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(54) NON-CONTACT POWER TRANSMISSION APPARATUS AND POWER TRANSMISSION DEVICE

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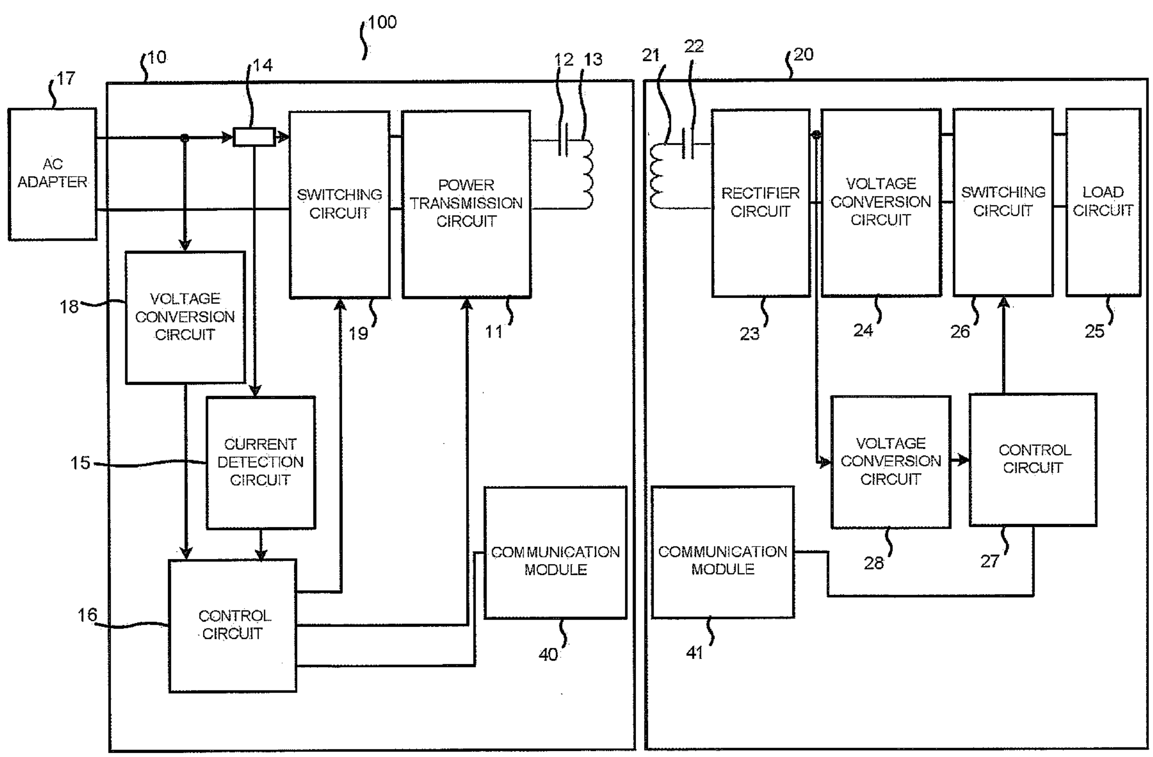
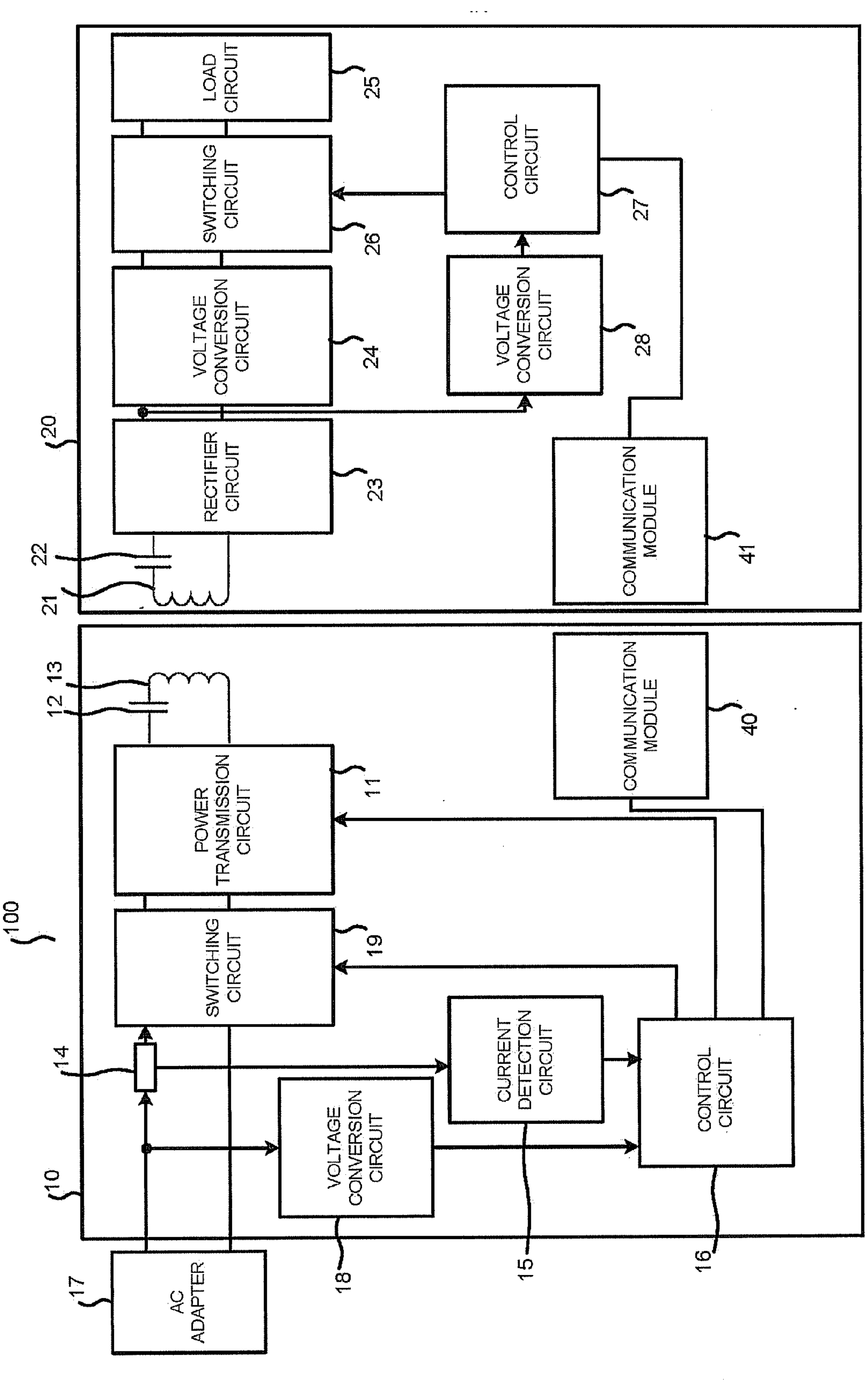
(57) **ABSTRACT**

A non-contact power transmission apparatus comprises a power transmission device configured to include a power transmission circuit that is connected to a power transmission coil and supplies power and a current detection circuit that detects current supplied to the power transmission circuit; and a power receiving device configured to include a rectifier circuit which is connected to a power receiving coil, a voltage conversion circuit which is connected to the rectifier circuit and converts into voltage of driving a load circuit and a switching circuit which connects or disconnects the voltage generated by the voltage conversion circuit with the load circuit.

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LOAD CIRCUIT
25
SWITCHING CIRCUIT
26
VOLTAGE CONVERSION CIRCUIT
24
RECTIFIER CIRCUIT
23
22
21
CONTROL CIRCUIT
27
VOLTAGE CONVERSION CIRCUIT
28
COMMUNICATION MODULE
41
100
10
13
12
POWER TRANSMISSION CIRCUIT
11
SWITCHING CIRCUIT
19
14
CURRENT DETECTION CIRCUIT
15
VOLTAGE CONVERSION CIRCUIT
18
CONTROL CIRCUIT
16
COMMUNICATION MODULE
40
AC ADAPTER
17

FIG.1

FIG.2

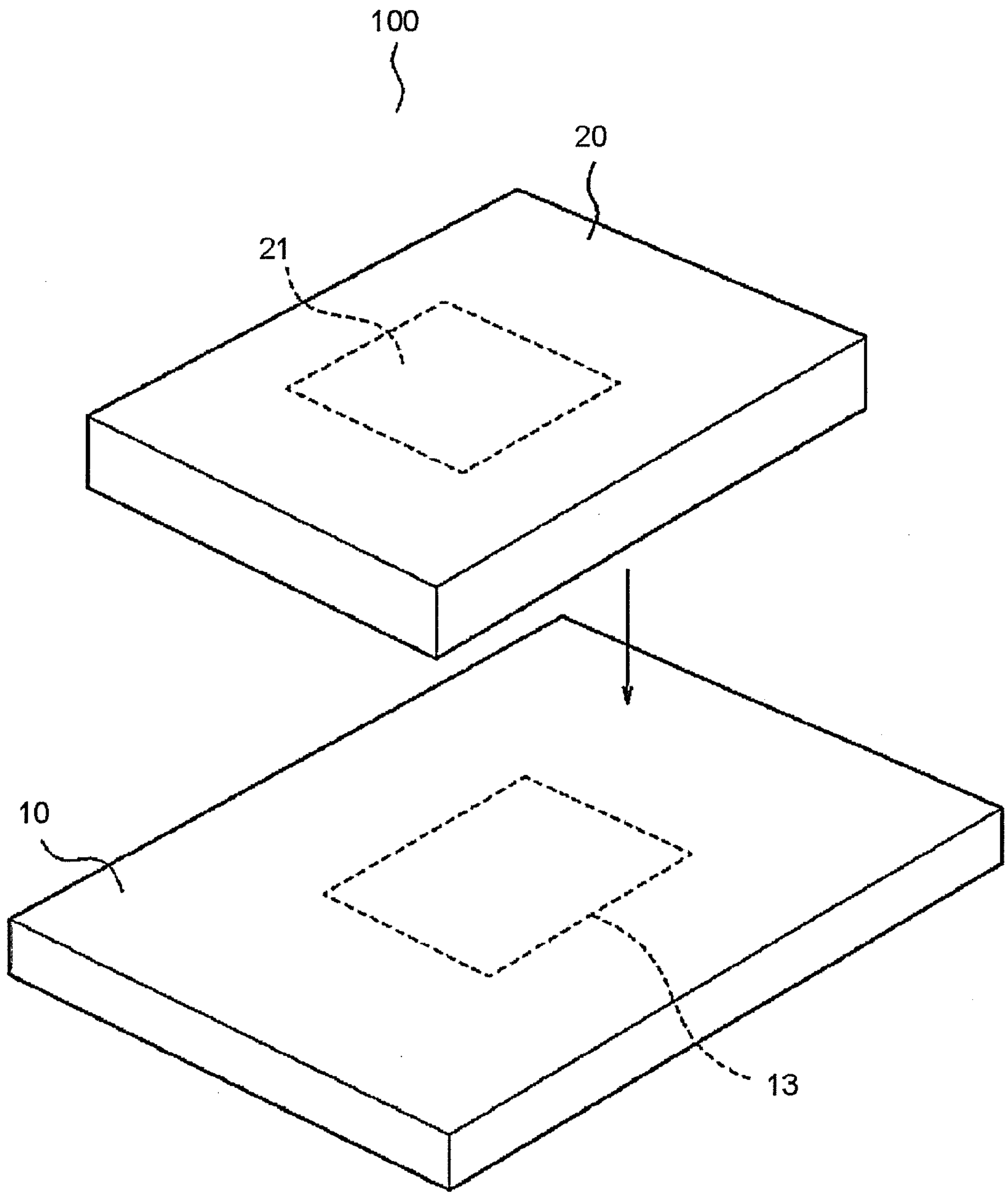


FIG.3

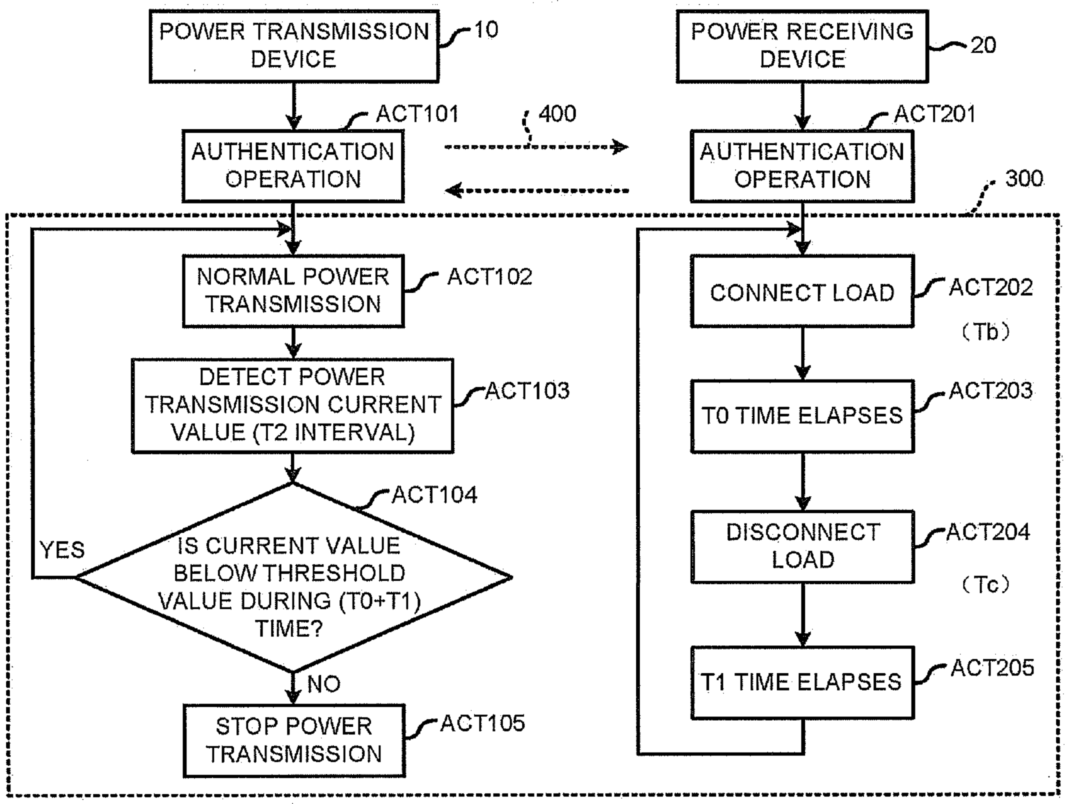

POWER TRANSMISSION DEVICE
10
POWER RECEIVING DEVICE
20
ACT101
400
ACT201
AUTHENTICATION OPERATION
AUTHENTICATION OPERATION
300
NORMAL POWER TRANSMISSION
ACT102
CONNECT LOAD
ACT202
(Tb)
DETECT POWER TRANSMISSION CURRENT VALUE (T2 INTERVAL)
ACT103
T0 TIME ELAPSES
ACT203
ACT104
YES
IS CURRENT VALUE BELOW THRESHOLD VALUE DURING (T0+T1) TIME?
DISCONNECT LOAD
ACT204
(Tc)
NO
T1 TIME ELAPSES
ACT205
STOP POWER TRANSMISSION
ACT105

FIG.4

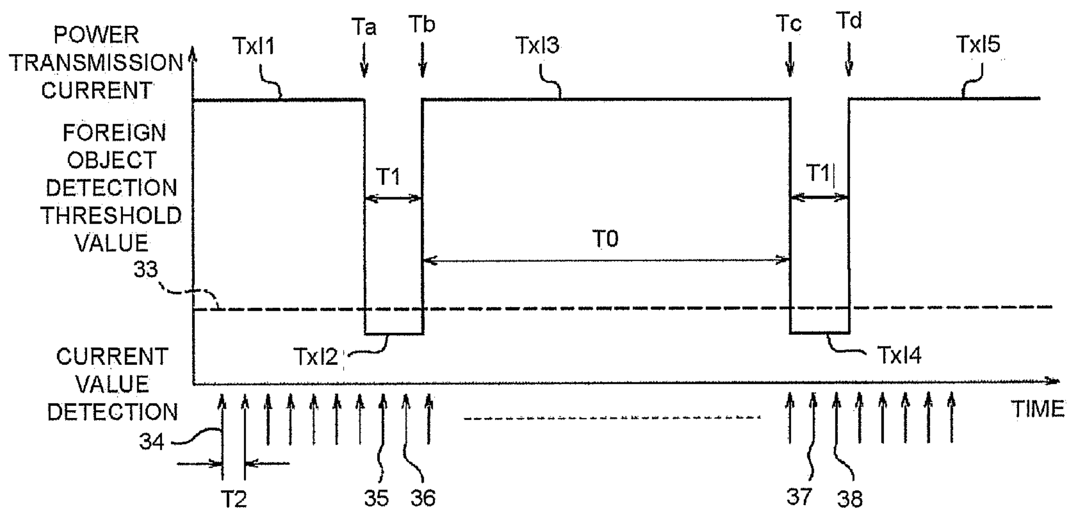

POWER TRANSMISSION CURRENT
TxI1
Ta
Tb
TxI3
Tc
Td
TxI5
FOREIGN OBJECT DETECTION THRESHOLD VALUE
33
T1
T1
T0
TxI2
TxI4
CURRENT VALUE DETECTION
34
TIME
T2
35
36
37
38

FIG.5

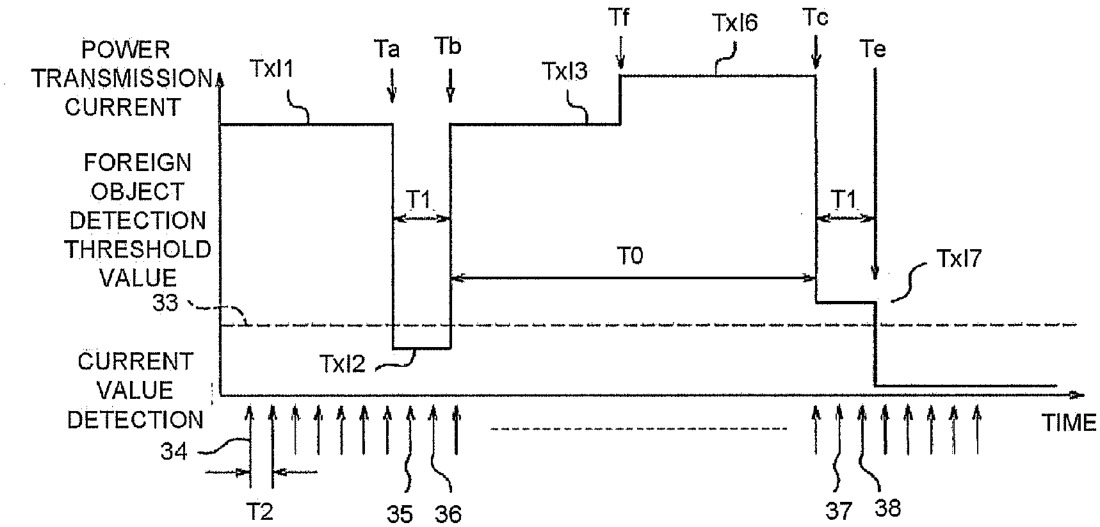

POWER TRANSMISSION CURRENT
FOREIGN OBJECT DETECTION THRESHOLD VALUE
33
CURRENT VALUE DETECTION
34
T2
TxI1
Ta
Tb
Tf
TxI3
TxI6
Tc
Te
T1
T0
T1
TxI7
TxI2
35
36
37
38
TIME

FIG.6

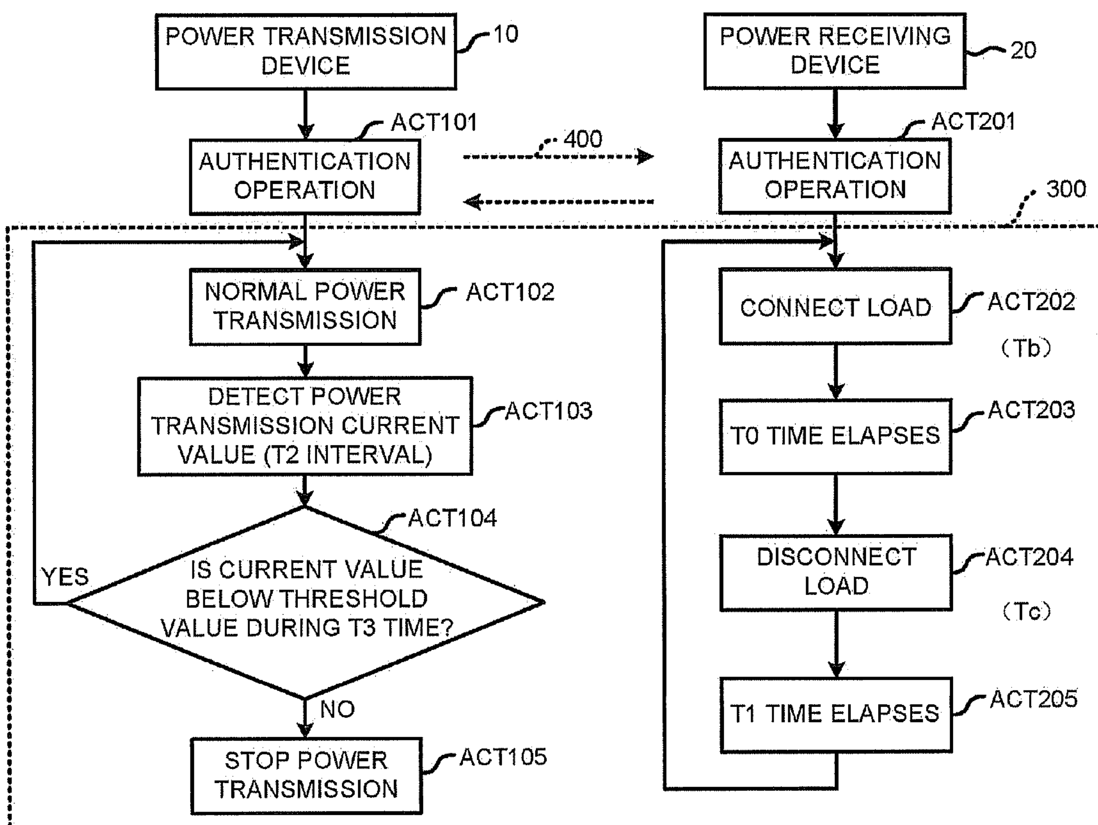
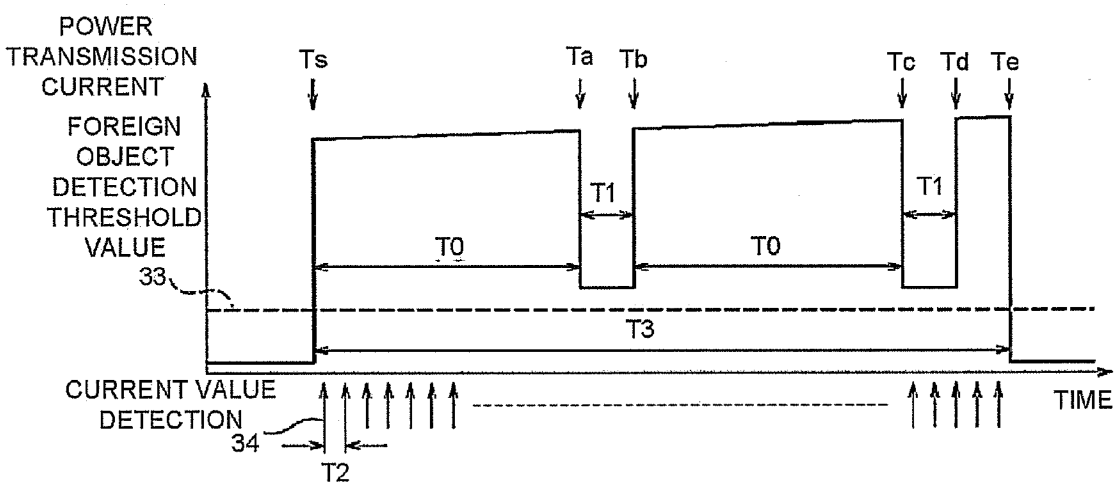
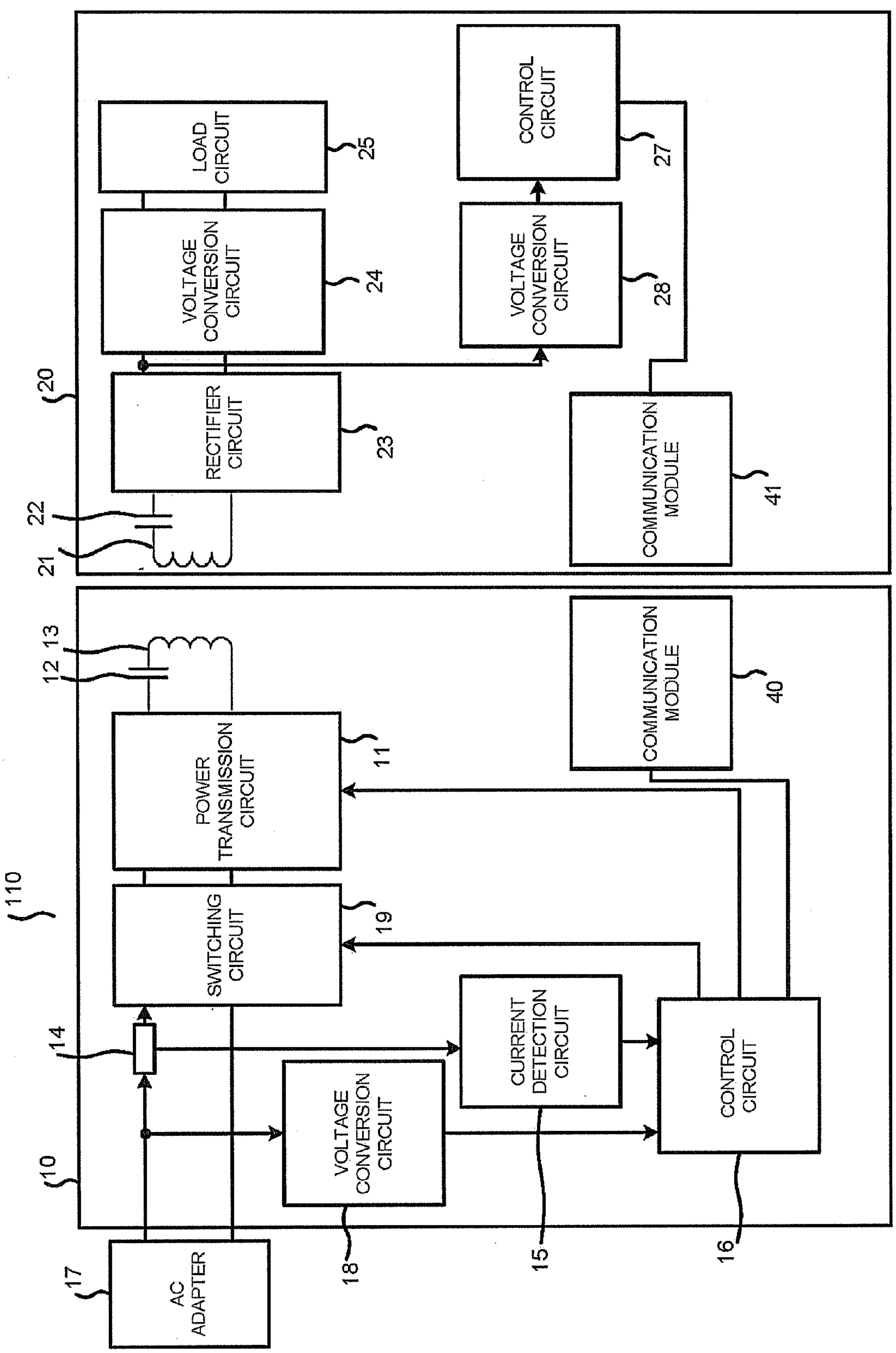

POWER TRANSMISSION DEVICE
10
ACT101
AUTHENTICATION OPERATION
400
POWER RECEIVING DEVICE
20
ACT201
AUTHENTICATION OPERATION
300
NORMAL POWER TRANSMISSION
ACT102
DETECT POWER TRANSMISSION CURRENT VALUE (T2 INTERVAL)
ACT103
ACT104
IS CURRENT VALUE BELOW THRESHOLD VALUE DURING T3 TIME?
YES
NO
STOP POWER TRANSMISSION
ACT105
CONNECT LOAD
ACT202
(Tb)
T0 TIME ELAPSES
ACT203
DISCONNECT LOAD
ACT204
(Tc)
T1 TIME ELAPSES
ACT205

FIG.7


POWER
TRANSMISSION
CURRENT
FOREIGN
OBJECT
DETECTION
THRESHOLD
VALUE
33
Ts
Ta
Tb
Tc
Td
Te
T1
T1
T0
T0
T3
CURRENT VALUE
DETECTION
34
T2
TIME


AC ADAPTER
VOLTAGE CONVERSION CIRCUIT
CURRENT DETECTION CIRCUIT
CONTROL CIRCUIT
SWITCHING CIRCUIT
POWER TRANSMISSION CIRCUIT
COMMUNICATION MODULE
RECTIFIER CIRCUIT
VOLTAGE CONVERSION CIRCUIT
LOAD CIRCUIT
VOLTAGE CONVERSION CIRCUIT
CONTROL CIRCUIT
COMMUNICATION MODULE
10
11
12
13
14
15
16
17
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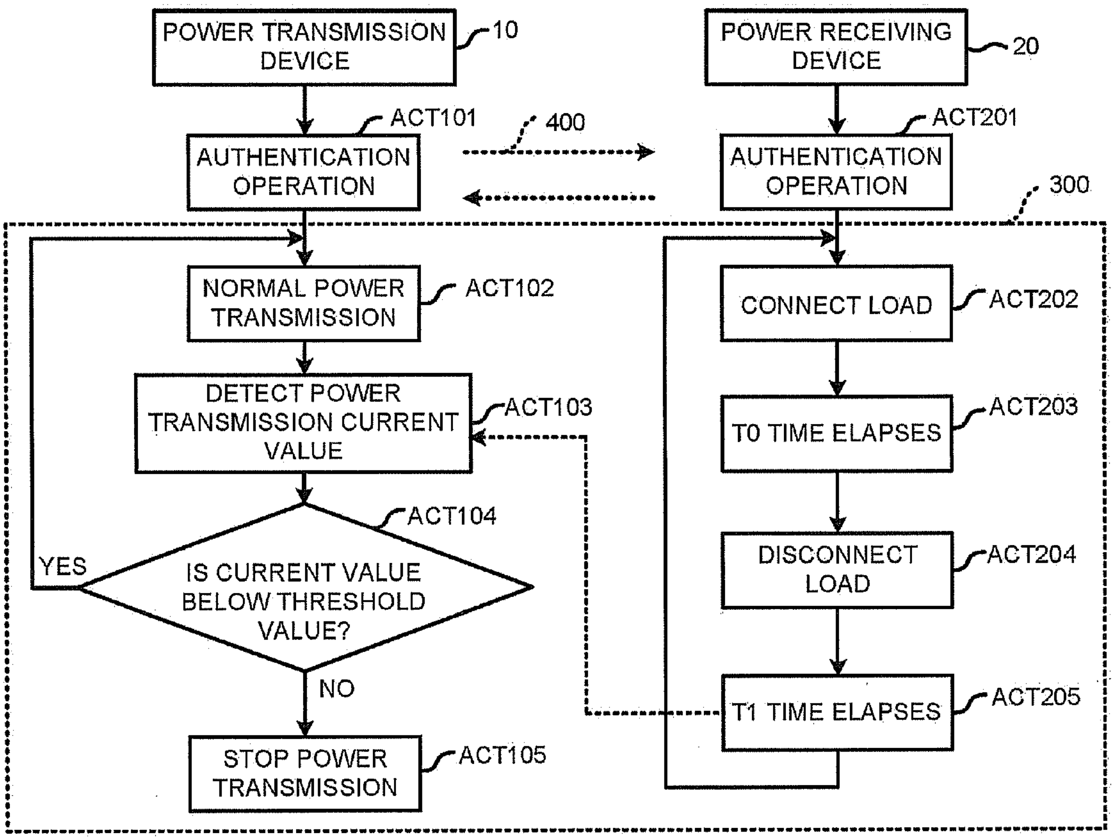
19
20
21
22
23
24
25
27
28
40
41
110

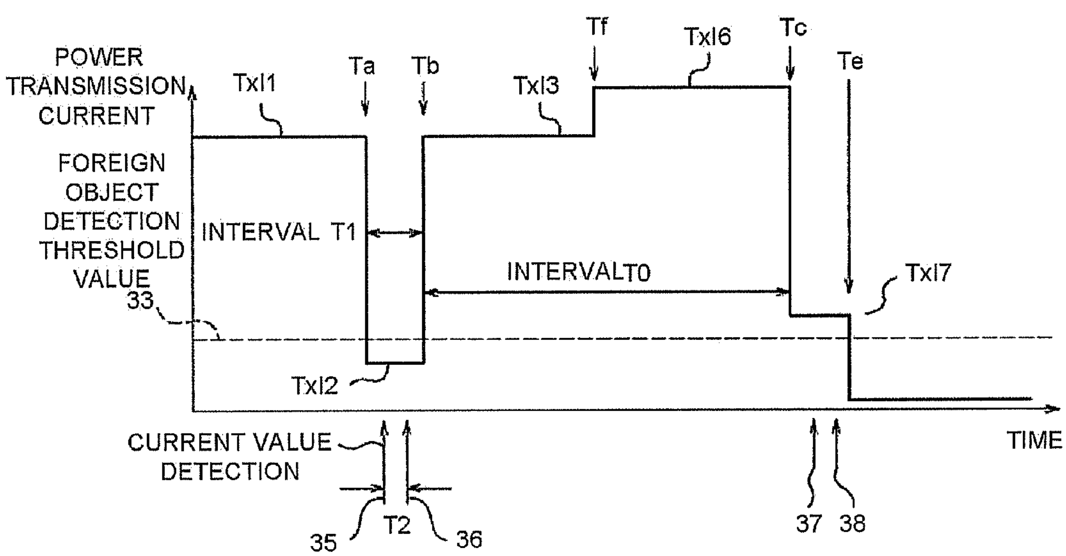
FIG.8

FIG.9



POWER TRANSMISSION DEVICE
10
POWER RECEIVING DEVICE
20
ACT101
400
ACT201
AUTHENTICATION OPERATION
AUTHENTICATION OPERATION
300
NORMAL POWER TRANSMISSION
ACT102
CONNECT LOAD
ACT202
DETECT POWER TRANSMISSION CURRENT VALUE
ACT103
T0 TIME ELAPSES
ACT203
ACT104
YES
IS CURRENT VALUE BELOW THRESHOLD VALUE?
DISCONNECT LOAD
ACT204
NO
T1 TIME ELAPSES
ACT205
STOP POWER TRANSMISSION
ACT105

FIG.10



POWER TRANSMISSION CURRENT
TxI1
Ta
Tb
TxI3
Tf
TxI6
Tc
Te
FOREIGN OBJECT DETECTION THRESHOLD VALUE
33
INTERVAL T1
INTERVALT0
TxI7
TxI2
CURRENT VALUE DETECTION
TIME
35
T2
36
37
38

NON-CONTACT POWER TRANSMISSION APPARATUS AND POWER TRANSMISSION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2014-222936, filed Oct. 31, 2014, the entire contents of which are incorporated herein by reference.

FIELD

[0002] Embodiments described herein relate generally to a non-contact power transmission apparatus for transmitting power in a non-contact manner to a power receiving device from a power transmission device.

BACKGROUND

[0003] In recent years, a non-contact power transmission apparatus for transmitting power in a non-contact manner is becoming popular. The non-contact power transmission apparatus, which is equipped with a power transmission device for supplying power and a power receiving device for receiving supplied power, uses electromagnetic coupling such as electromagnetic induction, magnetic field resonance and the like to transmit the power from the power transmission device to the power receiving device in a non-contact manner. The power receiving device is provided with a driving circuit for driving itself and a load circuit such as a charging circuit of secondary battery loaded in the power receiving device.

[0004] Japanese Unexamined Patent Application Publication No. 2011-229265 is known as a conventional technology of such a non-contact power transmission apparatus. In Patent Document 1, a non-contact power transmission apparatus is recorded which transmits power from the power transmission device to the power receiving device in a non-contact manner with the use of the electromagnetic coupling between the power transmission device and the power receiving device. A portable terminal serving as a power receiving device receives the power in a non-contact manner from a charger serving as a power transmission device and is charged by the secondary battery built in the portable terminal.

[0005] An authentication of whether or not the portable terminal mounted with the charger is a correct machine which should be mounted originally is carried out through communication using the electromagnetic coupling between the charger and the portable terminal mounted with the charger. When it is determined that the authentication is established, the portable terminal is assumed as a proper power transmission target and a continuous normal power transmission is started.

[0006] It is afraid that metal foreign objects are inserted between the charger serving as the power transmission device and the portable terminal serving as the power receiving device for some reasons. For example, while a coin is nipped between the power transmission device and the power receiving device by mistake, the charger is activated. In a conventional system of using the electromagnetic induction, as a frequency of about 100 kHz is often used, eddy current occurs in the metal foreign objects and heat is likely to be generated. Thus, in the technology recorded in Japanese Unexamined Patent Application Publication No. 2011-229265, it is possible to detect the metal foreign object during the period of normal power transmission, stop supplying power in a case in which the metal foreign object is detected and suppress the generation of heat of the metal foreign object.

[0007] A magnetic field resonance system capable of transmitting power is known as other non-contact power transmission system even if the power transmission device is separated from the power receiving device about a few cm. In the non-contact power transmission apparatus using the magnetic field resonance system, a frequency of a few MHz is often used for power transmission. For example, a frequency of 6.78 MHz or 13.56 MHz is used. In the magnetic field resonance system, it is unnecessary to closely contact the power transmission device with the power receiving device, as a gap exists between the power transmission device and the power receiving device, there is a possibility that foreign objects are nipped therebetween during the period of charging to the power receiving device in a non-contact manner for some reasons. In addition to the metal foreign objects such as coins and the like, for example, the foreign object also contains an IC card using 13.56 MHz. The IC card, thickness of which is about 1 mm and which includes an IC chip and an antenna wiring connected to the IC chip, operates while receiving the power from an IC card dedicated transmitter in a non-contact manner.

[0008] In a non-contact power transmission apparatus using frequencies 6.78 and 13.56, if the IC card which resonates with 13.56 MHz equal to double frequency of 6.78 MHz approaches to the power transmission device or is nipped between the power transmission device and the power receiving device, the IC card receives power and generates heat, and moreover the IC card can breakdown due to the generation of heat. Thus, it is important to detect the IC card, in addition to the metal foreign objects, which is called as foreign object detection.

[0009] The power consumed by the IC card is slight compared with the power transmitted to the power receiving device. For example, in a case in which the power received by the power receiving device of the non-contact power transmission apparatus is 20 W and the IC card receives 0.5 W power, even if the IC card is inserted between the power transmission device and the power receiving device, the received power only changes 0.5/20=0.025 (2.5%).

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a block diagram illustrating the structure of a non-contact power transmission apparatus according to a first embodiment;

[0011] FIG. **2** is a perspective view illustrating the structure of the non-contact power transmission apparatus according to the first embodiment;

[0012] FIG. **3** is a flowchart illustrating the operation of the non-contact power transmission apparatus according to the first embodiment;

[0013] FIG. **4** is a timing diagram illustrating the operation of the non-contact power transmission apparatus according to the first embodiment;

[0014] FIG. **5** is a timing diagram illustrating the operation of the non-contact power transmission apparatus according to the first embodiment;

[0015] FIG. **6** is a flowchart illustrating the operation of a non-contact power transmission apparatus according to a second embodiment;

[0016] FIG. **7** is a timing diagram illustrating the operation of the non-contact power transmission apparatus according to the second embodiment;

[0017] FIG. **8** is a block diagram illustrating the structure of the non-contact power transmission apparatus according to the second embodiment;

[0018] FIG. **9** is a flowchart illustrating the operation of a non-contact power transmission apparatus according to a third embodiment; and

[0019] FIG. **10** is a timing diagram illustrating the operation of the non-contact power transmission apparatus according to the third embodiment.

DETAILED DESCRIPTION

[0020] In accordance with an embodiment, a non-contact power transmission apparatus comprises a power transmission device which includes a power transmission coil, a power transmission circuit configured to be connected to the power transmission coil and supply power through the power transmission coil, a current detection circuit configured to detect current supplied to the power transmission circuit and a first control circuit configured to control the power transmission circuit; and a power receiving device which includes a power receiving coil, a rectifier circuit connected to the power receiving coil, voltage conversion circuit configured to be connected to the rectifier circuit and convert into voltage of driving a load circuit, a switching circuit configured to connect or disconnect the voltage generated by the voltage conversion circuit with the load circuit and a second control circuit configured to control the switching circuit.

[0021] The second control circuit, after starting to receive power, carries out a control processing to connect the load circuit during a period of time T**0**, then disconnect the load circuit during a period of time T**1** and repeat connection and disconnection.

[0022] The first control circuit carries out a control processing to detect repeatedly current values at an interval of period of time T**2** through the current detection circuit and stop power transmission if the current value is above a current threshold value during at least (T**0**+T**1**) time.

[0023] Hereinafter, the embodiment is described with reference to the accompanying drawings. Further, the same reference numerals indicate identical or similar structure in figures.

First Embodiment

[0024] FIG. **1** is a block diagram illustrating the structure of a non-contact power transmission apparatus **100** according to a first embodiment. FIG. **2** is a perspective view schematically illustrating a power transmission device **10** and a power receiving device **20** which constitute the non-contact power transmission apparatus **100**.

[0025] As shown in FIG. **1**, the non-contact power transmission apparatus **100** is provided with the power transmission device **10** which supplies power and the power receiving device **20** which receives the supplied power. The power output from a power transmission circuit **11** is transmitted to the power receiving device **20** with the use of an electromagnetic coupling such as an electromagnetic induction or a magnetic field resonance between a power transmission coil **13** and a power receiving coil **21**.

[0026] DC power is supplied to the power transmission device **10** from an external device via a power device such as AC adapter **17**. The power transmission device **10** is provided with the power transmission circuit **11** for generating AC power, a resonance circuit constituted by a condenser **12** and the power transmission coil **13**, a switching circuit **19** which supplies or stops supplying power to the power transmission circuit **11**, a current sensor **14** for detecting DC current input to the power transmission circuit **11**, a current detection circuit **15** for amplifying a tiny signal detected by the current sensor **14**, a control circuit **16** and a voltage conversion circuit **18**. The switching circuit **19** connects or disconnects the AC adapter **17** and the power transmission circuit **11** through a control signal from the control circuit **16** and switches the supply/stop of power from the power transmission device **10** to the power receiving device **20**. The current sensor **14** is a small resistance for detecting current. The control circuit **16** consists of a microcomputer and an oscillation circuit. The voltage conversion circuit **18** converts output voltage of the AC adapter **17** into a voltage suitable to circuit operation of each section in the power transmission device **10** and supplies it. The power transmission device **10** includes a communication module **40** and the power receiving device **20** includes a communication module **41**. The control circuits **16** and **27** exchange information relating to the power transmission and power reception in a non-contact manner through the communication modules **40** and **41**.

[0027] The power transmission circuit **11** generates AC power of frequency identical or almost identical to self-resonant frequency of the resonance circuit constituted by the condenser **12** and the power transmission coil **13**. The power transmission circuit **11** has FET as a switching element and turns on/off the FET through the output of the oscillation circuit in the control circuit **16**. The oscillation circuit in the control circuit **16** oscillates at a frequency identical or almost identical to self-resonant frequency of the resonance circuit constituted by the condenser **12** and the power transmission coil **13**. In the first embodiment, an operation of supplying or stopping supplying power from the power transmission device **10** to the power receiving device **20** is carried out by the switching circuit **19**. Without the use of the switching circuit **19**, it is also possible to supply or stop supplying power from the power transmission device **10** to the power receiving device **20** by turning on/off the switching element.

[0028] The frequency of the AC power generated by the power transmission circuit **11** uses a frequency of about 100 kHz in a case of using an electromagnetic induction system in power transmission and uses a frequency of a few MHz-tens of MHz in a case of using a magnetic field resonance system in power transmission. In a case of the magnetic field resonance system, specifically, 6.78 MHz and 13.56 MHz are often used. The present embodiment adopts 6.78 MHz. The present embodiment is not limited to operation frequency, and the electromagnetic induction system and the magnetic field resonance system can be used in a wide frequency band.

[0029] The power receiving device **20** is provided with a resonance element constituted by a power receiving coil **21** and a condenser **22**, a rectifier circuit **23** for converting alternating current into direct current, a voltage conversion circuit **24** for converting DC voltage output by the rectifier circuit **23** into a desired DC voltage and a load circuit **25**. Moreover, the power receiving device **20** further includes a switching circuit **26** for connecting/disconnecting the voltage conversion circuit **24** and the load circuit **25**. A control circuit **27** controls the connection/disconnection of the switching circuit **26**. The power receiving device **20** is also provided with a voltage conversion circuit **28** which converts DC voltage output by the rectifier circuit **23** into a DC voltage required by the control circuit **27**. The control circuit **27** is a microcomputer.

[0030] Self-resonant frequency of the resonance circuit constituted by the power receiving coil **21** and the condenser **22** of the power receiving device **20** is identical or almost identical to the self-resonant frequency of the resonance circuit constituted by the condenser **12** and the power transmission coil **13** of the power transmission device **10**. Due to the identical frequency, the electromagnetism is combined with each other and the power is transmitted from power transmission side to power receiving side more efficiently.

[0031] The load circuit **25** is a circuit of electronic equipment such as a portable terminal and a tablet terminal. The power received by the power receiving device **20** is used to operate the electronic equipment and charge the battery such as lithium ion built in the electronic equipment. It is described that the load circuit **25** is built in the power receiving device **20**; however, the load circuit **25** may be arranged at the outside of the power receiving device **20** and connected with the switching circuit **26** of the power receiving device **20** through a connector.

[0032] The condensers **12** and **22** are not necessarily constituted with electronic components which can also be replaced by electrostatic capacity between lines of each coil according to shapes of the power transmission coil **13** and the power receiving coil **21**. Further, the condenser **12** and the power transmission coil **13** are arranged in series and the condenser **22** and the power receiving coil **21** are arranged in series as well to constitute a series resonance circuit. In place of the series resonance circuit, the condenser **12** and the power transmission coil **13** may be arranged in parallel and the condenser **22** and the power receiving coil **21** may be arranged in parallel as well to constitute a parallel resonance circuit.

[0033] FIG. **2** shows the non-contact power transmission apparatus **100** in which the power receiving device **20** is arranged on the power transmission device **10**. The power receiving device **20** is placed on the power transmission device **10** in a direction indicated by an arrow and the power is transmitted to the power receiving device **20** by overlapping the power receiving coil **21** with the power transmission coil **13** of the power transmission device **10**. That is, the AC current flows in the power transmission coil **13** and thus magnetic field occurs in the power transmission coil **13**. On the other hand, under the effect of the electromagnetic coupling in the power receiving coil **21**, the AC current flows in the power receiving coil **21** and the DC power can be obtained by rectifying the current in the power receiving coil **21**.

[0034] In FIG. **2**, the power transmission device **10** consists of a plate-shaped housing which makes the power receiving device **20** easy to be placed thereon, and the power transmission coil **13** is arranged at the side of the power receiving device **20** inside the housing. The power receiving device **20**, which has a plate-shaped housing, can be placed on the power transmission device **10**. In the power receiving device **20**, the power receiving coil **21** is arranged at the side of the power transmission device **10** inside the housing to face the power transmission coil **13**.

[0035] The control structures of the power transmission device **10** and the power receiving device **20** of the non-contact power transmission apparatus **100** are described. A foreign object detection operation in a case in which a foreign object such as a metal, IC card and the like is nipped is mainly described.

[0036] FIG. **3** is a flowchart illustrating the operation during the charging to the battery of the load circuit **25**. FIG. **4** shows a timing diagram in a case in which the foreign object does not exist between the power transmission device **10** and the power receiving device **20**. FIG. **5** shows a timing diagram in a case in which the foreign object exists between the power transmission device **10** and the power receiving device **20**.

[0037] If the power receiving device **20** is placed on the power transmission device **10**, first, an authentication operation for confirming whether or not the power receiving device **20** is a regular power receiving device **20** is carried out. After the authentication is confirmed, the power is transmitted from the power transmission device **10** to the power receiving device **20**, and the processing proceeds to a charging operation (**300**). The control circuit **16** inquires a unique ID of the power receiving device **20** from the power transmission device **10** to the power receiving device **20** in an authentication operation Act **101**. The control circuit **27** responds the unique ID of the power receiving device **20** to the power transmission device **10** in response to the inquiry in the authentication operation ACT **101**. Through the inquiry of the ID from the power transmission device **10** to the power receiving device **20** and the response from the power receiving device **20** to the power transmission device **10**, whether or not the power receiving device **20** is a regular power receiving device **20** which should be charged is determined by the power transmission device **10**. In a case of a regular ID, the charging operation **300** is carried out, and in a case of non-regular ID, the power transmission is stopped and the charging operation is not carried out. The inquiry of ID is carried out through the communication modules **40** and **41** respectively arranged in the power transmission device **10** and the power receiving device **20**. The communication modules **40** and **41** may be, for example, a wireless communication module such as wireless communication and infrared ray communication, or may use both the power transmission and the communication module which consists of the power transmission coil **13** and the power receiving coil **21** as a load modulation system. In the present embodiment, no specific limitation is given to the method of the authentication operation.

[0038] In the power transmission device **10**, after the authentication operation (ACT **101**) is completed, the control circuit **16** carries out a normal power transmission to the power transmission circuit (ACT **102**). During the normal power transmission, the control circuit **16** detects power transmission current value at a time interval of T**2** (ACT **103**). The power transmission current value can be obtained by amplifying a small potential difference detected by the current sensor **14** in the power transmission device **10** by the current detection circuit **15** and converting the voltage value into the current value by the control circuit **16**.

[0039] In a state in which the power receiving device **20** receives the power from the power transmission device **10** in a non-contact manner, the control circuit **27** of the power receiving device **20** switches the switching circuit **26** every a specified time to connect/disconnect the load circuit **25**. As shown in FIG. **3**, in the power receiving device **20**, the load is connected (ACT **202**), and then after T**0** time elapses (ACT **203**), the load is disconnected (ACT **204**). Then, the load is connected again (ACT **202**) after T**1** time elapses (ACT **205**), and this operation is repeated. Herein, there is a relationship, that is, T2<T1<T0. During the period T0, the load circuit 25 is charged, and the load circuit 25 is not charged during the period T1. Therefore, power transmission efficiency changes in response to the ratio of non-charging period T1 to charging period T0. In order to charge more efficiently, it is necessary that T1 is a sufficiently small value with respect to T0. In order to detect the foreign object more correctly, it is necessary to select T2 period during which the current can be detected many times during T1 period.

[0040] The control circuit **16** of the power transmission device **10** monitors whether or not the power transmission current value is below a foreign object detection threshold value **33** over at least (T**0**+T**1**) time (ACT **104**), and if the power transmission current value is below the foreign object detection threshold value **33**, it is determined that there is no foreign object and power transmission is continued (ACT **102**). On the other hand, if the power transmission current value is above the foreign object detection threshold value **33** over (T**0**+T**1**) time, it is determined that there is a foreign object and power transmission is stopped (ACT **105**).

[0041] The timing diagram shown in FIG. **4** indicates the change of the power transmission current during the charging operation (**300**). If the control circuit **27** of the power receiving device **20** carries out a control processing to disconnect the load circuit **25** at timing of Ta from the moment the power transmission is started, power transmission current TxI**1**, which flows to supply the power to the load circuit **25** by that time, is lowered to a level of TxI**2** due to the load disconnection.

[0042] If the load circuit **25** is disconnected, the state is nearly equal to a state in which there is no power receiving device **20**, observing from the power transmission device **10**, and is a state in which the load is very light. As the load is light, the power transmission current is lowered to such a degree that it is consumed nearly within the power transmission device **10**.

[0043] Next, at timing of Tb after the T**1** time elapses from the timing of Ta, the control circuit **27** of the power receiving device **20** switches the switching circuit **26** to connect the load circuit **25** with the voltage conversion circuit **24**. As the load circuit **25** is connected, observing from the power transmission device **10**, the load becomes heavy, the power is supplied to the load circuit **25** and thus the power transmission current rises to a level of TxI**3**. Herein, if the state of the load circuit **25** does not change compared with the timing previous to timing Ta, the level of TxI**3** is equal to the level of TxI**1**.

[0044] The control circuit **27** of the power transmission device **20** disconnects the load circuit **25** again at timing Tc after T**0** time elapses from the timing Tb during which the load circuit **25** is connected. Due to the load disconnection, the level of the power transmission current is lowered to TxI**4**. If the load circuit **25** is connected again at timing Td after the T**1** time elapses from the timing Tc, the level of the power transmission current rises to TxI**5**. In particular, if a phenomenon that the foreign object is nipped between the power transmission device **10** and the power receiving device **20** does not occur, the TxI**4** is almost equal to the TxI**2** and the TxI**5** is almost equal to the TxI**3**. In this way, the control circuit **27** of the power transmission device **20** repeats the operations of disconnecting the load circuit **25**, connecting the load circuit **25** after T**1** time and disconnecting the load circuit **25** again after T**0** time during the charging operation.

[0045] The control circuit **16** of the power transmission device **10** sets the foreign object detection threshold value **33** as a threshold value of the current value for detecting the foreign object in advance. In a state in which the load circuit **25** is disconnected, the foreign object detection threshold value **33** is set to be a value greater than the values of current TxI**2** and current TxI**4** flowing through the power transmission device **10**. If the foreign object detection threshold value **33** is far greater than the values of current TxI**2** and current TxI**4**, as foreign object such as IC card the change of the power transmission current in which is relatively small cannot be detected, it is necessary to set the current TxI**2** and current TxI**4** to a proper value. If the foreign object is not nipped between the power transmission device **10** and the power receiving device **20**, as shown in FIG. **4**, the current values between the timing Ta and timing Tb and between the timing Tc and timing Td during which the load circuit **25** is disconnected are smaller than the foreign object detection threshold value **33**. Thus, the current values detected at timings of current value detections **35** to **36** and **37** to **38** are smaller than the foreign object detection threshold value **33**, and as it is determined that there is no foreign object, the power transmission is continued.

[0046] It is assumed that T**0** is 1 s, T**1** is 100 ms and T**2** is 10 ms as specific values. The power transmission current value TxI**1** is 800 mA in a state of no foreign object (normal state) and the power transmission current value TxI**2** is 100 mA in a state of disconnecting the load. It is assumed that the IC card is inserted between the power transmission device **10** and the power receiving device **20** and the current threshold value **33** is 120 mA.

[0047] The operation in a case in which the foreign object is nipped between the power transmission device **10** and the power receiving device **20** is described during the charging operation with reference to FIG. **5**.

[0048] The operation before timing Tf when the foreign object is nipped is similar to the case shown in FIG. **4**. At the timing Tf, if the foreign object such as a coin and an IC card is nipped, the power is also supplied to the foreign object to increase the power to be supplied and thus the power transmission current is also increased from TxI**3** to TxI**6**. If the control circuit **27** of the power receiving device **20** carries out a control to detach the load circuit **25** at timing Tc after T**0** time elapses from the timing Tb, the power transmission current is reduced from TxI**6** to TxI**7**. The power transmission current is reduced to TxI**7**; however, as the foreign object remains nipped, the power is supplied to the foreign object from the power transmission device **10**. As the power is continuously supplied to nipped foreign object, the value of TxI**7** is greater than the current value TxI**2** in a state in which no foreign object is nipped. As a result, the value of TxI**7** is higher than the foreign object detection threshold value **33**.

[0049] At timing of current value detection **37** to **38**, the control circuit **16** of the power transmission device **10** detects that the power transmission current value TxI**7** exceeds the foreign object detection threshold value **33**. If the power transmission current value is never below the foreign object detection threshold value **33** during the (T**0**+T**1**) time (ACT **104**), it is determined that the foreign object exists and the control circuit **16** stops the power transmission at timing Te (ACT **105**). Specifically, the control circuit **16** controls the switching circuit **19** and the current is not supplied to the power transmission circuit **11**.

[0050] The time Ta from the moment the power receiving device **20** starts receiving power to the moment the switching circuit **26** disconnects the load circuit **25** is not determined with the structure of the power receiving device **20**. As Ta is not determined, in a case in which the power transmission current value is above the foreign object detection threshold value **33** during the period of at least (T**0**+T**1**), the control circuit **16** determines that the foreign object exists. With such a structure, during the period when the load circuit **25** is charged in a non-contact manner, even if the foreign object is nipped between the power transmission device **10** and the power receiving device **20**, it is possible to detect the foreign object.

[0051] In the forgoing embodiment, the foreign object detection threshold value **33** is set between the current value TxI**2** or TxI**4** in a state in which the load circuit **25** of the power receiving device **20** is detached and the foreign object is not mixed yet and the current value TxI**7** at the time the foreign object is mixed. On the other hand, even if the foreign object detection threshold value **33** is set between the current value TxI**3** during charging and the current value TxI**6** at the time the foreign object is mixed during charging, the detection of the foreign object is possible. However, the current during charging changes according to the remaining amount of secondary battery serving as the load circuit **25** and the power transmission current changes even according to the position where the power receiving device **20** is placed, thus it is difficult to detect the foreign object stably. Therefore, it is desired to use a small current change in no-load state to set the foreign object detection threshold value **33**. By determining the foreign object detection threshold value **33** in advance based on the current in no-load state, even if the foreign object in which the change of the power transmission current is tiny is nipped, the non-contact power transmission apparatus **100** of the present embodiment can detect the foreign object.

Second Embodiment

[0052] The second embodiment is described with reference to FIG. **6** and FIG. **7**. FIG. **6** is a flowchart of the second embodiment. FIG. **7** shows a timing diagram of current detection according to the second embodiment. In the second embodiment, it is described that the foreign object has already existed from Ts time when charging is started. Prior to the Ts time, the execution of authentication operation between the power transmission device **10** and the power receiving device **20** is completed, and it is assumed that the authentication is established. In the second embodiment, the authentication state is assumed but the authentication operation is not particularly necessary, and there may be a system in which charging is started if the power receiving device **20** is placed on the power transmission device **10**. The apparatus structure of the second embodiment includes the structures of the power transmission device **10** and the power receiving device **20** described in the first embodiment.

[0053] Firstly, the power transmission device **10** carries out authentication operation (ACT **101**). ID is responded (**400**) by authentication operation (ACT **201**) of the power receiving device **20** in response to the inquiry of ID from the power transmission device **10**. After the authentication is determined, charging operation **300** is carried out. If the power transmission is started at Ts (ACT **102**), the power transmission device **10** detects the power transmission current value at a specified time interval of T**2** (ACT **103**). The control circuit **16** detects whether or not the power transmission current value is below the foreign object detection threshold value **33** during the T**3** time (ACT **104**). At any timing of every T**2** interval during the period of T**3**, it is determined that there is no foreign object if the power transmission current value is below the foreign object detection threshold value **33** and the power transmission is continued (ACT **102**). During the period of T**3**, it is determined that there is a foreign object if the power transmission current value is never below the foreign object detection threshold value **33** and the power transmission is stopped (ACT **105**).

[0054] Similar to the first embodiment, the power receiving device **20** repeats a control processing, that is, the load is connected (ACT **202**), the load is disconnected (ACT **204**) after T**0** time elapses (ACT **203**) and then the load is connected again (ACT **202**) after T**1** time elapses (ACT **205**). Time intervals T**2**, T**1** and T**0** have a relationship, that is, T**2**<T**1**<T**0**, similar to the first embodiment.

[0055] The period T**3** is determined in consideration of period T**0** of charging operation and period T**1** of non-charging operation as shown in FIG. **7**. The load circuit **25** is charged at period T**0** and the load circuit **25** is not charged at period T**1**. It is necessary that period T**3** is at least (T**0**+T**1**) time; however it is preferably longer than the (T**0**+T**1**) time in order to avoid error operations of foreign object determination. In the second embodiment, T**3** is a long time slightly longer than 2*(T**0**+T**1**) time. However, if T**3** time is too long, too much time is needed to determine whether or not there is a foreign object, and thus it is necessary to determine time T**3** required for the foreign object determination taking event probability of the error operations into consideration.

[0056] In FIG. **7**, if the power receiving device **20** is started to be charged from Ts time, a state in which the power transmission current is slowly increasing is indicated. In a case in which the load circuit **25** of the power receiving device **20** is a lithium ion battery, charging power is increased until the load circuit **25** is close to a full charge state generally. Thus, the power transmission current is slowly increasing during periods from Ts to Ta and from Tb to Tc. The lithium ion battery is widely used in the portable terminal and the like.

[0057] On the other hand, during a period (T**1**) from Ta to Tb and a period (T**1**) from Tc to Td, the load circuit **25** is in a non-charging state, and thus the power transmission current is a constant value. Therefore, if the foreign object detection threshold value **33** is set to be slightly higher than the power transmission current value of a state in which the load circuit **25** is detached, error detection of the foreign object can also be reduced.

[0058] As the power transmission current value is above the foreign object detection threshold value **33** over T**3** time, the power transmission device **10** determines that the foreign object exists and stops the power transmission at timing Te (ACT**105**).

[0059] The control circuit **16** of the power transmission device **10** holds charging period T**0**, non-charging period T**1** and time T**3** of determining foreign object in advance and conveys T**0** time and T**1** time from the power transmission device **10** to the power receiving device **20**. In place of this method, before the charging operation is started, exchange of information (**400**) is carried out between the power transmission device **10** and the power receiving device **20** and T**3** time is calculated according to information of T**0** time and T**1** time held by the power receiving device **20** in advance.

[0060] FIG. **8** shows the structure of other non-contact power transmission apparatus **110**. The non-contact power transmission apparatus **110** is the same as the non-contact power transmission apparatus **100** of the first embodiment except that the power receiving device **20** uses a voltage conversion circuit **24** with enable/disable function. In a case of using DC/DC converter IC in the voltage conversion circuit **24**, the voltage conversion circuit **24** with enable/disable function is used with DC/DC converter IC to replace the functions of the switching circuit **26**. That is, voltage generated by the voltage conversion circuit **24** functions as the switching circuit **26** to connect/disconnect with the load circuit **25**. Consequentially, the power receiving device **20** can be simply constituted. The structure of using the voltage conversion circuit **24** with enable/disable function is applicable from the first embodiment to the third embodiment.

[0061] Even with the structure described in the second embodiment above, during a non-contact charging process, it is possible to easily detect a state where a foreign object in which current change is tiny is inserted between the power transmission device and the power receiving device.

Third Embodiment

[0062] The third embodiment is described with reference to FIG. **9** and FIG. **10**. Circuit structure is the structure of the non-contact power transmission apparatus **100** or **110** described in the first or second embodiment. The operations of control circuits **16** and **27** are different from that described in the first or second embodiment.

[0063] In the third embodiment, communication is carried out between a communication equipment **40** of the power transmission device **10** and a communication equipment **41** of the power receiving device **20** to obtain synchronism, and the power transmission device **10** detects power transmission current only during a timing when the power receiving device **20** detaches the load circuit **25**.

[0064] FIG. **9** shows a flowchart illustrating foreign object detection during charging process. The operations of the power receiving device **20** are identical to that described in the first and second embodiments. However, the difference is that the control circuit **16** of the power transmission device **10** detects power transmission current value through communication modules **40** and **41** at a timing when T**1** time elapses (ACT **205**) after load is disconnected (ACT **204**).

[0065] In the power transmission device **10**, the control circuit **16** detects power transmission current value (ACT **103**) according to the elapsing of T**1** time (ACT **205**). By comparing the foreign object detection threshold value **33** and the power transmission current value (ACT **106**), the control circuit **16** determines that there is no foreign object if the current value is below the threshold value **33** and then continues normal power transmission (ACT **102**), or determines that there is a foreign object if the current value is above the threshold value **33** and then stops power transmission (ACT **105**).

[0066] FIG. **10** shows a timing chart of the third embodiment. Current value detection is carried out during a period from Ta to Tb and a period from Tc to Te when the power receiving device **20** detaches the load circuit **25**. Power transmission current value TxI**2** detected by current value detections **35** and **36** is smaller than the foreign object detection threshold value **33**, and thus the existence of the foreign object is determined at this point of time. In a state of non-existence of the foreign object, the power transmission current value is assumed to be TxI**3**. If the foreign object is mixed at Tf timing, the power transmission current only corresponding to a part where, power is deprived by the foreign object is increased (TxI**6**). Power transmission current value TxI**7** detected by current value detections **37** and **38** is greater than the foreign object detection threshold value **33**, and thus the control circuit **16** determines the existence of the foreign object and stops the power transmission.

[0067] Even in the third embodiment described above, during a non-contact charging process, it is possible to easily detect a state where a foreign object in which current change is tiny is inserted between the power transmission device **10** and the power receiving device **20**.

[0068] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the invention. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the invention. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the invention.

What is claimed is:

1. A non-contact power transmission apparatus, comprising:

a power transmission device which includes a power transmission coil, a power transmission circuit configured to be connected to the power transmission coil and supply power through the power transmission coil, a current detection circuit configured to detect current supplied to the power transmission circuit and a first control circuit configured to control the power transmission circuit; and

a power receiving device which includes a power receiving coil, a rectifier circuit configured to be connected to the power receiving coil, a voltage conversion circuit configured to be connected to the rectifier circuit and convert into voltage of driving a load circuit, a switching circuit configured to connect or disconnect the voltage generated by the voltage conversion circuit with the load circuit and a second control circuit configured to control the switching circuit, wherein

the second control circuit, after starting to receive power, carries out a control processing to connect the load circuit during a period of time T**0**, then disconnect the load circuit during a period of time T**1** and repeat connection and disconnection; and

the first control circuit carries out a control processing to detect repeatedly current values at an interval of time T**2** through the current detection circuit and stop power transmission if the current value is above a current threshold value during at least (T**0**+T**1**) time.

2. A non-contact power transmission apparatus, comprising:

a power receiving device configured to receive power in a non-contact manner and repeat connection and disconnection with load circuit to supply power to the load circuit; and

a power transmission device configured to detect power transmission current value when power is transmitted to the power transmission device and stop power transmission in a case in which the power transmission current value is greater than current threshold value during a period when the load circuit is detached.

3. A non-contact power transmission apparatus, comprising:

a power transmission device which includes a power transmission coil, a power transmission circuit configured to be connected to the power transmission coil and supply power through the power transmission coil, a current detection circuit configured to detect current supplied to the power transmission circuit and a first control circuit configured to control the power transmission circuit; and

a power receiving device which includes a power receiving coil, a rectifier circuit configured to be connected to the power receiving coil, a voltage conversion circuit configured to be connected to the rectifier circuit and convert into voltage of driving a load circuit, a switching circuit configured to connect or disconnect the voltage conversion circuit with the load circuit and a second control circuit configured to control the switching circuit, wherein

the second control circuit, after starting to receive power, carries out a control processing to connect the load circuit during a period of time T**0**, then disconnect the load circuit during a period of time T**1** and repeat connection and disconnection; and

the first control circuit carries out a control processing to detect current value during a period of the T**1** through the current detection circuit and stop power transmission if the current value is above a current threshold value.

4. The non-contact power transmission apparatus according to claim **1**, wherein

enable function of the voltage conversion circuit connects or disconnects the load circuit in the power receiving device as the switching circuit.

5. The non-contact power transmission apparatus according to claim **3**, wherein

enable function of the voltage conversion circuit connects or disconnects the load circuit in the power receiving device as the switching circuit.

6. A power transmission device, comprising:

a power transmission coil;

a power transmission circuit configured to supply current to the power transmission coil;

a current detection circuit configured to detect current supplied to the power transmission circuit; and

a control circuit configured to carry out a control processing to detect power transmission current value during power transmission through the current detection circuit at a specified time interval and stop power transmission if the power transmission current value is above a current threshold value of a specified time.

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