ground. The second reactive element of the second switch is intended to represent a very high reactance at the operating frequencies of the antenna. For this reason the second change-over terminal of the second switch is open. The third reactive element of the second switch is the capacitor C**53** and the fourth reactive element is the capacitor C**54**. The longitudinal portion of the matching circuit is constituted by the capacitor C**5**S.

In the example of FIG. **5** one blocking capacitor CB is located also between the common terminal of the first switch SW**1** and the separate conductor SCR.

If the matching circuit of FIG. **5** is used with a customary dual-band PIFA, its design is for example the following: C**51**=1.5 pF, C**52**=7 pF, L**51**=3.3 nH, L**52**=22 nH, C**53**=1.5 pF, C**54**=2.7 pF and C**5**S=4.7 pF. (Here the symbol Cij means both a certain component and its capacitance, correspondingly Lij.) By means of this kind of design the antenna impedance can be improved irrespective of the direction of the error in the Smith diagram, at least approximately.

FIG. **6** shows the principled structure of the control unit according to the invention as a block diagram. The control unit **650** is based on a processor, in which case it comprises a central processing unit **651**, a memory **652**, input interfaces **654** and output interfaces **655**. The control unit further comprises a converter **653**, which generates from the radio frequency measuring signals VFF and VRE the standing wave ratio SWR of the transmitting signal in the antenna transmission path, as a binary digit. The SWR signal and the set value signal PWR of the transmitting power and operating band signal BND, which also are binary, are led to the input interfaces **654**, from which the central processing unit **651** reads them. The central processing unit transfers the control data corresponding to the state combination of the switches in the matching circuit, which has been selected as a result of the adjusting process, to the output interfaces **655**, which send the data further to the matching circuit.

The memory **652** of the control unit contains i.a. a matching program PRG, which implements the adjusting process of the matching. The process is started again at regular intervals, and the interval of the startings is counted either by software or by a timer circuit including in the central processing unit **651**. Of course, the central processing unit and the whole control unit need in any case a clock signal CLK.

The control unit **650** with its software can be a separate unit of its own or it can be a part of another processor in the radio device.

FIG. **7** shows as a flow chart an example of the method according to the invention. Step **701** represents the starting situation, in which the transmitter is set to the transmitting state. In steps **702** and **703** it is waited, until the deadline for starting the adjusting process of the antenna matching expires. In step **704** it is read the information of the current set value of the transmitting power and operating band. The control unit provides this information by reading the input interfaces **654** seen in FIG. **6**. In step **705** it is defined, on grounds of the operating band, the set value of the transmitting power and the SWR value, a substantially smaller array, or the trial array, from the total array of the state combinations of the switches in the matching circuit. The number of the state combinations to be tried during the process is then reduced. The reduction takes place in accordance with a certain algorithm, from which an example below. In step **706** it is set the states of the switches of the matching circuit so that the state combination belongs to said trial array. Then (step **707**) it is read the SWR value of the signal to be transmitted, corresponding to this state combination, and the SWR value is saved in the memory. In step **708** it is checked whether all the state combinations, which belong to the trial array, have already gone through. If not, a new state combination is selected (step **709**) and step **706** is resumed. When all the state combinations belonging to the trial array have gone through, the lowest one of the SWR values, which correspond to the tried state combinations, is found (step **710**). Finally in the adjusting process, step **711**, the switches in the matching circuit are set to the states, which correspond to the found lowest SWR value. Step **702** is resumed after this to wait the starting moment of the next execution round of the process. The interval of the starting moments is e.g. 10 ms. The duration of the process is remarkably shorter depending naturally on the number of the state combinations and the performance of the processor in the control unit.

Alternatively, in step **704** it is read the information only of the current operating band, and in step **705** it is defined the trial array on grounds of the operating band, the default value of the transmitting power and the SWR value.

FIG. **8** shows an example of the method step **705** according to FIG. **7**. In the example the matching program PRG first reads the information of the operating band from the signals BND and possibly the set value of the transmitting power from the signal PWR and then finds the state combination for the switches in the matching circuit on grounds of these informations (step **81**). The state combination is optimal with the presumption that the external factors do not interfere the antenna matching. The optimal state combinations for different operating bands and possibly transmitting powers are stored in the memory of the control unit on grounds of the measurements made with the radio device in question, and in step **81** at least said information of band is used for addressing the memory. In addition, the information of the power is used, when the current set value of the transmitting power is taken into account. If the total transmitting power range is divided for example to four partial ranges in the control unit and the number of the operating bands is two, there are eight different state combinations in the memory for the execution of step **81**. In step **82** the states of the switches in the matching circuit are set in accordance with said supposed optimum, and the SWR value of the signal to be transmitted is read. If it is significantly more than one, the antenna matching must be interfered for external reasons. It does not appear from the SWR value, whether the matching error is to the inductive or capacitive direction. For this reason in the next step **83** it is defined, on grounds of the SWR value and current switch states, a state combination which corrects the matching error wholly according to estimate, if it is inductive. Correspondingly, in step **84** it is defined another state combination which corrects the matching error wholly according to estimate, if the error is capacitive. Naturally the order of the steps **83** and

84 does no matter. After this the operation continues to step 706 in FIG. 7. In this case said trial array is then constituted of only two combinations, from which the one will be selected, which provides a better SWR value. In this way the number of the rounds of the switch setting and SWR determining is reduced, and the matching process becomes as fast as possible.

The adjustment can also made more accurate so that some state combinations are selected in the 'surroundings' of the state combination providing the better SWR value, which constitute the final trial array. The 'surroundings' refer here to the fact that the loading impedances of the amplifier, which correspond to these state combinations, are close to each other in the Smith diagram.

The choices of the state combinations of the switches on grounds of the SWR value and current switch states are based on the calculation. The current switch states are taken into account by using also the impedances of the matching circuit, which correspond to the switch states, as factors in the calculation.

In FIG. 9 there is an example of the matching of an antenna provided with an arrangement according to the invention, shown by means of the reflection coefficient. The antenna is a usual dual-band PIFA, and the matching circuit belonging to the arrangement is like the one in FIG. 5 with the component values mentioned in its description. The example relates to the matching in the lower operating band, which is in this example intended to cover the frequency range 824-894 MHz of the GSM850 system. This range has been marked W1 in FIG. 9. The transmitting power is relatively low. Curve 91 shows the fluctuation of the reflection coefficient S11 as a function of frequency when the antenna is almost in a free space. In this case, the best matching in the lower operating band is obtained when the first switch SW1 is in state 3, or its common terminal is connected to the third change-over terminal, and also the second switch SW2 is in state 3. It is seen from the curve that the reflection coefficient is −5 dB or better in the frequency range W1. Curve 92 shows the fluctuation of the reflection coefficient when a finger of the user is at the antenna on the radiator, and the switches are in the above-mentioned states. It is seen from the curve that the lower resonance frequency of the antenna has been displaced clearly below the range W1 and the reflection coefficient is only between the values −3 dB and −5 dB in the range W1. Curve 93 shows the fluctuation of the reflection coefficient when a finger of the user still is in the same place on the radiator, and the switches are set in a new way. Now the best matching is obtained when the first switch SW1 is in state 4 and the second switch SW2 is in state 2. It is seen from the curve that the matching has been improved so that the reflection coefficient is −11 dB or better in the frequency range W1.

Regarding the upper operating band, improvements in the antenna matching can be done similarly, when it degrades.

In FIG. 10 there is an example of the matching of an antenna provided with an arrangement according to the invention, shown by means of the Smith diagram. In the example the antenna and the matching circuit are the same as in the example of FIG. 9. Also the impedance curves in the diagram correspond to the curves of the reflection coefficient in FIG. 9. Thus curve A1 shows the fluctuation of the impedance in the lower operating band as a function of frequency when the antenna is almost in a free space, curve A2 shows the fluctuation of the impedance when a finger of the user is at the antenna on the radiator and the switch states have not been changed, and curve A3 shows the fluctuation of the impedance when a finger of the user still is in the same place on the radiator, and the switches are set in a new way.

The nominal impedance of the transmission path is 50Ω. In the case of curve A1 the overall impedance is relatively close to it in the middle band, the reactive part being small. At the lower border of the band the impedance is clearly inductive (Z≈34Ω+j37Ω). At the upper border again the reactive part is very small, but the resistive part has fallen to the value of about 15Ω. In the case of curve A2 the mismatch is clearly visible, the impedance Z changing about the value 13Ω+j10Ω). In the matching case shown by curve A3 the impedance is almost precisely 50Ω at the lower border of the band. When moving to the upper border the impedance changes to the value of about 80Ω−j35Ω.

The method and arrangement according to the invention for matching the antenna of a radio device in transmitting condition has been described above. In the flow charts presenting the method, the functional blocks can be drawn also in other ways and in different order than in FIGS. 7 and 8 without changing the idea, though. The trial array of the state combinations of the switches can be defined, instead of the use of a table in the memory, also fully by calculation. In this case the information gathered in the preceding measurements is included in the parameters of the calculation formulas. The extent of the matching circuit belonging to the arrangement can vary a great deal, and the implementation of its reactive elements can vary. At least part of them can be also short planar transmission lines on the surface of a circuit board. The switching parts proper of the switches of the matching circuit are for example of PHEMT (Pseudomorphic High Electron Mobility Transistor) or MEMS (Micro Electro Mechanical System) type. The invention does not limit the structure and type of the antenna proper. The inventive idea can be applied in different ways within the scope defined by the independent claims 1 and 6.

The invention claimed is:

1. An apparatus for matching an antenna of a radio device, said apparatus comprising:

a power amplifier comprising a power measuring signal output interface;

a directional coupler comprising an impedance measuring signal output interface;

a control unit coupled to said power measuring signal output interface and said impedance measuring signal interface; and

a reactive matching circuit controlled at least in part by said control unit;

wherein said power amplifier, directional coupler and reactive matching circuit are positioned along a transmission path of said radio device.

2. The apparatus of claim 1, wherein the control unit is further configured to adjust an impedance value of the reactive matching circuit based at least on: (1) an operating band signal indicative of the current operating band of a transmitter associated with the radio device; (2) a power level signal indicative of the current transmitting power of the transmitter; and/or (3) one or more impedance signals indicative of an impedance mismatch associated with a transmitted signal.

3. The apparatus of claim 2, wherein the control unit further comprises a computer readable apparatus having at least one computer program stored thereon, the at least one computer program comprising a plurality of computer executable instructions that when executed by a central processing unit:

define a set of reactive matching circuit switching element combinations;

set said reactive matching circuit to each of said set of switching element combinations;

determine a standing wave ratio (SWR) value for each of said combinations;

choose a lowest one of said SWR values; and

adjust said reactive matching circuit based at least in part on said lowest one of said SWR value;

wherein the acts of defining, setting, determining, choosing and adjusting aids in the adjustment of the impedance value of the reactive matching circuit.

4. The apparatus of claim **3**, wherein the control unit further comprises a computer readable apparatus having at least one computer program stored thereon that define the set of reactive matching circuit switching element combinations, the at least one computer program comprising a plurality of computer executable instructions that when executed by a central processing unit:

select a first set of state combinations based on a defined operating band and a defined transmitting power of the radio device;

set the reactive matching circuit to each of the set of switching element combinations associated with the first set of state combinations;

obtain an SWR value for each of the switch combinations of the first set;

define a first state combination based at least in part on the obtained SWR value and current switching element states to correct a matching error if it is inductive; and

define a second state combination based at least in part on the obtained SWR value and current switching element states to correct a matching error if it is capacitive.

5. The apparatus of claim **4**, wherein said defined set of reactive matching circuit combinations comprises said first state combination and said second state combination.

6. The apparatus of claim **1**, wherein the reactive matching circuit comprises a plurality of multi-state switchable elements.

7. The apparatus of claim **6**, wherein each of the multi-state switchable elements is coupled to said transmission path of said radio device.

8. The apparatus of claim **7**, wherein the transmission path within said reactive matching circuit comprises a plurality of transverse portions, each transverse portion of the matching circuit comprising two multi-state switchable elements with each multi-state element comprising four change-over terminals.

9. The apparatus of claim **7**, wherein said control unit comprises:

a central processing unit;

a computer readable apparatus comprising a memory coupled to said central processing unit;

an input interface; and

an output interface;

wherein said computer readable apparatus has at least one computer program stored thereon, the at least one computer program comprising a plurality of computer executable instructions that when executed by the central processing unit:

read a plurality of input signals received via said input interface;

execute an algorithm based at least in part on said plurality of signals; and

output a plurality of output signals via said output interface.

10. The apparatus of claim **9**, wherein said plurality of output signals adjust the impedance characteristics associated with said reactive matching circuit.

11. The apparatus of claim **10**, wherein said multi-state switchable elements are selected from the group consisting of a pseudomorphic high electron mobility transistor (PHEMT), and a micro electro mechanical system (MEMS) technique.

12. The apparatus of claim **7**, wherein said control unit comprises:

a central processing unit;

a computer readable apparatus comprising a memory coupled to said central processing unit, wherein said computer readable apparatus has at least one computer program stored thereon, the at least one computer program comprising a plurality of computer executable instructions that are configured to, when executed by the central processing unit:

read an information associated with an operating band that is in use;

define a trial array comprised of a subset of state combinations, said trial array being substantially smaller than a total array of a plurality of state combinations of said multi-way switchable elements;

utilize at least a certain value of the transmitting power, said information associated with the operating band that is in use, and a standing wave ratio (SWR) value when defining the trial array;

set the multi-way switchable elements of the reactive matching circuit to each of the states associated with the subset of state combinations of the trial array;

determine the SWR value of the signal to be transmitted in each state and determine the lowest one of the SWR values determined; and

set the multi-state switchable elements of the reactive matching circuit to the state corresponding to the lowest one of the SWR values determined.

13. The apparatus of claim **12**, wherein said certain value of the transmitting power comprises a current set value of the transmitting power.

14. The apparatus of claim **12**, wherein said at least one computer program for defining the trial array further comprises a plurality of computer executable instructions that when executed by the central processing unit:

address a memory by means of at least the information associated with the operating band that is in use, the memory including a plurality of optimal state combinations for different operating bands and at least one transmitting power based on measurements made with the radio device;

set the states of the multi-state switchable elements in the matching circuit in accordance with the state combination retrieved from said memory;

read the SWR value of the signal to be transmitted;

define based at least in part on the read SWR value and current switching element states a first state combination which is arranged to correct a matching error if it is inductive, and a second state combination, which is arranged to correct the matching error if it is capacitive; and

determine the SWR values of the signal to be transmitted corresponding to the first and second state combinations.

15. The apparatus of claim **14**, wherein said trial array comprises the first state combination correcting an inductive matching error, and the second state combination correcting a capacitive matching error.

16. The apparatus of claim **14**, wherein the adjustment of the matching circuit is made more accurate by defining at least two state combinations which are arranged to correct inductive or capacitive matching error based on the determination of which type of correction has been found to provide a better SWR value, said at least two state combinations comprising said trial array.

17. An apparatus for matching an antenna of a radio device, wherein a transmitter of the radio device comprises a power amplifier controllable by its output power and a transmission path from the power amplifier to the antenna, the apparatus comprising:

a directional coupler in said transmission path to measure a level of a signal transmitted to the antenna and of a signal reflected from the antenna;

apparatus configured to determine a standing wave ratio (SWR) value of a signal in the transmission path of the antenna based at least in part on the measured signals provided with the directional coupler;

a pi-shaped adjustable reactive matching circuit with a control unit, and further comprising a longitudinal portion of the matching circuit that has a constant capacitance or inductance, and a plurality of transverse portions comprising at least one multiple-way switch, a common terminal of which is coupled to a separate conductor of said transmission path and wherein each change-over terminal is coupled to a ground conductor of the transmission path through a reactive element, the control unit having a first input adapted for operative coupling to a setting unit of an operating band of the radio device, and the control unit being operatively coupled to said directional coupler from its input side, and to said at least one switch in the matching circuit from its output side so as to permit setting of the switches, the control unit comprising:

apparatus configured to define a trial array of the state combinations of the switches in the matching circuit based at least in part on a certain value of the transmitting power, an information associated with the operating band and the SWR value;

apparatus configured to set the switches of the matching circuit in turn to the states according to each state combination of the trial array to determine the SWR values correspond to these combinations;

apparatus configured to compare the determined SWR values and for finding the lowest one of them; and

apparatus configured to start an adjusting process of the antenna matching at regular intervals.

18. The apparatus of claim 17, characterized in that each transverse portion of the matching circuit comprises two multiple-way switches, and each multiple-way switch comprises four change-over terminals.

19. The apparatus of claim 17, characterized in that the control unit is based on a processor and comprises a central processing unit, a memory, input interfaces, output interfaces and a program in accordance with the adjusting process stored in the memory.

20. The apparatus of claim 17, characterized in that said multiple-way switches are implemented by a pseudomorphic high electron mobility transistor (PHEMT) or a micro electro mechanical system (MEMS) technique.

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