

(19)



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(11)

EP 0 381 398 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:
03.01.1996 Bulletin 1996/01

(51) Int Cl.⁶: **H01P 5/04**

(21) Application number: **90300870.4**

(22) Date of filing: **29.01.1990**

(54) **Automatic impedance adjusting apparatus for microwave load and automatic impedance adjusting method therefor**

Gerät zur automatischen Impedanz-Einstellung für eine Mikrowellenbelastung und Verfahren dafür
Appareil pour ajuster automatiquement l'impédance pour une charge micro-ondes et procédé à cet effet

(84) Designated Contracting States:
DE FR GB

(30) Priority: **30.01.1989 JP 22038/89**
26.09.1989 JP 251684/89
24.01.1990 JP 14457/90

(43) Date of publication of application:
08.08.1990 Bulletin 1990/32

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• **PATENT ABSTRACTS OF JAPAN vol. 10, no. 137 (E-405)(2194) 21 May 1986, & JP-A- 61 1101 (FUJITSU K.K.) 07 January 1986,**
• **PATENT ABSTRACTS OF JAPAN vol. 9, no. 95 (E-310)(1818) 24 April 1985, & JP-A- 59 221020 (NIPPON SHINKU GIJUTSU K.K.) 12 December 1984,**

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EP 0 381 398 B1

Description

The present invention relates to an automatic impedance adjusting apparatus for a microwave load and an automatic impedance adjusting method therefor, and more particularly to an automatic impedance adjusting apparatus for adjusting an impedance seen looking towards a microwave load at a point of a microwave transmission line to a desirable impedance such as an impedance of a microwave oscillator, and an automatic impedance adjusting method therefor.

Fig. 1 shows a conventional automatic microwave impedance matching apparatus proposed in Japanese laid open publication No. (JP-A) 63-15502/1988.

Referring to Fig. 1, a rectangular waveguide 100 of the automatic impedance matching apparatus is connected between a microwave oscillator and a microwave load. On the microwave oscillator side in the rectangular waveguide 100, there is arranged a voltage standing wave detector composed of five probes PR11 to PR15 therein aligned at an equal distance of $g/8$ in the longitudinal direction thereof, wherein λg is an average waveguide length of the microwave propagating in the rectangular waveguide 100. On the microwave load side in the rectangular waveguide 100, two pairs of composite stubs ST1 and ST2 are arranged at different positions in the longitudinal direction thereof.

The first composite stub ST1 is composed of two stubs S11 and S12 mounted at both ends of a seesaw rod, and the stubs S11 and S12 are driven by a stub driving motor M11 so as to be inserted into and drawn out from the rectangular waveguide 100 reciprocally by a seesaw motion of the seesaw rod. On the other hand, the second composite stubs ST2 is composed of two stubs S13 and S14 mounted at both ends of another seesaw rod, and the stubs S13 and S14 are driven by another stub driving motor M12 in the same manner as the stubs S11 and S12 of the first composite stub ST1.

A voltage standing wave of the microwave propagating in the rectangular waveguide 100 is detected by diodes DI11 to DI15 connected to the probes PR11 to PR15, respectively. After the output of the diode DI11 is outputted to the anode of the diode DI15 so as to compose the output of the diode DI15 therewith, the composed output is inputted to an input terminal of a differential amplifier AMP11 through a resistor R11. Each output of the diodes DI12 and DI14 is inputted to each input terminal of a differential amplifier AMP12, and the output of the diode DI13 is inputted to another input terminal of the differential amplifier AMP11.

The output of the differential amplifier AMP11 is outputted to the stub driving motor M11 through a power amplifier AMP21, and the output of the differential amplifier AMP12 is outputted to the stub driving motor M12 through a power amplifier AMP22.

In the automatic microwave impedance matching apparatus constructed above, output voltages V_{a11} and V_{a12} of respective differential amplifiers AMP11 and

AMP12 are expressed by the following equations with voltages V_{p11} to V_{p15} of the voltage standing wave detected by respective probes PR11 to PR15.

$$V_{a11} = V_{p11} - V_{p14} \quad (1)$$

$$V_{a12} = \frac{1}{2} (V_{p11} + V_{p15}) - V_{p13} \quad (2)$$

When the stub driving motors M11 and M12 are driven according to the output voltages V_{a11} and V_{a12} , respectively, the voltage standing wave in the rectangular waveguide 100 changes, namely, an impedance seen looking toward the load at the voltage standing wave detector changes. Since the probes PR11 to PR15 are arranged at an equal distance of $\lambda g/8$ in the longitudinal direction of the rectangular waveguide 100, the output voltages V_{a11} and V_{a12} of respective differential amplifiers AMP11 and AMP12 are orthogonal to each other. Therefore, in the feed back system of the automatic impedance matching apparatus, the composite stubs ST1 and ST2 are driven by the stub driving motor M11 and M12 so that each of the output voltages V_{a11} and V_{a12} becomes zero. When both the output voltages V_{a11} and V_{a12} become zero, the impedance of the microwave oscillator is matched to the load impedance.

However, when the above automatic microwave impedance matching apparatus is applied to an apparatus comprising a plasma generating apparatus such as a plasma etching apparatus, a plasma CVD apparatus or the like, the following problems are caused.

(1) A state of a plasma generated by the plasma generating apparatus may change suddenly, and then, a load impedance thereof may change. In this case, the conventional automatic impedance matching apparatus can not track the change in the load impedance thereof accurately, resulting in a hunting phenomenon therein.

(2) As shown in Fig. 2, there is a hysteresis in a relationship between an output power of the microwave oscillator and a load impedance of the plasma generating apparatus, and particularly, the hysteresis has two discontinuous points 101 and 102. Therefore, the load impedance changes discontinuously at respective discontinuous points 101 and 102, and then, the automatic impedance matching apparatus can not match the load impedance to the impedance of the microwave oscillator.

It is known to those skilled in the art that a plasma may be generated more stably in a state slightly shifted from the impedance matching state. Therefore, it has been desired that the impedance seen looking towards the load is automatically adjusted to a desirable impedance. However, the automatic microwave impedance matching apparatus described above cannot adjust the impedance seen looking towards the load to a desirable impedance.

Japanese laid-open publication no. JP-A-61-1101 discloses a microwave processing apparatus utilising a control system which automatically provides triple stub tuning on a microwave line associated with a magnetron

to control the sequential tuning of each of the three stubs.

US patent no. 3617953 discloses an impedance matching device for automatically and continuously matching a time varying microwave load to a fixed frequency microwave power source and its output line.

Attention is also directed to Patents Abstracts of Japan, vol. 10, no. 137 (E405)(2194) 21 May 1986, and JP-A-61 1101 (Fijitsu K.K.) 07 January 1986, and to 'Foundations for Microwave Engineering', International Student Edition, McGraw-Hill Physical and Quantum Electronics Series, R.E. Collin, 1966, pages 212-217.

It would be desirable to be able to provide an automatic impedance adjusting method and/or apparatus capable of more stably and more precisely adjusting an impedance seen looking towards a microwave load to a desirable impedance such as an impedance of a microwave oscillator, even if the load impedance changes.

According to one aspect of the present invention there is provided an automatic microwave impedance adjusting method including a first step of measuring either an impedance seen looking towards a microwave load at a predetermined reference point of a microwave transmission line of a rectangular waveguide connected between a microwave oscillator and said microwave load or a reflection coefficient thereat by detecting a voltage standing wave of a microwave propagating on said microwave transmission line;

wherein said method includes:

a second step of calculating insertion lengths of first to third stubs of variable impedance means so as to adjust said impedance seen looking towards said microwave load to a desired value corresponding to an inputted desired reflection coefficient, responsive to said value measured at said first step, said first to third stubs being mounted on said microwave load side of said reference point on said microwave transmission line, and mounted at different points in an order of said first to third stubs at equal spaces of a quarter of said waveguide length in the longitudinal direction of said rectangular waveguide, and a third step of inserting said first to third stubs into said rectangular waveguide by insertion lengths calculated at said second step, thereby adjusting said impedance seen looking towards said microwave load to said desired value,

characterised in that a whole region within a Smith chart representing an impedance seen looking towards said microwave load is divided into a first region for executing said impedance adjusting process of said third step using first and second stubs when an impedance point seen looking towards said microwave load at said reference point is located within said first region, a second region for executing said impedance adjusting process of said third step using said second and third stubs when said impedance point is located within said second region, and a third region for executing said impedance adjust-

ing of said third step using all said first to third stubs when said impedance point is located within said third region, said third region being defined as a partial region of said first region for any positive coordinate value of a V-axis of a UV orthogonal coordinate of the Smith chart; and

wherein said second step includes:

calculating an impedance seen looking towards said microwave load at said reference point responsive to said value measured at said first step; and judging whether an impedance point of said calculated impedance is located within either said first region, said second region or said third region on said Smith chart; and

wherein said third step includes:

executing said impedance adjusting process of said third step using said first and second stubs when it is judged that said impedance point of said calculated impedance is located within said first region, executing said impedance adjusting process of said third step using said second and third stubs when it is judged that said impedance point of said calculated impedance is located within said second region, and executing said impedance adjusting process of said third step using all said first to third stubs when it is judged that said impedance point of said calculated impedance is located within said third region.

There is also provided a method according to the one aspect of the invention wherein a whole region within a Smith chart representing an impedance seen looking towards said microwave load is divided into a first region for executing said impedance adjusting process of said third step using said first and second stubs when an impedance point seen looking towards said microwave load at said reference point is located within said first region, and a second region for executing said impedance adjusting process of said third step using said second and third stubs when said impedance point is located within said second region;

wherein said second step includes:

calculating an impedance seen looking towards said microwave load at said reference point responsive to said value measured at said first step, and judging whether an impedance point of said calculated impedance is located within either said first region or said second region of said Smith chart, and wherein said third step includes:

executing said impedance adjusting process of said third step using said first and second stubs when it is judged that said impedance point of said calculated impedance is located within said first region, and executing said impedance adjusting process of said third step using said second and third stubs when it is judged that said impedance point of said calculated impedance is located within said second

region.

In all said methods, the processes of said first to third steps may be repeated.

According to a further aspect of the invention, there is provided an automatic microwave impedance adjusting apparatus for performing the above methods and comprising:

a microwave transmission line connected between a microwave oscillator and a microwave load, said microwave transmission line being a rectangular waveguide,

measuring means for measuring either an impedance seen looking towards said microwave load at a mounted point thereof or a reflection coefficient thereat by detecting a voltage standing wave of a microwave propagating on said microwave transmission line,

variable impedance means for changing an impedance to be connected to a mounted point thereof, and

control means for controlling said variable impedance means responsive to a value measured by said measuring means so as to adjust said impedance to a desired value corresponding to an inputted desired reflection coefficient, characterised in that

said variable impedance means are mounted on said microwave load side of said measuring means on said microwave transmission line, said variable impedance means comprising three stubs mounted at different points at equal spaces of a quarter of said waveguide wavelength in the longitudinal direction of said rectangular waveguide, and said control means comprises:

calculating means for calculating insertion lengths of first to third stubs of variable impedance means so as to adjust said impedance seen looking towards said microwave load to a desired value corresponding to an inputted desired reflection coefficient, responsive to said value measured by said measuring means, and

insertion control means for inserting said first to third stubs into said rectangular waveguide by insertion lengths calculated by said calculating means, thereby adjusting said impedance seen looking towards said microwave load to said desired value, wherein a whole region within a Smith chart representing an impedance seen looking towards said microwave load is divided into a first region for executing said impedance adjusting process of said insertion control means using first and second stubs when an impedance point seen looking towards said microwave load at said reference point is located within said first region, a second region for executing said impedance adjusting process of said insertion control means using said second and third stubs

when said impedance point is located within said second region, and a third region for executing said impedance adjusting of said insertion control means using all said first to third stubs when said impedance point is located within said third region, said third region being defined as a partial region of said first region for any positive coordinate value of a V-axis of a UV orthogonal coordinate of the Smith chart; and

wherein said calculating means comprises:

means for calculating an impedance seen looking towards said microwave load at said reference point responsive to said value measured by said measuring means; and

means for judging whether an impedance point of said calculated impedance is located within either said first region, said second region or said third region on said Smith chart; and

wherein said insertion control means comprises:

executing said impedance adjusting process of said insertion control means using said first and second stubs when it is judged that said impedance point of said calculated impedance is located within said first region, executing said impedance adjusting process of said insertion control means using said second and third stubs when it is judged that said impedance point of said calculated impedance is located within said second region, and executing said impedance adjusting process of said insertion control means using all said first to third stubs when it is judged that said impedance point of said calculated impedance is located within said third region.

By way of example only, the apparatus and method of the invention will now be described in greater detail with reference to the accompanying drawings of which:

Fig. 1 is a schematic diagram showing a conventional automatic microwave impedance matching apparatus;

Fig. 2 is a graph showing a relationship between a output power of a microwave oscillator and a load impedance $|Z|$ of a plasma generating apparatus;

Fig. 3 is a schematic diagram showing an automatic microwave impedance adjusting apparatus of a preferred embodiment according to the present invention;

Fig. 4 is a schematic block diagram showing a controller of the automatic microwave impedance adjusting apparatus shown in Fig. 3 and peripheral units thereof;

Fig. 5 is a chart showing a voltage standing wave pattern in a rectangular waveguide shown in Fig. 3; Fig. 6 is a crank diagram showing respective vectors of the voltage standing wave at mounted points of respective probes shown in Fig. 3;

Fig. 7 is a circuit diagram showing an equivalent circuit of a triple-stub tuner arranged between the

microwave oscillator and the plasma generating apparatus shown in Fig. 3;

Figs. 8 and 9 are reflection coefficient charts and Smith charts showing an admittance contour thereon when stubs S1, S2 and S3 of the triple-stub tuner shown in Fig. 3 are inserted into and drawn out from the rectangular waveguide;

Figs. 10 to 20 are reflection coefficient charts and Smith charts showing an action of the automatic microwave impedance adjusting apparatus shown in Figs. 1 and 2;

Fig. 21 is a graph showing a relationship between an insertion length of each stub of the triple-stub tuner shown in Fig. 1 when inserted into the rectangular waveguide, and a susceptance connected to the stub point;

Fig. 22 is a flowchart showing a main routine of an automatic impedance adjusting process executed by a CPU of the controller shown in Fig. 4;

Fig. 23 is a flowchart showing a subroutine of an impedance adjusting process using stubs S2 and S3; and

Fig. 24 is a flowchart showing a subroutine of an impedance adjusting process using stubs S1 and S1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

An automatic microwave impedance adjusting apparatus of a preferred embodiment according to the present invention will be described below, in the order of the following items, with reference to the attached drawings.

- (1) Composition of an automatic impedance adjusting apparatus
- (2) Composition of a controller and peripheral units thereof
- (3) Voltage standing wave detector
- (4) Triple-stub tuner
- (5) Action of the automatic impedance adjusting apparatus
- (6) Impedance matching process
- (7) Modifications

It is to be noted that, in this specification, a normalized impedance and a normalized admittance which are given by dividing an impedance and an admittance at a point of a rectangular waveguide 13 by a characteristic impedance of the rectangular waveguide 13 are referred to as an impedance and an admittance hereinafter, respectively.

Fig. 3 shows the automatic microwave impedance adjusting apparatus of the preferred embodiment according to the present invention, and Fig. 4 shows a controller 50 of the automatic microwave impedance adjusting apparatus and peripheral units thereof.

The automatic microwave impedance adjusting apparatus of the present preferred embodiment mainly comprises:

- (a) a voltage standing wave detector 31 composed of three probes PR1, PR2 and PR3 for detecting an amplitude of a voltage standing wave of a microwave propagating in the rectangular waveguide 13 which is connected between a microwave oscillator 10 and a plasma generating apparatus 30, the voltage standing wave detector 13 being arranged on the microwave oscillator 10 side in the rectangular waveguide 13;
 - (b) a triple-stub tuner 32 composed of three stubs S1, S2 and S3 for connecting an admittance in parallel to the transmission line of the rectangular waveguide 13 when driven by stepping motors M1, M2 and M3, the triple-stub tuner 32 being arranged on the plasma generating apparatus 30 side in the rectangular waveguide 13; and
 - (c) the controller 50 for calculating a reflection coefficient Γ at the probe PR1 of the voltage standing wave detector 31 from amplitudes of the voltage standing wave detected by the voltage standing wave detector 31, calculating a desirable admittance Y_s corresponding to a desirable reflection coefficient Γ_s which has been previously inputted using a keyboard 72, calculating insertion lengths of the stubs S1, S2 and S3 required for adjusting an admittance Y_o seen looking toward a load of the plasma generating apparatus 30 at a mounted point Ps_1 of the stub S1 mounted in the rectangular waveguide 13 (referred to as a reference point hereinafter) to the calculated desirable admittance Y_s , and outputting driving signals for driving the stepping motors M1, M2 and M3 so that the stubs S1, S2 and S3 are inserted into the rectangular waveguide 13 by the above calculated insertion lengths, respectively; and
- the automatic microwave impedance adjusting apparatus is characterized in that an impedance (referred to as a reference impedance hereinafter) Z_o seen looking toward the plasma generating apparatus 30 at the reference point Ps_1 is automatically adjusted to a desirable impedance Z_s corresponding to the inputted desirable reflection coefficient Γ_s .

The automatic microwave impedance adjusting apparatus has a single operation mode for executing only one impedance adjusting process for adjusting the reference impedance Z_o to the desirable impedance Z_s corresponding to the inputted desirable reflection coefficient Γ_s without taking into consideration a change in the load impedance of the plasma generating apparatus 30, and a repeat operation mode for repeating the above impedance adjusting process with taking into consideration the change in the load impedance thereof.

(1) Composition of Automatic impedance adjusting apparatus

Referring to Fig. 3, between the microwave oscillator 10 and the plasma generating apparatus 30, there are connected an isolator 11 for making a microwave outputted from the microwave oscillator 10 propagate toward only the plasma generating apparatus 30, a directional coupler 12, in one port of which there is mounted a diode DI10 for detecting a power of a progressive wave of the microwave propagating therein, the rectangular waveguide 13 wherein there are mounted the voltage standing wave detector 31 and the triple-stub tuner 32, a rectangular waveguide 14 wherein there is formed a hole 14h for flowing cooling air thereinto, a taper waveguide 15 for transforming the TE₁₀ mode which is the principal mode of the isolator 11 and the rectangular waveguides 13 and 14 into the TE₁₁ mode which is the principle mode of a circular waveguide 16, in the order of the isolator 11, the directional coupler 12, the rectangular waveguides 13 and 14 and the taper waveguide 15, in the longitudinal direction thereof. It is to be noted that a connection point of the rectangular waveguide 14 and the taper waveguide 15 is referred to as a load end 14t seen looking at the rectangular waveguide 13 of the automatic microwave impedance adjusting apparatus.

The power of the progressive wave of the microwave outputted from the microwave oscillator 10 is detected by the diode DI10 connected to one port of the directional coupler 12, and the detection output is inputted to a power detector 10d. The power detector 10d outputs a detection signal indicating a power level, which is direct proportional to the square of the detection output, to a power controller 10c. The power controller 10c controls the microwave oscillator 10 according to the above detection signal so that the microwave power outputted therefrom is kept a predetermined constant power level.

The voltage standing wave detector 31 comprises three probes PR1, PR2 and PR3 which are mounted on the microwave oscillator 10 side in the rectangular waveguide 13. These probes PR1, PR2 and PR3 are mounted in the order of PR1, PR2 and PR3 from the microwave oscillator 10 side at equal spaces of $\lambda_g/6$ in the longitudinal direction of the rectangular waveguide 13 in the center portion of the longitudinal side of the section thereof so as to project thereinto, wherein λ_g is a waveguide length of the microwave propagating in the rectangular waveguide 13. Mounted points of the probes PR1, PR2 and PR3 in the longitudinal direction of the rectangular waveguide 13 are labeled Pda, Pdb and Pdc hereinafter, respectively.

The voltage standing wave of the microwave propagating in the rectangular waveguide 13 is detected by the diodes DI1, DI2 and DI3 which are respectively connected to the probes PR1, PR2 and PR3, and respective detection outputs thereof are inputted to voltage detectors 40a, 40b and 40c, respectively. The voltage detectors 40a, 40b and 40c detect the voltages of the detection

outputs, and output detection signals indicating detected voltage levels to analogue to digital converters (referred to as A/D converters hereinafter) 67a, 67b and 67c, respectively.

The triple-stub tuner 32 comprises three stubs S1, S2 and S3 which are mounted on the plasma generating apparatus 30 side in the rectangular waveguide 13. These stubs S1, S2 and S3 are mounted in the order of S1, S2 and S3 from the microwave oscillator 10 side at equal spaces of $\lambda_g/4$ in the longitudinal direction of the rectangular waveguide 13 in the center portion of the longitudinal side of the section thereof so as to be inserted into and drawn out from the rectangular waveguide 13 in a direction perpendicular to the longitudinal side of the section thereof. It is to be noted that the stub S1 is mounted at a mounted point Ps₁ apart by a distance of $\lambda_g/2$ in the longitudinal direction of the rectangular waveguide 13 from the mounted point Pda of the probe PR1 of the voltage standing wave detector 31. Mounted points of respective stubs S1, S2 and S3 are labeled Ps₁, Ps₂ and Ps₃ in the longitudinal direction of the rectangular waveguide 13.

As described later, pulse signals indicating the insertion lengths or the drawing-out lengths of respective stubs S1, S2 and S3 to be inserted into or drawn out from the rectangular waveguide 13, and polarity signals indicating the insertion or the drawing-out operation thereof are outputted from an interface 65 of the controller 50 to respective motor drivers 41a, 41b and 41c. Responsive to these signals, the motor drivers 41a, 41b and 41c amplify the pulse signals, and output the amplified pulse signals having polarities indicated by the above polarity signals to the stepping motors M1, M2 and M3, respectively. The stepping motors M1, M2 and M3 respectively drive the stubs S1, S2 and S3 according to the pulse signals so as to insert them into the rectangular waveguide 13 by insertion lengths corresponding to the pulse numbers of the pulse signals, or draw out them therefrom by drawing-out lengths corresponding to the pulse numbers of the pulse signals.

The plasma generating apparatus 30 is provided for performing an oxidation process for a high temperature superconductor W of oxide group. On the outer peripheral portion of the circular waveguide 16 of the plasma generating apparatus 30, there is mounted an electromagnet 17 for applying a magnetic field onto a glass plasma container 18g having a half egg shape which is mounted in the center portion of the circular waveguide 16, in order to not only generate a plasma utilizing an electron cyclotron motion but also store the generated plasma effectively within the plasma container 18g. Furthermore, in the outer peripheral portion of the circular waveguide 16, there is formed a cooling air outlet 16a for exhausting the cooling air which has been flowed from the hole 14h of the rectangular waveguide 14 into the outside of the circular waveguide 16. It is to be noted that the cooling air is flowed thereinto in order to prevent the temperature of the plasma container 18g from in-

creasing when the plasma container 18g receives an energy from the plasma generated therein, so as to prevent the plasma container 18g from being broken due to the over heating.

In the center portion positioned between the plasma container 18g mounted in the circular waveguide 16 and a plasma processing chamber 18 for processing a superconductor W to be processed, there is formed a plasma outlet 20 for flowing out the plasma generated in the plasma container 18g into the plasma chamber 18. On the outer peripheral portion of the plasma outlet 20, there is mounted a ring-shaped electrode 20a which is electrically connected to a positive electrode of a direct-current voltage source 21 and ground. Furthermore, a negative electrode of the direct-current voltage source 21 is electrically connected to a support mechanism 19m.

In the center portion of the plasma processing chamber 18, there is arranged a table 19 for mounting the superconductor W to be processed. The table 19 is connected to the support mechanism 19m for moving the table 19 in directions as indicated by arrows 19a. Further, in the positions opposing to each other of the outer peripheral portion of the plasma processing chamber 18, there are formed an oxygen gas inlet 18h for supplying oxygen gas into the plasma processing chamber 18, and an oxygen gas outlet 18j for exhausting the supplied oxygen gas into the outside of the plasma processing chamber 18.

In the plasma generating apparatus constructed above, after the table 19 on which the superconductor W to be processed is brought close to the plasma outlet 20 by the support mechanism 10m, the inside of the plasma processing chamber 18 is kept at an oxygen gas pressure in the range from 10^{-4} Torr to 10^{-2} Torr, and then, the superconductor W to be processed is heated at a temperature in the range from 200 °C to 400 °C. Thereafter, a microwave having a frequency such as 2.45 GHz is generated by the microwave oscillator 10. The generated microwave propagates in the isolator 11, the directional coupler 12, the rectangular waveguides 13 and 14, the taper waveguide 15, and the circular waveguide 16, and is incident to the plasma processing chamber 18. On the other hand, a magnetic field is applied to the microwave incident into the circular waveguide 16 in a direction perpendicular to the propagation direction of the microwave by the electromagnet 17, so as to generate an electron cyclotron resonance for the incident microwave at the position on the left side in Fig. 3 of the superconductor W to be processed which is arranged in the plasma processing chamber 18. Furthermore, a negative voltage such as a voltage in the range from -5 V to -100 V is applied to the ring-shaped electrode 20a mounted on the outer peripheral portion of the plasma outlet 20 relative to a potential of the table 19 on which the superconductor W to be processed is mounted. After a time in the range from 30 minutes to one hour has passed in this state, a film of the superconductor W is oxidized, and then, a superconductor having

a high temperature superconductor characteristics can be obtained.

(2) Composition of Controller and Peripheral units thereof

Fig. 4 shows the controller 50 for controlling the operation of the automatic microwave impedance adjusting apparatus and the peripheral units thereof.

Referring to Fig. 4, the controller 50 comprises a central processing unit (referred to as a CPU hereinafter) 60 for controlling the impedance adjusting process of the automatic microwave impedance adjusting apparatus, a read only memory (referred to as a ROM hereinafter) 61 for storing a system program for executing the process of the CPU 60 and data required for executing the above system program, and a random access memory (referred to as a RAM hereinafter) 62 for being used as a working area and storing data required in the processing of the CPU 60.

The controller 50 further comprises a display interface 63 connected to a display 71, a keyboard interface 64 connected to the keyboard 72, the A/D converters 67a, 67b and 67c, an interface 66 connected to the A/D converters 67a, 67b and 67c, and an interface 65 connected to the motor drivers 41a, 41b and 41c. In the controller 50, the CPU 60, the ROM 61, the RAM 62, the display interface 63, the keyboard interface 64 and the interfaces 65 and 66 are connected to each other through a bus 67.

Respective detection signals outputted from the voltage detectors 40a, 40b and 40c are A/D converted to digital data, and then, the digital data are transferred to the RAM through the interface 66 and the bus 67, and are stored therein. The CPU 60 calculates data of the insertion lengths or the drawing-out lengths of respective stubs S1, S2 and S3 required for adjusting the reference impedance Z_0 seen looking toward the load at the reference point Ps_1 to the above desirable impedance Z_s from the digital data of the detection signals, and a desirable reflection coefficient Γ_s which has been previously inputted using the keyboard 72, and outputs the calculated data and data indicating the insertion or the drawing-out operation of respective stubs S1, S2 and S3, to the interface 65 through the bus 67.

Responsive to the data, the interface 65 generates the pulse signals indicating the insertion lengths or the drawing-out lengths of respective stubs S1, S2 and S3 to be inserted into or drawn out from the rectangular waveguide 13, and the polarity signals indicating the insertion or the drawing-out operation thereof, to respective motor drivers 41a, 41b and 41c. It is to be noted that the impedance adjusting process executed by the CPU 60 will be described in detail later, with reference to flowcharts shown in Figs. 22 to 24.

The display 71 displays impedance points seen looking toward the load on a Smith chart, and the insertion lengths of respective stubs S1, S2 and S3, according

to the data inputted from the CPU 60 through the display interface 63.

The keyboard 72 comprises a operation mode selection key (not shown) for selecting either the repeat operation mode or the single operation mode, and a set of ten keys (not shown) for inputting the absolute value $|\Gamma|$ and the phase θ of the reflection coefficient Γ corresponding to the desirable impedance Z_s , and outputs the inputted data to the CPU 60 through the keyboard interface 64.

(3) Voltage standing wave detector

The voltage standing wave detector 31 comprises three probes PR1, PR2 and PR3 mounted at respective points Pda, Pdb and Pdc in the longitudinal direction of the rectangular waveguide 13 at equal spaces of $\lambda_g/6$, as described above.

Fig. 5 shows a voltage standing wave pattern IVstl when there is a reflected wave propagating from the load end 14t in the rectangular waveguides 13 and 14, namely, the load impedance Z_L seen looking toward the load at the reference point is mismatched to the impedance seen looking toward the microwave oscillator 10.

Referring to Fig. 5, the amplitude IVstl of the voltage standing wave changes periodically with a period of $\lambda_g/2$. In Fig. 5, the amplitudes of the voltage standing wave at the points Pda, Pdb and Pdc are labeled IVal, IVbl and IVcl, respectively.

Fig. 6 is a phasor diagram showing a relationship among vectors $\vec{V}_a$, $\vec{V}_b$ and $\vec{V}_c$ of the amplitudes V_a , V_b and V_c of the voltage standing wave, a vector $\vec{D}$ of a progressive wave voltage D , and a vector $\vec{E}$ of a reflected wave voltage E . In Fig. 6, θ_0 is a phase of the reflected wave voltage E relative to a point where the amplitude IVstl of the voltage standing wave becomes a maximum. Then, the reflection coefficient Γ_0 at the mounted point Pda of the probe PR1 is expressed as follows:

$$\Gamma_0 = |\Gamma_0| \cdot e^{j\theta_0} \quad (3)$$

Since the mounted point Pda of the probe PR1 is apart by a distance of $\lambda_g/2$ in the longitudinal direction of the rectangular waveguide 13 from the reference point P_{s1} at which the stub S1 is mounted, the reflection coefficient Γ_0 expressed by the above equation (3) is a reflection coefficient at the reference point P_{s1} .

As shown in Fig. 6, respective vectors $\vec{V}_a$, $\vec{V}_b$ and $\vec{V}_c$ of the amplitudes of the voltage standing wave are a sum of the vector $\vec{D}$ of the progressive wave voltage D and the vector $\vec{E}$ of the reflected voltage E . Respective end points of the vector $\vec{V}_a$, $\vec{V}_b$ and $\vec{V}_c$ are positioned on a circle having a radius equal to the amplitude of the vector $\vec{E}$ of the reflected wave voltage E and a center point which is located at the end point Pdd of the vector $\vec{D}$ of the progressive wave voltage D so that each difference between respective phases thereof

becomes

$$\frac{2}{3} \pi.$$

When the amplitude IVstl of the voltage standing wave becomes a maximum, the phase θ_0 becomes zero, and the reflection coefficient Γ_0 becomes $|\Gamma_0|$. On the other hand, the amplitude IVstl of the voltage standing wave becomes a minimum, the phase θ_0 becomes π , and the reflection coefficient Γ_0 becomes $-|\Gamma_0|$.

Furthermore, as is apparent from Fig. 6, the squares of respective amplitudes of the voltage standing wave $IVal^2$, $IVbl^2$ and $IVcl^2$ detected by the probes PR1, PR2 and PR3 are expressed as follows:

$$IVal^2 = |E|^2 + |D|^2 - 2|E| \cdot |D| \cdot \cos(\pi - \theta_0) \quad (4)$$

$$IVbl^2 = |E|^2 + |D|^2 - 2|E| \cdot |D| \cdot \cos\left(\pi - \theta_0 + \frac{4}{3}\pi\right) \quad (5)$$

$$IVcl^2 = |E|^2 + |D|^2 - 2|E| \cdot |D| \cdot \cos\left(\pi - \theta_0 + \frac{2}{3}\pi\right) \quad (6)$$

Furthermore, the absolute value $|\Gamma_0|$ of the reflection coefficient Γ_0 is expressed as follows:

$$|\Gamma_0| = \frac{|E|}{|D|} \quad (7)$$

Therefore, since respective amplitudes IVal, IVbl and IVcl of the voltage standing wave can be measured by the voltage standing wave detector 31, the absolute value $|\Gamma_0|$ and the phase θ_0 of the reflection coefficient Γ_0 can be obtained by calculating the solutions of the simultaneous equations (4) to (7). Furthermore, the admittance or the impedance seen looking toward the plasma generating apparatus 30 at the reference point P_{s1} can be calculated using equations (9) to (11) which are described later, from the absolute value $|\Gamma_0|$ and the phase θ_0 .

(4) Triple-stub tuner

The triple-stub tuner 32 comprises three stubs S1, S2 and S3 mounted at respective points P_{s1} , P_{s2} and P_{s3} of the rectangular waveguide 13 at equal spaces of $\lambda_g/4$ in the longitudinal direction thereof, as described above.

Fig. 21 shows a relationship between an insertion length L of each of the stubs S1, S2 and S3 when inserted into the rectangular waveguide 13, and a susceptance B connected to the mounted point of each stub in the rectangular waveguide 13.

As is apparent from Fig. 21, as the insertion length L of each of the stubs S1, S2 and S3 increases, the susceptance B of the mounted point increases. Namely, each of the stubs S1, S2 and S3 operates as an admittance element having a pure susceptance B .

Fig. 7 shows an equivalent circuit of the triple-stub tuner 32 which is connected between the microwave oscillator 10 and the plasma generating apparatus 30.

Referring to Fig. 7, the microwave oscillator 10, respective admittance elements Y_{s1} , Y_{s2} and Y_{s3} of the stubs S1, S2 and S3, and a load admittance Y_L of the plasma generating apparatus are connected in parallel. Therefore, the triple-stub tuner 32 can adjust the admittance $Y_o = G_o + jB_o$ seen looking toward the load of the plasma generating apparatus 30 at the reference point Ps_1 where the stub S1 is mounted, to a desirable admittance $Y_s = 1/Z_s$.

For example, in order to match the load admittance Y_o seen looking toward the plasma generating apparatus 30 to the admittance of the microwave oscillator 10, it is apparent that the stubs S1, S2 and S3 are respectively inserted into the rectangular waveguide 13 by such insertion lengths that the admittance Y_o seen looking toward the plasma generating apparatus 30 at the reference point Ps_1 is matched to the admittance $Y_{so} = 1/Z_{so}$ seen looking toward the microwave oscillator 10 at the reference point Ps_1 .

In the automatic microwave impedance adjusting apparatus of the present preferred embodiment, there is calculated the insertion lengths of respective stubs S1, S2 and S3 required for adjusting the admittance Y_o seen looking toward the load of the plasma generating apparatus 30 at the reference point Ps_1 to a desirable admittance Y_s including the admittance Y_{so} seen looking toward the microwave oscillator 10 at the reference point Ps_1 , by the CPU 60 of the controller 50, and then, the stepping motors M1, M2 and M3 are driven so that the stubs S1, S2 and S3 are inserted into the rectangular waveguide 13 by the calculated insertion lengths, respectively.

Fig. 8 shows a relationship between a Smith chart and a UV orthogonal coordinates (referred to as a UV coordinates hereinafter) of a complex plane of a reflection coefficient Γ .

As shown in Fig. 8, the reflection coefficient Γ_o at the reference point Ps_1 is expressed as follows:

$$\Gamma_o = |\Gamma_o| \cdot e^{j\theta_o} = u_o + jv_o \quad (8)$$

where u_o and v_o are a coordinate value of the U-axis and a coordinate value of the V-axis of the UV coordinates.

Furthermore, the admittance $Y_o = 1/Z_o$ seen looking toward the load of the plasma generating apparatus 30 at the reference point Ps_1 is uniquely expressed as follows:

$$\begin{aligned} Y_o &= G_o + jB_o \\ &= \frac{1 - |\Gamma_o| \cdot e^{j\theta_o}}{1 + |\Gamma_o| \cdot e^{j\theta_o}} \\ &= \frac{1 - u_o - jv_o}{1 + u_o + jv_o} \end{aligned} \quad (9)$$

An admittance point P_p of the admittance Y_o is shown on the Smith chart and the UV coordinates of Fig. 8. Furthermore, the conductance G_o and the susceptance b_o of the admittance Y_o are uniquely expressed as follows:

$$G_o = \frac{1 - u_o^2 - v_o^2}{(1 + u_o)^2 + v_o^2} \quad (10)$$

$$B_o = \frac{-2v_o}{(1 + u_o)^2 + v_o^2} \quad (11)$$

Furthermore, transforming the above equations (8) and (9) gives:

$$\left(u_o + \frac{G_o}{G_o + 1}\right)^2 + v_o^2 = \left(\frac{1}{G_o + 1}\right)^2$$

(12)

$$(u_o + 1)^2 + \left(v_o + \frac{1}{B_o}\right)^2 = \left(\frac{1}{B_o}\right)^2 \quad (13)$$

The above equation (12) represents a $G = G_o$ circle which includes the admittance point P_p on the Smith chart and is tangent to a $U = -1$ straight line, as shown in Fig. 8. Also, the above equation (13) represents a $B = B_o$ circle which includes the admittance point P_p on the Smith chart and a point of the UV coordinates $(-1, j0)_{uv}$, as shown in Fig. 8.

It is to be noted that, in the specification and Figs. 8 to 20, UV coordinates of an admittance point located on the Smith chart are represented hereinafter by a coordinate representation with a suffix "uv" such as $(0, j)_{uv}$, $(1, j0)_{uv}$, and also, coordinates of an admittance point located on the Smith chart which indicate a conductance and a susceptance thereof is represented hereinafter by a coordinate representation without any suffix such as (G_o, jB_o) .

When the insertion length of the stub S1 located at the reference point Ps_1 or the stub S3 located at the point Ps_3 apart from the reference point Ps_1 by a distance of $\lambda_g/2$ in the longitudinal direction of the rectangular waveguide 13 is changed, only the susceptance B to be connected to the point Ps_1 at Ps_3 of the rectangular waveguide 13 changes, as described above. Therefore, when the insertion length of the stub S1 or S3 of the triple-stub tuner 32 is changed, the admittance point P_p of the admittance Y_o seen looking toward the load of the plasma generating apparatus 30 at the points Ps_1 and Ps_3 moves on the $G = G_o$ circle on the Smith chart shown in Fig. 8.

Furthermore, an admittance point of an admittance Y_o' seen looking toward the load of the plasma generating apparatus 30 at the point Ps_2 of the stub S2 is located at a point P_p' given when the admittance point P_p of the admittance Y_o on the Smith chart is rotated around the original O of the UV coordinates by 180 degrees, and the admittance Y_o' is uniquely expressed as follows:

$$\begin{aligned}
 Y_o' &= G_o' + jB_o' \\
 &= \frac{1 + |\Gamma_d| \cdot e^{j\theta_o}}{1 - |\Gamma_d| \cdot e^{j\theta_o}} \\
 &= \frac{1 + u_o + jv_o}{1 - u_o - jv_o} \quad (14)
 \end{aligned}$$

It is to be noted that respective references of an admittance, a conductance and a susceptance seen looking toward the load of the plasma generating apparatus 30 are suffixed with a dash mark ' so as to distinguish them from those seen looking toward the load at the reference point Ps₁.

Further, the conductance Go' and the susceptance Bo' of the admittance Yo' are uniquely expressed as follows:

$$G_o' = \frac{1 - u_o^2 - v_o^2}{(1 - u_o)^2 + v_o^2} \quad (15)$$

$$B_o' = \frac{2v_o}{(1 - u_o)^2 + v_o^2} \quad (16)$$

Furthermore, transforming the above equations (15) and (16) gives:

$$\left(u_o - \frac{G_o'}{G_o' + 1}\right)^2 + v_o^2 = \left(\frac{1}{G_o' + 1}\right)^2 \quad (17)$$

$$(u_o - 1)^2 + \left(v_o - \frac{1}{B_o'}\right)^2 = \left(\frac{1}{B_o'}\right)^2 \quad (18)$$

The above equation (17) represents a G' = Go' circle which includes the admittance point Pp' on the Smith chart and is tangent to a U = 1 straight line, as shown in Fig. 9, and the G' = Go' circle and the G = Go circle are point symmetric with respect to the origin O of the UV coordinates. Also, the above equation (18) represents a B' = Bo' circle which includes the admittance point Pp' on the Smith chart and a point of the UV coordinates (1, j0)_{uv}, as shown in Fig. 8, and the B' = Bo' circle and the B = Bo circle are point symmetric with respect to the origin O of the UV coordinates.

It is to be noted that, in Figs. 9 to 20, the coordinates of the Smith chart are represented by coordinates of an admittance point of an admittance seen looking toward the load at the reference point Ps₁. Furthermore, in all Figs. 9 to 20, a G = G' = ∞ circle which includes points of the UV coordinates (1, j0)_{uv}, (0, j)_{uv}, (-1, j0)_{uv} and (0, -j)_{uv} is drawn as a maximum reference circle.

When the insertion length of the stub S2 located at the point Ps₂ of the rectangular waveguide 13 is changed, only the susceptance B to be connected to the point Ps₂ of the rectangular waveguide 13 changes, as described above. Therefore, when the insertion length of the stub S2 of the triple-stub tuner 32 is changed, the admittance point Pp' of the admittance Yo' seen looking toward the load of the plasma generating apparatus 30

at the points Ps₂ moves on the G' = Go' circle on the Smith chart shown in Fig. 9.

In the impedance adjusting process executed by the CPU 60 of the controller 50 as described later, the susceptance Bo' of the admittance Yo' seen looking toward the load at the point Ps₂ of the stub S2 is calculated from the UV coordinates of the admittance point Po of the admittance Yo seen looking toward the load at the reference point Ps₁, and also, the susceptance Bo of the admittance Yo seen looking toward the load at the reference point Ps₁ is calculated from the UV coordinates of the admittance point Pp' of the admittance Yo' seen looking toward the load at the point Ps₂ of the stub S2. In these calculations, the converted susceptance can be calculated by inverting respective signs of the coordinate values of the U-axis and V-axis and substituting the inverted UV coordinates into the equation (11).

(5) Action of Automatic impedance adjusting apparatus

Fig. 22 is flowchart showing a main routine of an impedance adjusting process executed by the CPU 60 of the controller 50. The main routine includes two subroutines executed at steps #7 and #8 of Fig. 22.

(5-1) Main routine of Impedance adjusting process

Referring to Fig. 22, first of all, at step #1, either the repeat operation mode or the single operation mode is selected using the operation mode selection key of the keyboard 72, and then, at step #2, an absolute value |Γ_s| and a phase θ_s of a desirable reflection coefficient Γ_s corresponding to a desirable impedance Z_s seen looking toward the load at the reference point Ps₁ are inputted using a set of ten keys of the keyboard 72.

Thereafter, at step #3, the CPU 60 calculates a conductance G_s and a susceptance B_s of a desirable admittance Y_s corresponding to the inputted reflection coefficient Γ_s, using the equations (9) to (11) from the absolute value |Γ_s| and the phase θ_s which have been inputted, wherein the admittance point of the desirable admittance Y_s is located at an intersection Ps of the G = G_s circle and the B = B_s circle on the Smith chart, as shown in Fig. 10. Thereafter, there are calculated a conductance G_s' and a susceptance B_s' of an admittance Y_s' seen looking toward the load at the point Ps₂ of the stub S2 which is given when the phase of the admittance Y_s is inverted, using the equations (15) and (16).

Furthermore, at step #4, there are calculated the amplitudes of the voltage standing wave |V_a|, |V_b| and |V_c| from respective voltages detected by the diodes DI1, DI2 and DI3 which are respectively connected to the probes PR1, PR2 and PR3 of the voltage standing wave detector 31, and then, at step #5, there are calculated the absolute value |Γ_o| and the phase θ_o of the reflection coefficient Γ_o at the reference point Ps₁ by calculating the solutions of the simultaneous equations (4) to (7). It is to be noted that the admittance point of the admittance

(referred to as a reference admittance hereinafter) Y_o corresponding to the calculated reflection coefficient Γ_o at the reference point Ps_1 is located at an intersection Po of the $G = G_o$ circle and the $B = B_o$ circle on the Smith chart, as shown in Fig. 11.

Thereafter, at step #6, it is judged whether the admittance point Po of the reference admittance Y_o detected by the voltage standing wave detector 31 is located within a tuning region Rx_1 shown in Fig. 12, or a tuning region Ry_1 shown in Fig. 15. Then, if the admittance point Po is located within the tuning region Rx_1 , the program flow goes to step #7, and then, the impedance adjusting process using the stubs S2 and S3 is executed so as to adjust the reference admittance Y_o to the above desirable admittance Y_s , and the program flow goes to step #9. On the other hand, if the admittance point Po is located within the tuning region Ry_1 , the program flow goes to step #8, and then, the impedance adjusting process using the stubs S1 and S2 is executed so as to adjust the reference admittance Y_o to the above desirable admittance Y_s , and the program flow goes to step #9.

As shown in Fig. 12, the tuning region Rx_1 is a region located within the $G = G' = \infty$, and is composed of a sum of:

- (a) a region located within a $G' = G_s'$ circle which includes the admittance point Ps of the admittance Y_s on the Smith chart, and is tangent to the $U = 1$ straight line; and
- (b) a region of all the positive coordinate of the V -axis of the UV coordinates given excluding a region located within a $G = G_s$ circle which includes the admittance point Ps and is tangent to the $U = -1$ straight line. If the admittance point Po of the reference admittance Y_o on the Smith chart is located in the tuning region Rx_1 , the reference admittance Y_o can be adjusted to the desirable admittance Y_s using two stubs S2 and S3.

Furthermore, as shown in Fig. 15, the tuning region Ry_1 is a region located within the $G = G' = \infty$ given excluding the tuning region Rx_1 . If the admittance point Po of the reference admittance Y_o is located in the tuning region Ry_1 on the Smith chart the reference admittance Y_o can be adjusted to the desirable admittance Y_s using two stubs S1 and S1.

It is to be noted that, if the admittance point Po is located on the $G = G_s$ circle of a boundary line between the tuning regions Rx_1 and Ry_1 , the above impedance adjusting process can be executed using only either stub S1 or S3. On the other hand, if the admittance point Po is located on the $G' = G_s'$ circle of a boundary line between the tuning regions Rx_1 and Ry_1 , the above impedance adjusting process can be executed using only the stub S2.

Furthermore, at step #9, it is judged whether or not the operation mode is set at the repeat operation mode. If the operation mode is set at the repeat operation mode,

the program flow goes to step #4, and then, the processes from steps #4 are repeated. On the other hand, if the operation mode is set at the single operation mode, the impedance adjusting mode is completed.

5 The repeat operation mode is useful for adjusting the impedance seen looking toward the load having a load impedance changing with a time such as the plasma generating apparatus 30. Namely, at a time t_0 , there is calculated reflection coefficient r_o corresponding to the reference admittance Y_o in the processes of steps #4 and #5. However, if the load impedance at a time t_1 defined after the time t_0 is shifted from the load impedance at the time t_0 , the reference admittance Y_o after executing the impedance adjusting process at step #7 or #8 is mismatched to the desirable admittance Y_s corresponding to the desirable reflection coefficient r_s which has been previously inputted at step #2. If the repeat operation mode is set in the automatic microwave impedance adjusting apparatus, the automatic microwave impedance adjusting apparatus has such an advantage that the impedance adjusting process can be executed depending on a change in the load impedance of the load such as the plasma generating apparatus 30, even though the load impedance changes.

25 In order to match the impedance seen looking toward the microwave oscillator 10 to the impedance seen looking toward the load of the plasma generating apparatus 30, at step #2, "zero" and "any number" are inputted as the absolute value $|\Gamma_s|$ and the phase θ_s of the reflection coefficient Γ_s , respectively.

30 Furthermore, in the case of the load of the plasma generating apparatus 30, the reference impedance seen looking toward the load may not become a certain desirable impedance stably due to a frequent change in the load impedance of the plasma generating apparatus 30, even though the impedance adjusting process of the present preferred embodiment is executed so that the reference impedance seen looking toward the load at the reference point Ps_1 is matched to the impedance seen toward the microwave oscillator 10. In this case, at step #2, there are inputted an absolute value $|\Gamma_s|$ and a phase θ_s of a desirable reflection coefficient Γ_s close to the impedance matching point located at the origin O of the UV coordinates so as to adjust the above reference admittance Y_o to a desirable admittance Y_s corresponding the above inputted reflection coefficient Γ_s , resulting in a stable reference impedance seen looking toward the load at the reference point Ps_1 .

50 (5-2) Subroutine of Impedance adjusting process using Stubs S2 and S3

Fig. 23 is a flowchart showing the subroutine of the impedance adjusting process using the stubs S2 and S3 (step #7 of Fig. 22).

Referring to Fig. 23, first of all, at step #11, there is calculated a susceptance B_o seen looking toward the load at the reference point Ps_1 using the equations (8)

and (11) from the absolute value $|\Gamma_o|$ and the phase θ_o of the reflection coefficient Γ_o at the reference point Ps_1 which have been calculated at step #5, and then, at step #12, there are calculated the UV coordinates of an intersection Pa of the $G = G_o$ circle and the $G' = G_s'$ circle shown in Fig. 13, using the equation (12) and (17).

Thereafter, at step #13, there is calculated a susceptance B_a of the intersection Pa from the UV coordinates of the intersection Pa , and then, at step #14, there is calculated a susceptance B_{30} to be connected by the stub $S3$ to the transmission line of the rectangular waveguide 13, which is expressed by the following equation (19):

$$B_{30} = B_a - B_o \quad (19)$$

The susceptance B_{30} is a difference between respective susceptances of the admittance points Po and Pa which are located on the $G = G_o$ circle on the Smith chart shown in Fig. 13.

Thereafter, at step #15, there is calculated a susceptance B_a' seen looking toward the load at the point Ps_2 of the stub $S2$ using the equation (11), as described above, from the UV coordinates of the above susceptance B_a .

Thereafter, at step #16, there is calculated a susceptance B_{20}' to be connected by the stub $S2$ to the transmission line of the rectangular waveguide 13, which is expressed by the following equation (20):

$$B_{20}' = B_s' - B_a' \quad (20)$$

The susceptance B_{20}' is a difference between respective susceptances of the admittance points Ps and Pa which are located on the $G' = G_s'$ circle on the Smith chart shown in Fig. 14.

Thereafter, at step #17, there are calculated insertion lengths of the stubs $S2$ and $S3$ using the relationship between the insertion length L thereof and the susceptance B shown in Fig. 21 which has been previously measured, from the calculated susceptances B_{20}' and B_{30} , and then, at step #18, the stepping motors $M2$ and $M3$ are driven, respectively, so that the stubs $S2$ and $S3$ are inserted into the rectangular waveguide 13 by the calculated insertion lengths. Then, the reference admittance Y_o is adjusted to the desirable admittance Y_s .

(5-3) Subroutine of Impedance adjusting process using Stubs $S1$ and $S2$

Fig. 24 is a flowchart showing the subroutine of the impedance adjusting process using the stubs $S1$ and $S2$ (step #8 of Fig. 22).

Referring to Fig. 24, first of all, at step #21, there is calculated a susceptance B_o' seen looking toward the load at the point Ps_2 using the equations (15) and (16) from the absolute value $|\Gamma_o|$ and the phase θ_o of the reflection coefficient Γ_o at the reference point Ps_1 which have been calculated at step #5, and then, at step #22,

there are calculated the UV coordinates of an intersection Pb of the $G' = G_o'$ circle and the $G = G_s$ circle shown in Fig. 16, using the equation (12) and (17).

Thereafter, at step #23, there is calculated a susceptance B_b' of the intersection Pb from the UV coordinates of the intersection Pb , and then, at step #24, there is calculated a susceptance B_{20}' to be connected by the stub $S2$ to the transmission line of the rectangular waveguide 13, which is expressed by the following equation (21):

$$B_{20}' = B_b' - B_o' \quad (21)$$

The susceptance B_{20}' is a difference between respective susceptances of the admittance points Po and Pb which are located on the $G' = G_o'$ circle on the Smith chart shown in Fig. 16.

Thereafter, at step #25, there is calculated a susceptance B_b seen looking toward the load at the reference point Ps_1 using the equation (11), as described above, from the UV coordinates of the above susceptance B_b' .

Thereafter, at step #26, there is calculated a susceptance B_{10} to be connected by the stub $S1$ to the transmission line of the rectangular waveguide 13, which is expressed by the following equation (22):

$$B_{10} = B_s - B_b \quad (22)$$

The susceptance B_{10} is a difference between respective susceptances of the admittance points Ps and Pb which are located on the $G = G_s$ circle on the Smith chart shown in Fig. 17.

Thereafter, at step #27, there are calculated insertion lengths of the stubs $S1$ and $S2$ using the relationship between the insertion length L thereof and the susceptance B shown in Fig. 21 which has been previously measured, from the calculated susceptances B_{10} and B_{20}' , and then, at step #28, the stepping motors $M1$ and $M2$ are driven, respectively, so that the stubs $S1$ and $S2$ are inserted into the rectangular waveguide 13 by the calculated insertion lengths. Then, the reference admittance Y_o is adjusted to the desirable admittance Y_s .

(6) Impedance matching process

Figs. 18 and 19 are Smith charts and complex planes of UV coordinates showing tuning regions Rx_0 and Ry_0 corresponding to the tuning regions Rx_1 and Ry_1 , in the case of an impedance matching process for matching the reference admittance Y_o seen looking toward the load of the plasma generating apparatus 30 at the reference point Ps_1 to the admittance $Y_{so} = 1/Z_{so}$ seen looking toward the microwave oscillator 10 thereat.

In Figs. 18 and 19, the tuning region Rx_0 is a region where the impedance matching process is executed using the stubs $S2$ and $S3$ when the admittance point Po of the reference admittance Y_o is located within the tuning region Rx_0 on the Smith chart, and the tuning region

Ry₀ is a region where the impedance matching process is executed using the stubs S1 and S2 when the admittance point Po of the reference admittance Yo is located within the tuning region Ry₀ on the Smith chart.

As shown in Figs. 18 and 19, the admittance point Ps of the desirable admittance Ys becomes the origin Pso of the UV coordinates, and a boundary line between the tuning regions Rx₀ and Ry₀ is composed of half the G = 1 circle for any positive coordinate value of the V-axis of the UV coordinates, and half the G' = 1 circle for any negative coordinate value of the V-axis of the UV coordinates.

The impedance matching process shown in Fig. 18 is executed in a manner similar to that of the subroutine of step #7, and the impedance matching process shown in Fig. 19 is executed in a manner similar to that of the subroutine of step #8.

(7) Modifications

At step #6 of the present preferred embodiment, it is judged whether the admittance point Po of the reference admittance Yo is located within the tuning region Rx₁ or Ry₁, and then, the impedance adjusting process using the stubs S2 and S3 is executed if the point Po is located within the tuning region Rx₁, on the other hand, the impedance adjusting process using the stubs S1 and S2 is executed if the point Po is located within the tuning region Ry₁. However, the present invention is not limited to this. If the admittance point Po is located at a partial region (referred to as a tuning region Rz₁ hereinafter) of the tuning region Ry₁ for any positive coordinate value of the V-axis of the UV coordinates, an impedance adjusting process may be executed using all the stubs S1, S2 and S3. Then, the reference admittance Yo can be adjusted to a desirable admittance Ys, for a time shorter than that of the impedance adjusting process using the stubs S1 and S2, in the above case.

Fig. 18 is a Smith chart and a complex plane of a UV coordinates showing an operation of an impedance matching process using all the stubs S1, S2 and S3.

If the admittance point Po of the reference admittance Yo is located within a tuning region Rz₀ on the Smith chart shown in Fig. 18, the impedance matching process is executed using all the stubs S1, S2 and S3, wherein the tuning region Rz₀ is a region located within half the G = 1 for any positive value of the V-axis of the UV coordinates.

In the impedance matching process, as shown in the Smith chart of Fig. 20, the admittance point Po of the reference admittance Yo is moved using the stub S3 to an intersection Pa of the G = Go circle and the U-axis, and then, the admittance point Pa is moved using the stub S2 to an intersection Pb of the G = 1 circle and a G' = Ga', wherein the G' = Ga' circle includes the admittance point Pa and is tangent to the U = 1 straight line. Thereafter, the admittance point Pb is moved using the stub S1 to the impedance matching point Pso. Thus, the sus-

ceptances of respective stubs S1, S2 and S3 are changed so as to match the reference admittance Yo to the admittance Yso seen looking toward the microwave oscillator 10 at the reference points Ps₁. the calculation of this impedance matching process is executed in a manner similar to that of the subroutine of step #7 or #8.

In the present preferred embodiment, there are calculated the absolute value |Γ_o| and the phase θ_o of the reflection coefficient |Γ_o| at the reference point by the CPU 60 from the amplitudes of the voltage standing wave detected by respective probes PR1, PR2 and PR3 by the standing wave measuring method using the probes PR1, PR2 and PR3 and the diodes DI1, DI2 and DI3. However, the present invention is not limited to this. For example, after measuring the impedance seen looking to a load at a point of a microwave transmission line by another measuring method for measuring the impedance thereof, a reflection coefficient corresponding to the measured impedance may be calculated, and then, the impedance adjusting process of the present invention may be executed.

In the voltage standing wave detector 31 of the present preferred embodiment, three probes PR1, PR2 and PR3 are mounted at equal spaces of λg/6 in the longitudinal direction of the rectangular waveguide 13. However, the present invention is not limited to this. At least three probes may be mounted at different points at predetermined spaces, one of which is not a product of any natural number and the length λg/2. Each space between the probes is preferably set at a length equal to a product of any natural number and the length λg/6 except for products of any natural number and the length λg/2. For example, when each space between the probes is set at the length λg/3, the squares of the amplitudes of the voltage standing wave detected by respective probes PR1, PR2 and PR3 are expressed as follows:

$$|V_a|^2 = |E|^2 + |D|^2 - 2|E| \cdot |D| \cdot \cos(\pi - \theta_o) \quad (23)$$

$$|V_b|^2 = |E|^2 + |D|^2 - 2|E| \cdot |D| \cdot \cos\left(\pi - \theta_o + \frac{8}{3}\pi\right) \quad (24)$$

$$|V_d|^2 = |E|^2 + |D|^2 - 2|E| \cdot |D| \cdot \cos\left(\pi - \theta_o + \frac{4}{3}\pi\right) \quad (25)$$

In the present preferred embodiment, the space in the longitudinal direction of the rectangular waveguide 13 between the stub S1 and the probe PR1 is set at the length λg/2 for convenience of the explanation. However, the present invention is not limited to this. This space may be set at any distance.

At step #2 of Fig. 22 of the present preferred embodiment, there are inputted the absolute value |Γ_s| and the phase θ_o of the reflection coefficient Γ_s corresponding

to the desirable impedance Z_s seen looking toward the load at the reference point Ps_1 . However, the present invention is not limited to this. A resistance R_s and a reactance X_s of a desirable impedance Z_s may be inputted, or a conductance G_s and a susceptance B_s of a desirable admittance Y_s corresponding to a desirable impedance Z_s may be inputted.

Claims

1. An automatic microwave impedance adjusting method including a first step of measuring either an impedance seen looking towards a microwave load (3) at a predetermined reference point of a microwave transmission line of a rectangular waveguide (13) connected between a microwave oscillator (10) and said microwave load (30) or a reflection coefficient thereof by detecting a voltage standing wave of a microwave propagating on said microwave transmission line;

wherein said method includes:

a second step of calculating insertion lengths of first to third stubs (S_1 , S_2 and S_3) of variable impedance means so as to adjust said impedance seen looking towards said microwave load (30) to a desired value corresponding to an inputted desired reflection coefficient, responsive to said value measured at said first step, said first to third stubs (S_1 , S_2 and S_3) being mounted on said microwave load side of said reference point on said microwave transmission line, and mounted at different points in an order of said first to third stubs (S_1 , S_2 and S_3) at equal spaces of a quarter of said waveguide length in the longitudinal direction of said rectangular waveguide (13), and

a third step of inserting said first to third stubs (S_1 , S_2 and S_3) into said rectangular waveguide (13) by insertion lengths calculated at said second step, thereby adjusting said impedance seen looking towards said microwave load (30) to said desired value, characterised in that a whole region within a Smith chart representing an impedance seen looking towards said microwave load (30) is divided into a first region (R_y) for executing said impedance adjusting process of said third step using first and second stubs (S_1 , S_2) when an impedance point seen looking towards said microwave load (30) at said reference point is located within said first region (R_y), a second region (R_x) for executing said impedance adjusting process of said third step using said second and third stubs (S_2 , S_3) when said impedance point is located within said second region (R_x), and a third region (R_z) for executing

said impedance adjusting of said third step using all said first to third stubs (S_1 , S_2 and S_3) when said impedance point is located within said third region (R_z), said third region (R_z) being defined as a partial region of said first region (R_y) for any positive coordinate value of a V-axis of a UV orthogonal coordinate of the Smith chart; and

wherein said second step includes:

calculating an impedance seen looking towards said microwave load (30) at said reference point responsive to said value measured at said first step; and

judging whether an impedance point of said calculated impedance is located within either said first region (R_y), said second region (R_x) or said third region (R_z) on said Smith chart; and wherein said third step includes:

executing said impedance adjusting process of said third step using said first and second stubs (S_1 , S_2) when it is judged that said impedance point of said calculated impedance is located within said first region (R_y), executing said impedance adjusting process of said third step using said second and third stubs (S_2 , S_3) when it is judged that said impedance point of said calculated impedance is located within said second region (R_x), and executing said impedance adjusting process of said third step using all said first to third stubs (S_1 , S_2 and S_3) when it is judged that said impedance point of said calculated impedance is located within said third region (R_z).

2. A method as claimed in claim 1, wherein a whole region within a Smith chart representing an impedance seen looking towards said microwave load (30) is divided into a first region for executing said impedance adjusting process of said third step using said first and second stubs (S_1 , S_2) when an impedance point seen looking towards said microwave load (30) at said reference point is located within said first region, and a second region for executing said impedance adjusting process of said third step using said second and third stubs (S_2 , S_3) when said impedance point is located within said second region;

wherein said second step includes:

calculating an impedance seen looking towards said microwave load (30) at said reference point responsive to said value measured at said first step, and

judging whether an impedance point of said calculated impedance is located within either said first region or said second region of said Smith chart, and

wherein said third step includes:

executing said impedance adjusting process of said third step using said first and second stubs (S1, S2) when it is judged that said impedance point of said calculated impedance is located within said first region, and executing said impedance adjusting process of said third step using said second and third stubs (S2, S3) when it is judged that said impedance point of said calculated impedance is located within said second region.

3. A method as claimed in any one of claims 1 and 2, wherein said processes of said first to third steps are repeated.

4. An automatic microwave impedance adjusting apparatus for performing the method of any one of claims 1 to 3 and comprising:

a microwave transmission line connected between a microwave oscillator (10) and a microwave load (3), said microwave transmission line being a rectangular waveguide (13), measuring means for measuring either an impedance seen looking towards said microwave load (30) at a mounted point thereof or a reflection coefficient thereat by detecting a voltage standing wave of a microwave propagating on said microwave transmission line,

variable impedance means (32) for changing an impedance to be connected to a mounted point thereof, and

control means (5) for controlling said variable impedance means (32) responsive to a value measured by said measuring means so as to adjust said impedance to a desired value corresponding to an inputted desired reflection coefficient,

characterised in that

said variable impedance means (32) are mounted on said microwave load side of said measuring means on said microwave transmission line, said variable impedance means (32) comprising three stubs (S1, S2 and S3) mounted at different points at equal spaces of a quarter of said waveguide wavelength in the longitudinal direction of said rectangular waveguide (13), and

said control means (5) comprises:

calculating means for calculating insertion lengths of first to third stubs (S1, S2 and S3) of variable impedance means so as to adjust said impedance seen looking towards said microwave load (30) to a desired value corresponding to an inputted desired reflection coefficient, responsive to said value measured by said measuring means, and

insertion control means for inserting said first to

third stubs (S1, S2 and S3) into said rectangular waveguide (13) by insertion lengths calculated by said calculating means, thereby adjusting said impedance seen looking towards said microwave load (30) to said desired value,

wherein a whole region within a Smith chart representing an impedance seen looking towards said microwave load (30) is divided into a first region (Ry) for executing said impedance adjusting process of said insertion control means using first and second stubs (S1, S2) when an impedance point seen looking towards said microwave load (30) at said reference point is located within said first region (Ry), a second region (Rx) for executing said impedance adjusting process of said insertion control means using said second and third stubs (S2, S3) when said impedance point is located within said second region (Rx), and a third region (Rz) for executing said impedance adjusting of said insertion control means using all said first to third stubs (S1, S2 and S3) when said impedance point is located within said third region (Rz), said third region (Rz) being defined as a partial region of said first region (Ry) for any positive coordinate value of a V-axis of a UV orthogonal coordinate of the Smith chart; and wherein said calculating means comprises: means for calculating an impedance seen looking towards said microwave load (30) at said reference point responsive to said value measured by said measuring means; and

means for judging whether an impedance point of said calculated impedance is located within either said first region (Ry), said second region (Rx) or said third region (Rz) on said Smith chart; and

wherein said insertion control means comprises:

executing said impedance adjusting process of said insertion control means using said first and second stubs (S1, S2) when it is judged that said impedance point of said calculated impedance is located within said first region (Ry), executing said impedance adjusting process of said insertion control means using said second and third stubs (S2, S3) when it is judged that said impedance point of said calculated impedance is located within said second region (Rx), and executing said impedance adjusting process of said insertion control means using all said first to third stubs (S1, S2 and S3) when it is judged that said impedance point of said calculated impedance is located within said third region (Rz).

Patentansprüche

1. Verfahren zur automatischen Mikrowellenimpedanzeinstellung, bei dem in einem ersten Schritt entweder die Impedanz gemessen wird, die man sieht, wenn man an einem vorbestimmten Referenzpunkt einer Mikrowellenübertragungsleitung eines rechtwinkligen Wellenleiters (13), der einen Mikrowellenoszillator (10) und eine Mikrowellenbelastung (30) verbindet, in Richtung der Mikrowellenbelastung (30) schaut, oder der dortige Reflexionskoeffizient durch Messung einer stehenden Spannungswelle einer sich auf dieser Mikrowellenübertragungsleitung ausbreitenden Mikrowelle,

wobei das Verfahren folgendes umfaßt:

einen zweiten Schritt, bei dem die Einfügelängen von ersten bis dritten Blindleitungen (S1, S2 und S3) variabler Impedanz derart berechnet werden, daß die Impedanz, die man sieht, wenn man in Richtung der Mikrowellenbelastung (30) schaut, auf einen gewünschten Wert eingestellt wird, der einem eingegebenen gewünschten Reflexionskoeffizient entspricht, in Abhängigkeit vom im ersten Schritt gemessenen Wert, wobei die ersten bis dritten Blindleitungen (S1, S2 und S3) vom Referenzpunkt gesehen auf der Seite der Mikrowellenbelastung auf der Mikrowellenübertragungsleitung angeordnet sind, und wobei sie von der ersten bis zur dritten Blindleitung (S1, S2 und S3) an verschiedenen Punkten mit gleichen Abständen, deren Größe einem Viertel der Länge des Wellenleiters entspricht, in Längsrichtung des rechtwinkligen Wellenleiters (13) angeordnet sind, und

einen dritten Schritt, bei dem die ersten bis dritten Blindleitungen (S1, S2 und S3) in den rechtwinkligen Wellenleiter (13) eingefügt werden mit Einfügelängen, die im zweiten Schritt berechnet wurden, um somit die Impedanz, die man in Richtung auf die Mikrowellenbelastung (30) sieht, auf den gewünschten Wert einzustellen,

dadurch gekennzeichnet, daß ein vollständiges Gebiet innerhalb eines Smithschen Leitungsdiagramms, das eine Impedanz darstellt, die man sieht, wenn man in Richtung der Mikrowellenbelastung (30) sieht, unterteilt ist in ein erstes Gebiet (Ry) für das Durchführen des Impedanzeinstellverfahrens des dritten Schrittes, das die ersten und zweiten Blindleitungen (S1, S2) benutzt, wenn ein Impedanzpunkt, den man sieht, wenn man am Referenzpunkt in Richtung der Mikrowellenbelastung (30) schaut, sich im ersten Gebiet (Ry) befindet, in ein zweites Gebiet (Rx) für das Durchführen des Impedanzeinstellverfahrens des dritten Schrit-

tes, das die zweiten und dritten Blindleitungen (S2, S3) verwendet, wenn der Impedanzpunkt sich im zweiten Gebiet (Rx) befindet, und in ein drittes Gebiet (Rz) für das Durchführen des Impedanzeinstellverfahrens des dritten Schrittes, das alle der ersten bis dritten Blindleitungen (S1, S2 und S3) verwendet, wenn der Impedanzpunkt sich im dritten Gebiet (Rz) befindet, wobei das dritte Gebiet (Rz) definiert ist als Teilgebiet eines ersten Gebietes (Ry) für irgendeinen positiven Koordinatenwert einer V-Achse einer rechtwinkligen UV Koordinate des Smithschen Leitungsdiagramms; und

wobei der zweite Schritt folgendes umfaßt:

die Berechnung einer Impedanz, die man sieht, wenn man am Referenzpunkt, abhängig vom im ersten Schritt gemessenen Wert, in Richtung der Mikrowellenbelastung (30) schaut; und die Beurteilung, ob ein Impedanzpunkt der berechneten Impedanz sich entweder im ersten Gebiet (Ry), im zweiten Gebiet (Rx) oder im dritten Gebiet (Rz) im Smithschen Leitungsdiagramm befindet; und

wobei der dritte Schritt folgendes umfaßt:

die Ausführung des Impedanzeinstellverfahrens des dritten Schrittes, das die ersten und zweiten Blindleitungen (S1, S2) verwendet, wenn ermittelt wurde, daß der Impedanzpunkt der berechneten Impedanz sich im ersten Gebiet (Ry) befindet, die Ausführung des Impedanzeinstellverfahrens des dritten Schrittes, das die zweiten und dritten Blindleitungen (S2, S3) verwendet, wenn ermittelt wurde, daß der Impedanzpunkt der berechneten Impedanz sich im zweiten Gebiet (Rx) befindet, und die Ausführung des Impedanzeinstellverfahrens des dritten Schrittes, das alle der ersten bis dritten Blindleitungen (S1, S2 und S3) verwendet, wenn ermittelt wurde, daß der Impedanzpunkt der berechneten Impedanz sich im dritten Gebiet (Rz) befindet.

2. Verfahren nach Anspruch 1, bei dem ein vollständiges Gebiet innerhalb eines Smithschen Leitungsdiagramms, das eine Impedanz darstellt, die man sieht, wenn man in Richtung der Mikrowellenbelastung (30) sieht, unterteilt ist in ein erstes Gebiet (Ry) für das Durchführen des Impedanzeinstellverfahrens des dritten Schrittes, das die ersten und zweiten Blindleitungen (S1, S2) benutzt, wenn ein Impedanzpunkt, den man sieht, wenn man vom Referenzpunkt in Richtung der Mikrowellenbelastung (30) schaut, sich im ersten Gebiet (Ry) befindet, und in ein zweites Gebiet für das Durchführen des Impedanzeinstellverfahrens des dritten Schrittes, das die zweiten und dritten Blindleitungen (S2, S3) verwendet, wenn der Impedanzpunkt sich im zweiten Gebiet befindet,

- wobei der zweite Schritt folgendes umfaßt:
 die Berechnung einer Impedanz, die man sieht,
 wenn man am Referenzpunkt, abhängig vom im
 ersten Schritt gemessenen Wert, in Richtung
 der Mikrowellenbelastung (30) schaut; und 5
 die Beurteilung, ob ein Impedanzpunkt der
 berechneten Impedanz sich entweder im ersten
 Gebiet oder im zweiten Gebiet des Smithschen
 Leitungsdiagramm befindet, und
 wobei der dritte Schritt folgendes umfaßt: 10
 die Ausführung des Impedanzeinstellverfah-
 rens des dritten Schrittes, das die ersten und
 zweiten Blindleitungen (S1, S2) verwendet,
 wenn ermittelt wurde, daß der Impedanzpunkt
 der berechneten Impedanz sich im ersten 15
 Gebiet befindet, und die Ausführung des Impe-
 danzeinstellverfahrens des dritten Schrittes,
 das die zweiten und dritten Blindleitungen (S2,
 S3) verwendet, wenn ermittelt wurde, daß der
 Impedanzpunkt der berechneten Impedanz 20
 sich im zweiten Gebiet befindet.
3. Verfahren nach einem der Ansprüche 1 und 2, wobei
 die Verfahren der ersten bis dritten Schritte wieder- 25
 holt werden.
4. Vorrichtung zur automatischen Mikrowellenimpe-
 danzeinstellung zur Durchführung des Verfahrens
 nach einem der Ansprüche 1 bis 3, wobei die Vor- 30
 richtung folgendes umfaßt:
- eine Mikrowellenübertragungsleitung, die einen
 Mikrowellenoszillator (10) und eine Mikrowel-
 lenbelastung (30) verbindet, wobei die Mikro- 35
 wellenübertragungsleitung aus einem recht-
 winkligen Wellenleiter (13) besteht,
 eine Meßvorrichtung zur Messung entweder
 einer Impedanz, die man sieht, wenn man von
 einem Montagepunkt aus in Richtung der Mikro- 40
 wellenbelastung (30) sieht, oder eines dortigen
 Reflexionskoeffizienten durch das Messen
 einer stehenden Spannungswelle einer sich auf
 dieser Mikrowellenübertragungsleitung aus-
 breiten Mikrowelle, 45
 variable Impedanzvorrichtungen (32) für das
 Verändern einer Impedanz, die an einem Mon-
 tagepunkt mit ihr verbunden werden sollen; und
 eine Steuervorrichtung (5) zur Steuerung der
 variablen Impedanzvorrichtungen (32) in 50
 Abhängigkeit von einem Wert, der von der
 Meßvorrichtung gemessen wurde, um die
 Impedanz auf einen gewünschten Wert einzu-
 stellen, der einem eingegebenen gewünschten
 Reflexionskoeffizient entspricht,
dadurch gekennzeichnet, daß 55
 die variablen Impedanzvorrichtungen (32) auf
 der Seite der Mikrowellenbelastung der
 Meßeinrichtung auf der Mikrowellenübertra-

gungsleitung montiert sind, wobei die variablen
 Impedanzvorrichtungen (32) drei Blindleitun-
 gen (S1, S2 und S3) umfassen, die an verschie-
 denen Punkten mit gleichen Abständen vonein-
 ander in Längsrichtung des rechtwinkligen Wel-
 lenleiters (13) montiert sind, wobei die
 Abstände eine Größe haben, die gleich ist
 einem Viertel der Wellenlänge des Wellenlei-
 ters, und
 wobei die Steuervorrichtung folgendes umfaßt:
 eine Berechnungsvorrichtung zur Berechnung
 der Einfügelängen der ersten bis dritten Blind-
 leitungen (S1, S2 und S3) variabler Impedanz,
 um die Impedanz, die man in Richtung der
 Mikrowellenbelastung (30) sieht, auf einen
 gewünschten Wert einzustellen, der einem ein-
 gegebenen gewünschten Reflexionskoeffizient
 entspricht, abhängig vom Wert, der durch die
 Meßvorrichtung gemessen wurde, und
 eine Einfügesteuervorrichtung zum Einfügen
 dieser ersten bis dritten Blindleitungen (S1, S2
 und S3) in den rechtwinkligen Wellenleiter (13)
 mit Einfügelängen, die durch die Berechnungs-
 vorrichtung berechnet wurden, um somit die
 Impedanz, die man sieht, wenn man in Richtung
 der Mikrowellenbelastung (30) schaut, auf den
 gewünschten Wert einzustellen,
 wobei ein vollständiges Gebiet innerhalb eines
 Smithschen Leitungsdiagramms, das eine
 Impedanz darstellt, die man sieht, wenn man in
 Richtung der Mikrowellenbelastung (30) sieht,
 unterteilt ist in ein erstes Gebiet (Ry) für das
 Durchführen des Impedanzeinstellverfahrens
 der Einfügesteuervorrichtung, das erste und
 zweite Blindleitungen (S1, S2) benutzt, wenn
 ein Impedanzpunkt, den man sieht, wenn man
 am Referenzpunkt in Richtung der Mikrowellen-
 belastung (30) schaut, sich im ersten Gebiet
 (Ry) befindet, in ein zweites Gebiet (Rx) für das
 Durchführen des Impedanzeinstellverfahrens
 der Einfügesteuervorrichtung, das die zweiten
 und dritten Blindleitungen (S2, S3) verwendet,
 wenn der Impedanzpunkt sich im zweiten
 Gebiet (Rx) befindet, und ein drittes Gebiet (Rz)
 für das Durchführen der Impedanzeinstellung
 der Einfügesteuervorrichtung, die alle der
 ersten bis dritten Blindleitungen (S1, S2 und S3)
 verwendet, wenn der Impedanzpunkt sich im
 dritten Gebiet (Rz) befindet, wobei das dritte
 Gebiet (Rz) definiert ist als Teilgebiet des ersten
 Gebietes (Ry) für irgendeinen positiven Koordinatenwert einer V-Achse einer rechtwinkligen UV Koordinate des Smithschen Leitungsdiagramms; und
 wobei die Berechnungsvorrichtung folgendes
 umfaßt:
 eine Vorrichtung zur Berechnung einer Impe-
 danz, die man sieht, wenn man am Referenz-

punkt, abhängig vom von der Meßvorrichtung gemessenen Wert, in Richtung der Mikrowellenbelastung (30) schaut; und
 eine Vorrichtung zur Beurteilung, ob ein Impedanzpunkt der berechneten Impedanz sich entweder im ersten Gebiet (Ry), im zweiten Gebiet (Rx) oder im dritten Gebiet (Rz) im Smithschen Leitungsdiagramm befindet; und
 wobei die Einfügesteuervorrichtung folgendes umfaßt:
 die Ausführung des Impedanzeinstellverfahrens der Einfügesteuervorrichtung, das die ersten und zweiten Blindleitungen (S1, S2) verwendet, wenn ermittelt wurde, daß der Impedanzpunkt der berechneten Impedanz sich im ersten Gebiet (Ry) befindet, die Ausführung des Impedanzeinstellverfahrens der Einfügesteuervorrichtung, das die zweiten und dritten Blindleitungen (S2, S3) verwendet, wenn ermittelt wurde, daß der Impedanzpunkt der berechneten Impedanz sich im zweiten Gebiet (Rx) befindet, und die Ausführung des Impedanzeinstellverfahrens der Einfügesteuervorrichtung, das alle der ersten bis dritten Blindleitungen (S1, S2 und S3) verwendet, wenn ermittelt wurde, daß der Impedanzpunkt der berechneten Impedanz sich im dritten Gebiet (Rz) befindet.

Revendications

1. Procédé de réglage automatique d'une impédance hyperfréquence incluant une première étape de mesure de soit une impédance vue en regardant en direction d'une charge hyperfréquence (3) en un point de référence prédéterminé d'une ligne de transmission hyperfréquence d'un guide d'onde rectangulaire (13) connecté entre un oscillateur hyperfréquence (10) et ladite charge hyperfréquence (30) soit un coefficient de réflexion à ce niveau en détectant une onde stationnaire de tension d'une hyperfréquence se propageant sur ladite ligne de transmission hyperfréquence,

dans lequel ledit procédé inclut :
 une seconde étape de calcul de longueurs d'insertion de premier à troisième adaptateurs d'impédance (S1, S2 et S3) d'un moyen d'impédance variable de manière à régler ladite impédance vue en regardant en direction de ladite charge hyperfréquence (30) à une valeur souhaitée correspondant à un coefficient de réflexion souhaité entré, en réponse à ladite valeur mesurée lors de ladite première étape, lesdits premier à troisième adaptateurs d'impédance (S1, S2 et S3) étant montés sur ledit côté de charge hyperfréquence dudit point de référence sur ladite ligne de transmission hyperfré-

quence et étant montés en différents points selon l'ordre desdits premier à troisième adaptateurs d'impédance (S1, S2 et S3) selon des espaces égaux valant chacun un quart de ladite longueur du guide d'onde suivant la direction longitudinale dudit guide d'onde rectangulaire (13) ; et

une troisième étape d'insertion desdits premier à troisième adaptateurs d'impédance (S1, S2 et S3) dans ledit guide d'onde rectangulaire (13) sur des longueurs d'insertion calculées lors de ladite seconde étape pour ainsi régler ladite impédance vue en regardant en direction de ladite charge hyperfréquence (30) à ladite valeur souhaitée,

caractérisé en ce qu'une région globale à l'intérieur d'un abaque de Smith représentant une impédance vue en regardant en direction de ladite charge hyperfréquence (30) est divisée en une première région (Ry) pour exécuter ledit processus de réglage d'impédance de ladite troisième étape en utilisant les premier et second adaptateurs d'impédance (S1, S2) lorsqu'un point d'impédance vu en regardant en direction de ladite charge hyperfréquence (30) au niveau dudit point de référence est localisé à l'intérieur de ladite première région (Ry), en une seconde région (Rx) pour exécuter ledit processus de réglage d'impédance de ladite troisième étape en utilisant lesdits second et troisième adaptateurs d'impédance (S2, S3) lorsque ledit point d'impédance est localisé à l'intérieur de ladite seconde région (Rx) et en une troisième région (Rz) pour exécuter ledit réglage d'impédance de ladite troisième étape en utilisant la totalité desdits premier à troisième adaptateurs d'impédance (S1, S2 et S3) lorsque ledit point d'impédance est localisé à l'intérieur de ladite troisième région (Rz), ladite troisième région (Rz) étant définie en tant que région partielle de ladite première région (Ry) pour une quelconque valeur de coordonnée positive d'un axe V et pour une coordonnée orthogonale UV de l'abaque de Smith ; et
 dans lequel ladite seconde étape inclut :
 le calcul d'une impédance vue en regardant en direction de ladite charge hyperfréquence (30) au niveau dudit point de référence en réponse à ladite valeur mesurée lors de ladite première étape ; et
 l'appréciation de si oui ou non un point d'impédance de ladite impédance calculée est localisé à l'intérieur soit de ladite première région (Ry), soit de ladite seconde région (Rx), soit de ladite troisième région (Rz) sur ledit abaque de Smith ; et
 dans lequel ladite troisième étape inclut :
 l'exécution dudit processus de réglage d'impé-

dance de ladite troisième étape en utilisant lesdits premier et second adaptateurs d'impédance (S1, S2) lorsqu'il est apprécié que ledit point d'impédance de ladite impédance calculée est localisé à l'intérieur de ladite première région (Ry), l'exécution dudit processus de réglage d'impédance de ladite troisième étape en utilisant lesdits second et troisième adaptateurs d'impédance (S2, S3) lorsqu'il est apprécié que ledit point d'impédance de ladite impédance calculée est localisé à l'intérieur de ladite seconde région (Rx) et l'exécution dudit processus de réglage d'impédance de ladite troisième étape en utilisant la totalité desdits premier à troisième adaptateurs d'impédance (S1, S2 et S3) lorsqu'il est apprécié que ledit point d'impédance de ladite impédance calculée est localisé à l'intérieur de ladite troisième région (Rz).

2. Procédé selon la revendication 1, dans lequel une région globale à l'intérieur d'un abaque de Smith représentant une impédance vue en regardant en direction de ladite charge hyperfréquence (30) est divisée en une première région pour exécuter ledit processus de réglage d'impédance de ladite troisième étape en utilisant lesdits premier et second adaptateurs d'impédance (S1, S2) lorsqu'un point d'impédance vu en regardant en direction de ladite charge hyperfréquence (30) audit point de référence est localisé dans ladite première région et en une seconde région pour exécuter ledit processus de réglage d'impédance de ladite troisième étape en utilisant lesdits second et troisième adaptateurs d'impédance (S2, S3) lorsque ledit point d'impédance est localisé à l'intérieur de ladite seconde région,

dans lequel ladite seconde étape inclut :

le calcul d'une impédance vue en regardant en direction de ladite charge hyperfréquence (30) au niveau dudit point de référence en réponse à ladite valeur mesurée lors de ladite première étape ; et

l'appréciation de si oui ou non un point d'impédance de ladite impédance calculée est localisé à l'intérieur de soit ladite première région, soit ladite seconde région dudit abaque de Smith ; et

dans lequel ladite troisième étape inclut :

l'exécution dudit processus de réglage d'impédance de ladite troisième étape en utilisant lesdits premier et second adaptateurs d'impédance (S1, S2) lorsqu'il est apprécié que ledit point d'impédance de ladite impédance calculée est localisé à l'intérieur de ladite première région et en exécutant ledit processus de réglage d'impédance de ladite troisième étape en utilisant lesdits second et troisième adapta-

teurs d'impédance (S2, S3) lorsqu'il est apprécié que ledit point d'impédance de ladite impédance calculée est localisé à l'intérieur de ladite seconde région.

3. Procédé selon l'une quelconque des revendications 1 et 2, dans lequel lesdits processus desdites première à troisième étapes sont répétés.

4. Appareil de réglage automatique d'impédance hyperfréquence permettant de réaliser le procédé selon l'une quelconque des revendications 1 à 3 et comprenant :

une ligne de transmission hyperfréquence connectée entre un oscillateur hyperfréquence (10) et une charge hyperfréquence (3), ladite ligne de transmission hyperfréquence étant un guide d'onde rectangulaire (13) ;

un moyen de mesure pour mesurer soit une impédance vue en regardant en direction de ladite charge hyperfréquence (30) en son point de montage soit un coefficient de réflexion à ce niveau en détectant une onde stationnaire de tension d'une hyperfréquence se propageant sur ladite ligne de transmission hyperfréquence ;

un moyen d'impédance variable (32) pour modifier une impédance à connecter en son point de montage ; et

un moyen de commande (5) pour commander ledit moyen d'impédance variable (32) en réponse à une valeur mesurée par ledit moyen de mesure de manière à régler ladite impédance à une valeur souhaitée correspondant à un coefficient de réflexion souhaité entré, caractérisé en ce que :

ledit moyen d'impédance variable (32) est monté sur ledit côté de charge hyperfréquence dudit moyen de mesure sur ladite ligne de transmission hyperfréquence, ledit moyen d'impédance variable (32) comprenant trois adaptateurs d'impédance (S1, S2 et S3) montés en différents points selon des espaces égaux valant chacun un quart de ladite longueur d'onde du guide d'onde suivant la direction longitudinale dudit guide d'onde rectangulaire (13) ; et ledit moyen de commande (5) comprend :

un moyen de calcul pour calculer les longueurs d'insertion des premier à troisième adaptateurs d'impédance (S1, S2 et S3) du moyen d'impédance variable de manière à régler ladite impédance vue en regardant en direction de ladite charge hyperfréquence (30) à une valeur souhaitée correspondant à un coefficient de réflexion souhaité entré en réponse à ladite valeur mesurée par ledit moyen de mesure ; et un moyen de commande d'insertion pour insé-

rer lesdits premier à troisième adaptateurs d'impédance (S1, S2 et S3) dans ledit guide d'onde rectangulaire (13) sur des longueurs d'insertion calculées par ledit moyen de calcul en réglant ainsi ladite impédance vue en regardant en direction de ladite charge hyperfré-
 5 quence (30) à ladite valeur souhaitée, dans lequel une région globale à l'intérieur d'un abaque de Smith représentant une impédance vue en regardant en direction de ladite charge hyperfréquence (30) est divisée en une première région (Ry) pour exécuter ledit processus de réglage d'impédance dudit moyen de com-
 10 mande d'insertion en utilisant les premier et second adaptateurs d'impédance (S1, S2) lorsqu'un point d'impédance vu en regardant en direction de ladite charge hyperfréquence (30) au niveau dudit point de référence est localisé à l'intérieur de ladite première région (Ry), en une seconde région (Rx) pour exécuter ledit
 15 processus de réglage d'impédance dudit moyen de commande d'insertion en utilisant lesdits second et troisième adaptateurs d'impédance (S2, S3) lorsque ledit point d'impédance est localisé à l'intérieur de ladite seconde région (Rx) et en une troisième région (Rz) pour exé-
 20 cuter ledit réglage d'impédance dudit moyen de commande d'insertion en utilisant la totalité desdits premier à troisième adaptateurs d'impédance (S1, S2 et S3) lorsque ledit point d'impédance est localisé à l'intérieur de ladite troi-
 25 sième région (Rz), ladite troisième région (Rz) étant définie en tant que région partielle de ladite première région (Ry) pour une quelconque valeur de coordonnée positive d'un axe V et pour une coordonnée orthogonale UV de l'abaque de Smith ; et
 30 dans lequel ledit moyen de calcul comprend : un moyen pour calculer une impédance vue en regardant en direction de ladite charge hyperfréquence (30) au niveau dudit point de réfé-
 35 rence en réponse à ladite valeur mesurée par ledit moyen de mesure ; et un moyen pour apprécier si oui ou non un point d'impédance de ladite impédance calculée est localisé à l'intérieur soit de ladite première
 40 région (Ry), soit de ladite seconde région (Rx), soit de ladite troisième région (Rz) sur ledit abaque de Smith ; et dans lequel ledit moyen de commande d'insertion comprend :
 45 l'exécution dudit processus de réglage d'impédance dudit moyen de commande d'insertion en utilisant lesdits premier et second adaptateurs d'impédance (S1, S2) lorsqu'il est apprécié que ledit point d'impédance de ladite impédance calculée est localisé à l'intérieur de ladite pre-
 50 mière région (Ry), en exécutant ledit processus

de réglage d'impédance dudit moyen de com-
 mande d'insertion en utilisant lesdits second et
 troisième adaptateurs d'impédance (S2, S3)
 lorsqu'il est apprécié que ledit point d'impé-
 dance de ladite impédance calculée est localisé
 à l'intérieur de ladite seconde région (Rx) et en
 exécutant ledit processus de réglage d'impé-
 dance dudit moyen de commande d'insertion en
 utilisant la totalité desdits premier à troisième
 adaptateurs d'impédance (S1, S2 et S3)
 lorsqu'il est apprécié que ledit point d'impé-
 dance de ladite impédance calculée est localisé
 à l'intérieur de ladite troisième région (Rz).

Fig. 1 PRIOR ART

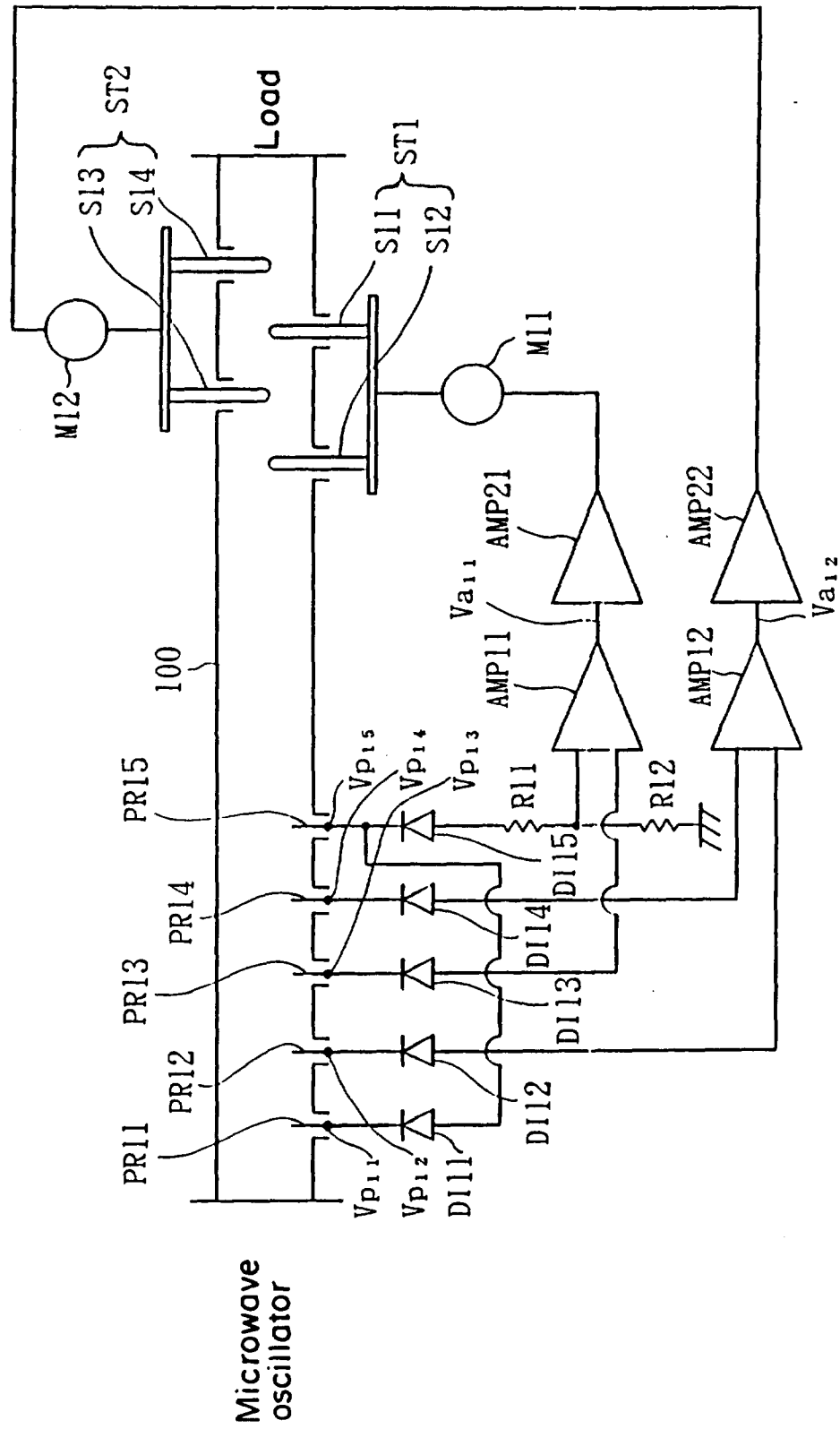


Fig. 2
PRIOR ART

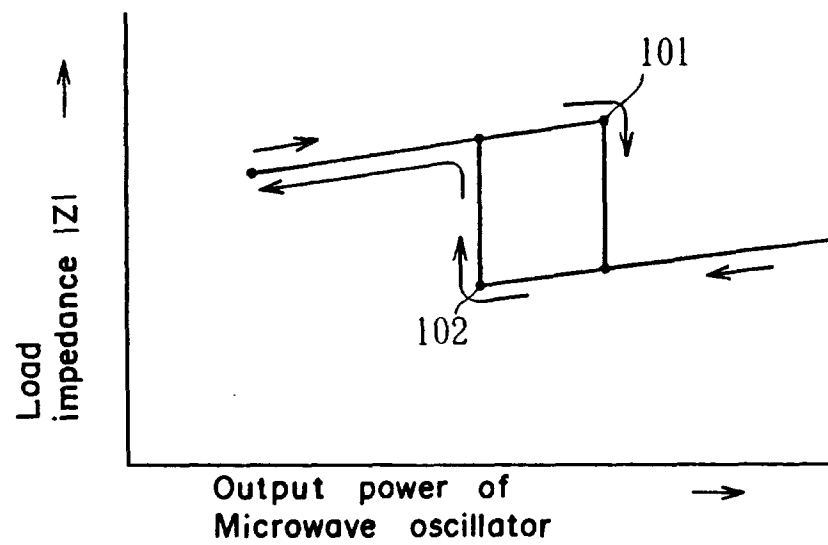
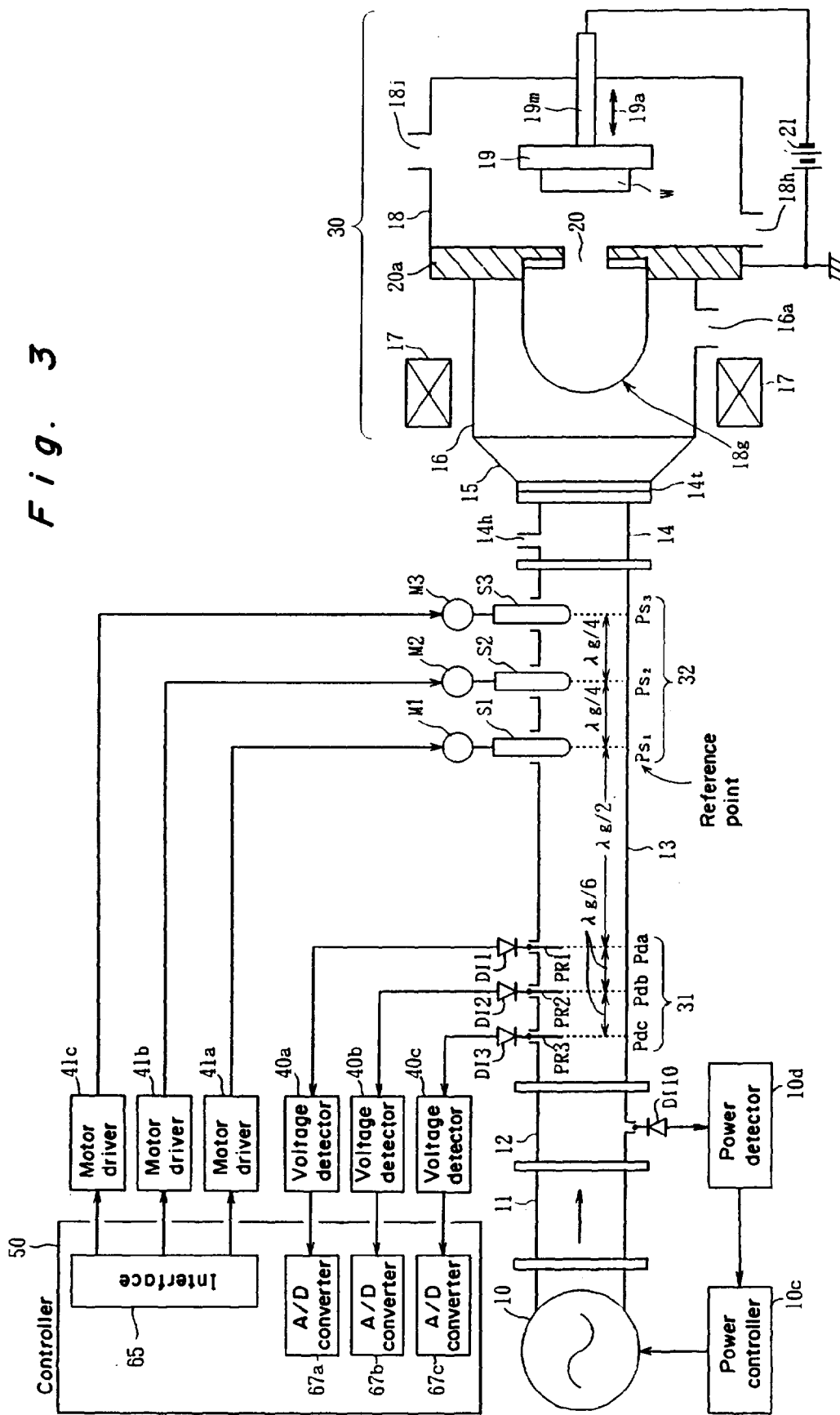


Fig. 3



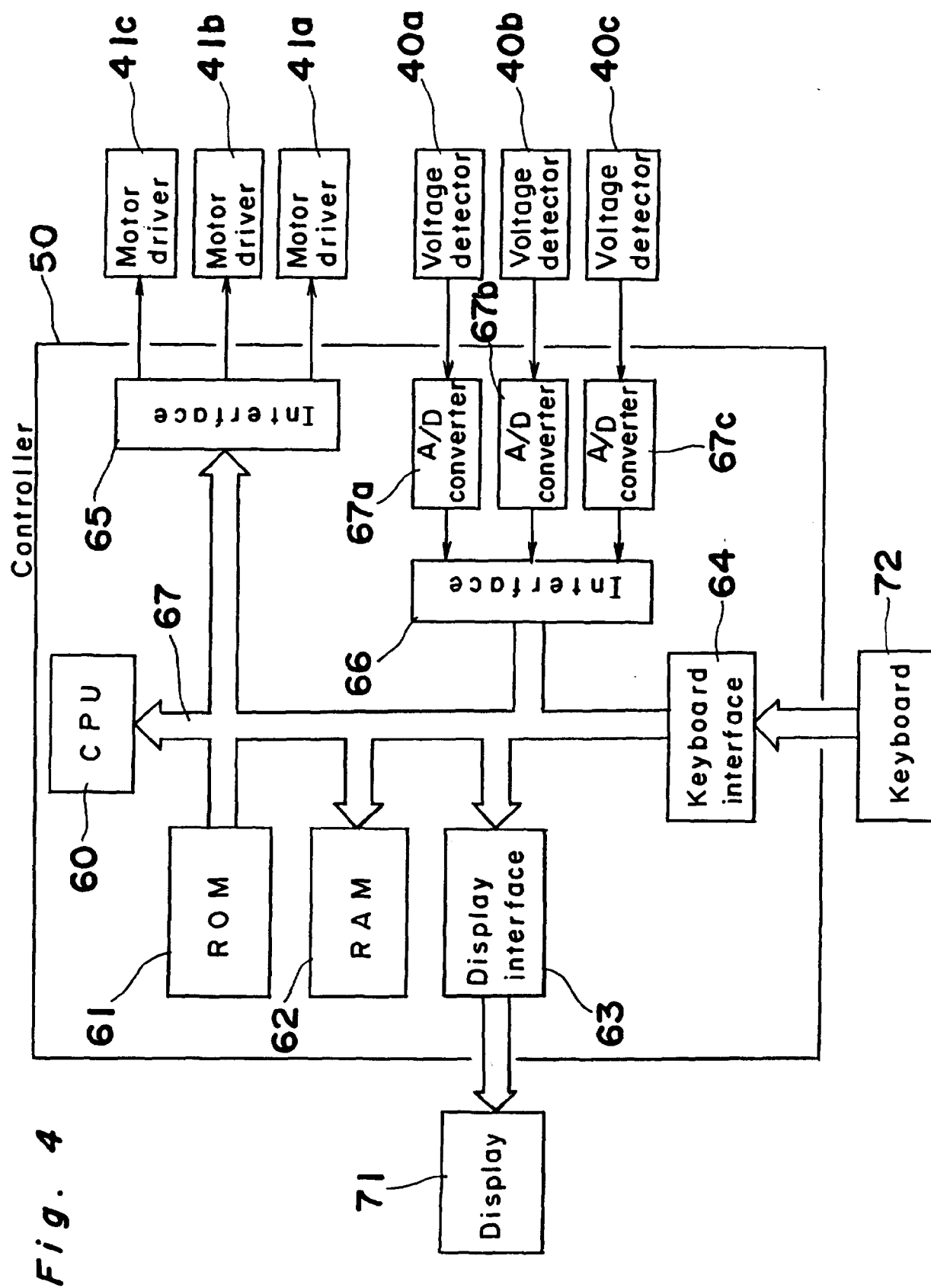


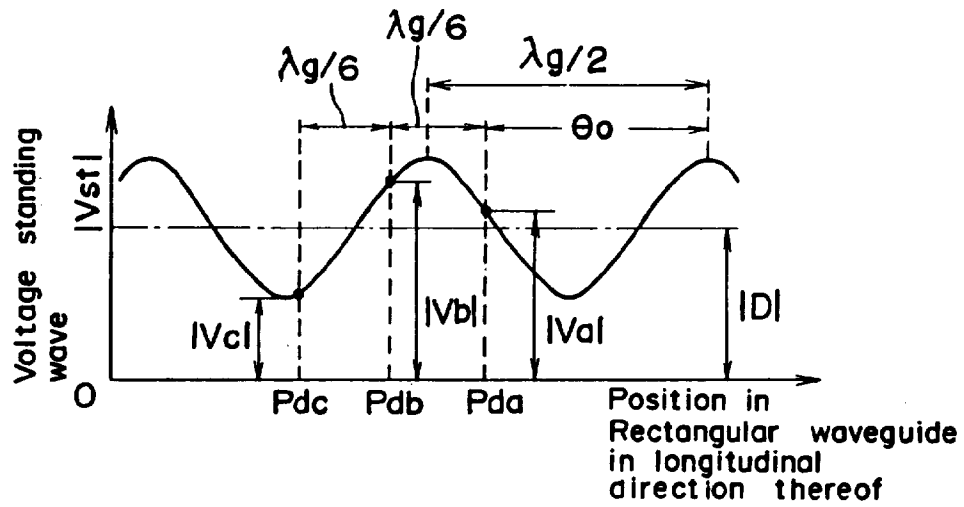
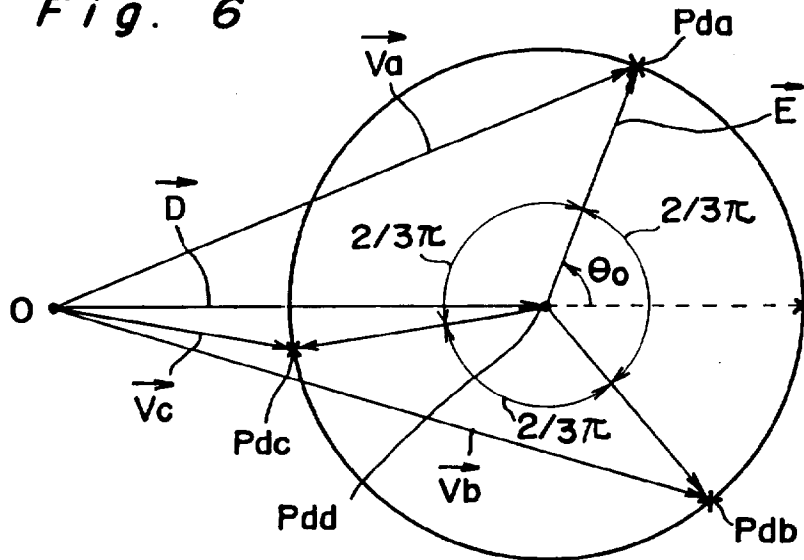
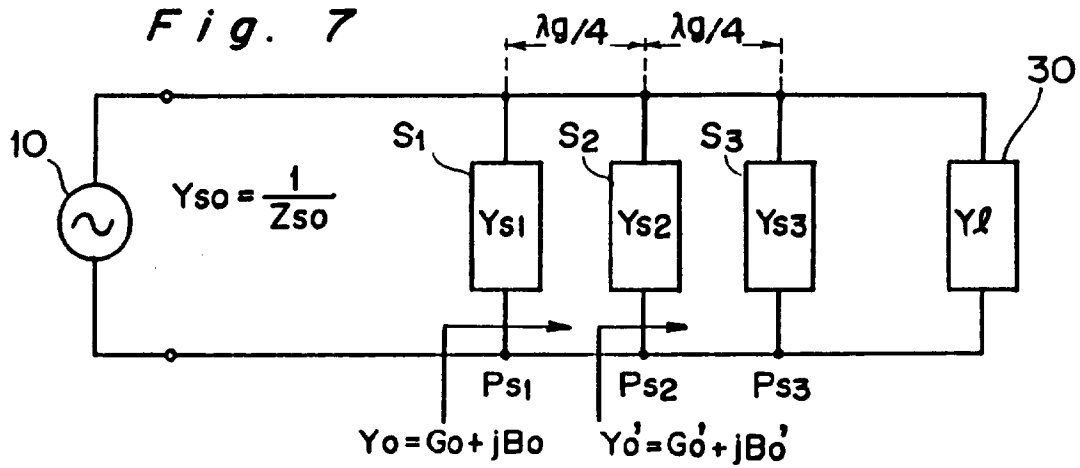
Fig. 5*Fig. 6**Fig. 7*

Fig. 8

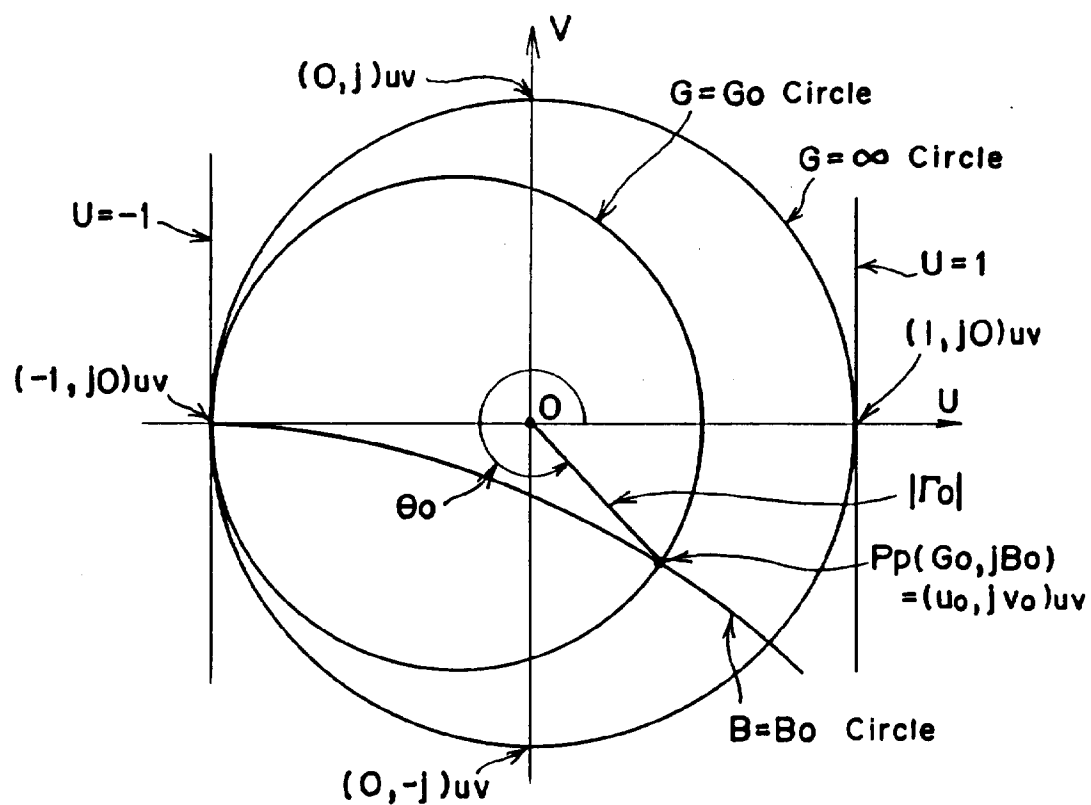


Fig. 9

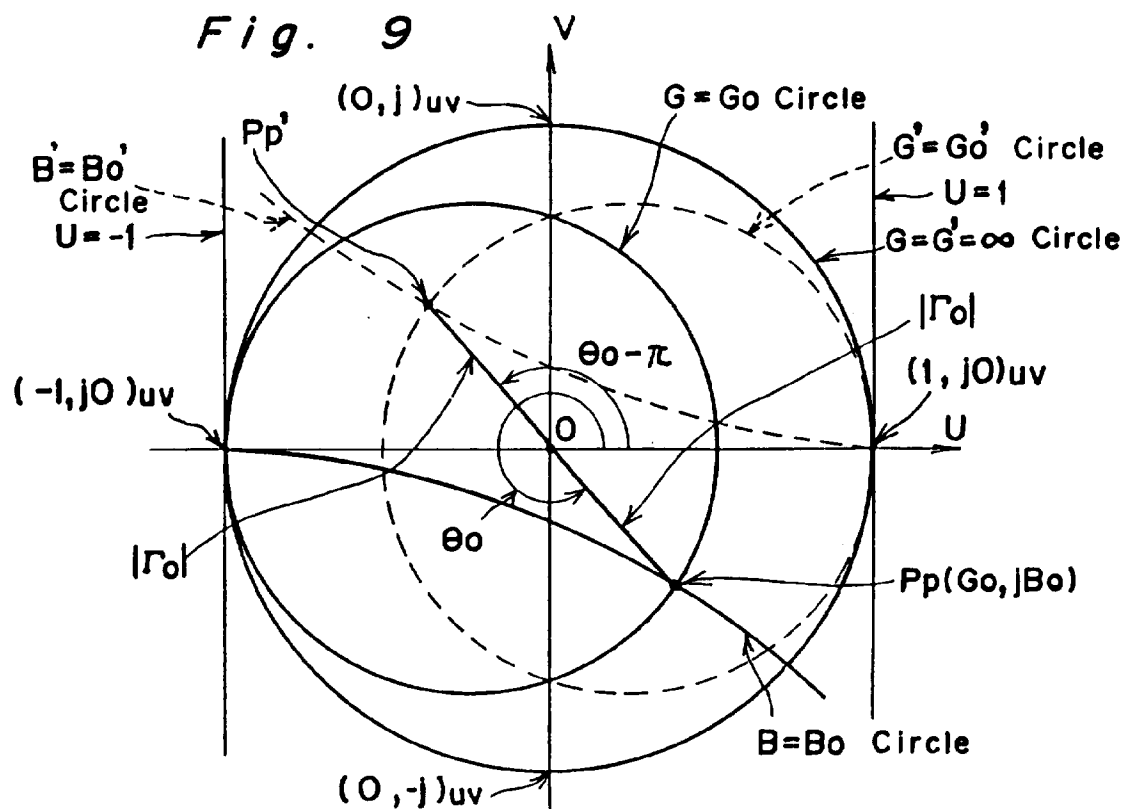


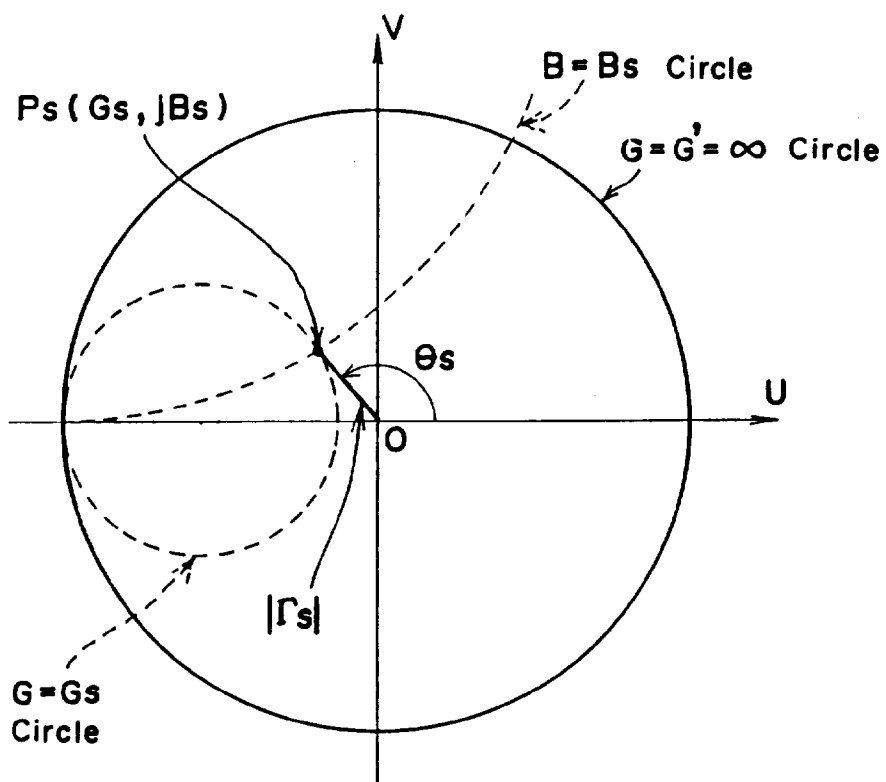
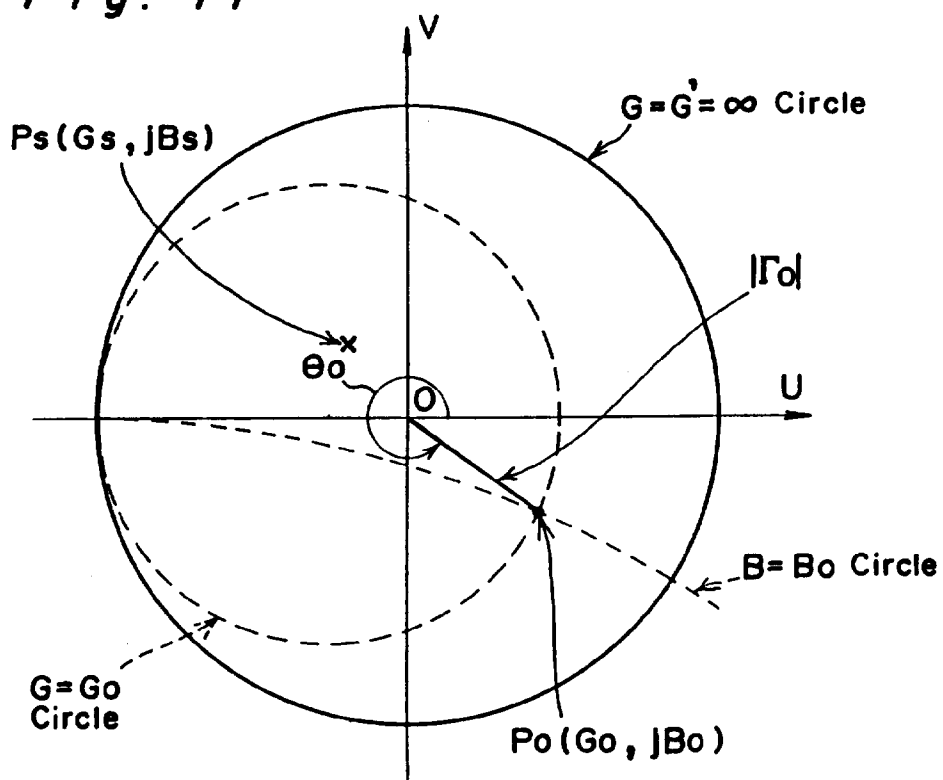
Fig. 10*Fig. 11*

Fig. 12

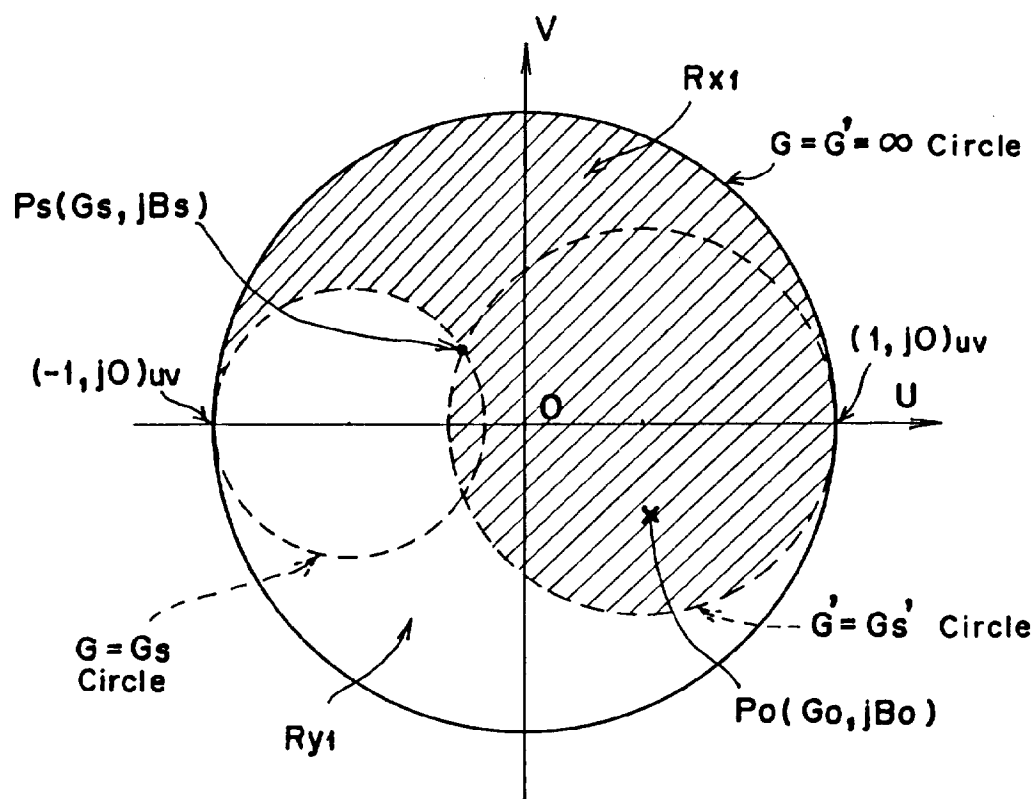


Fig. 13

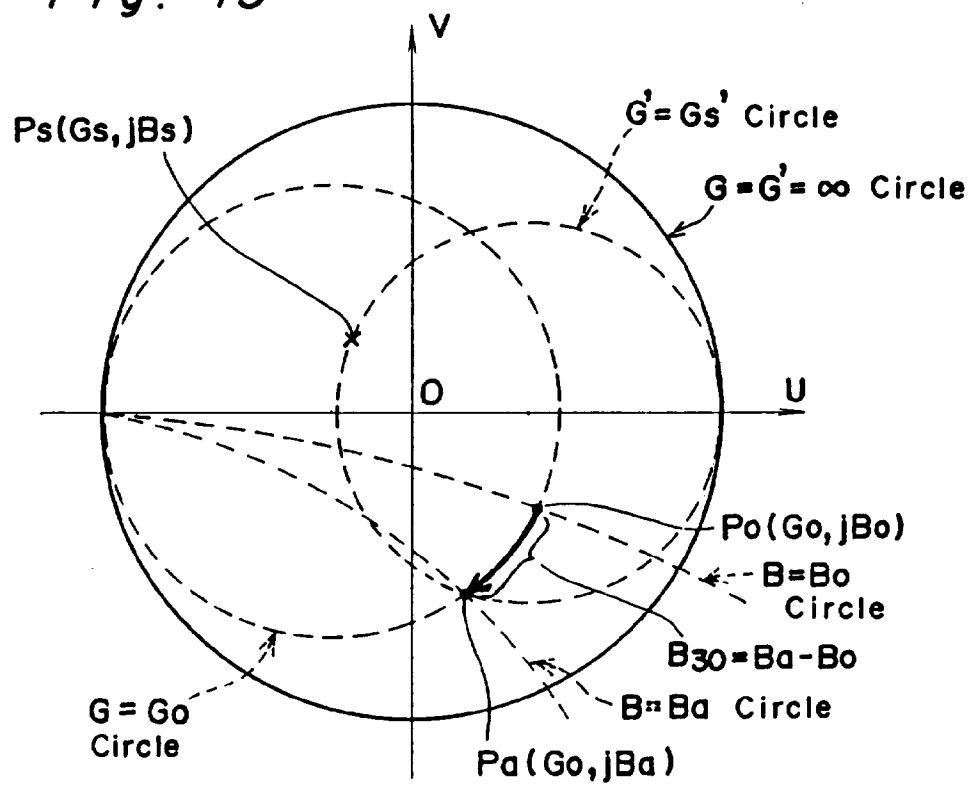


Fig. 14

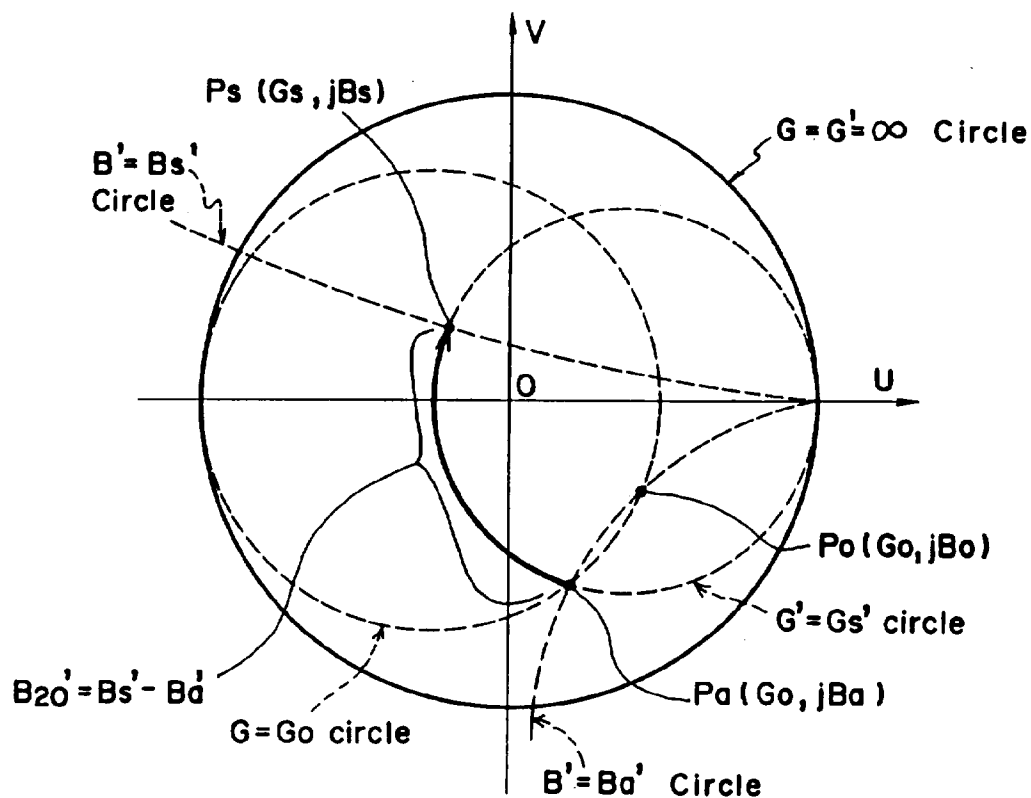


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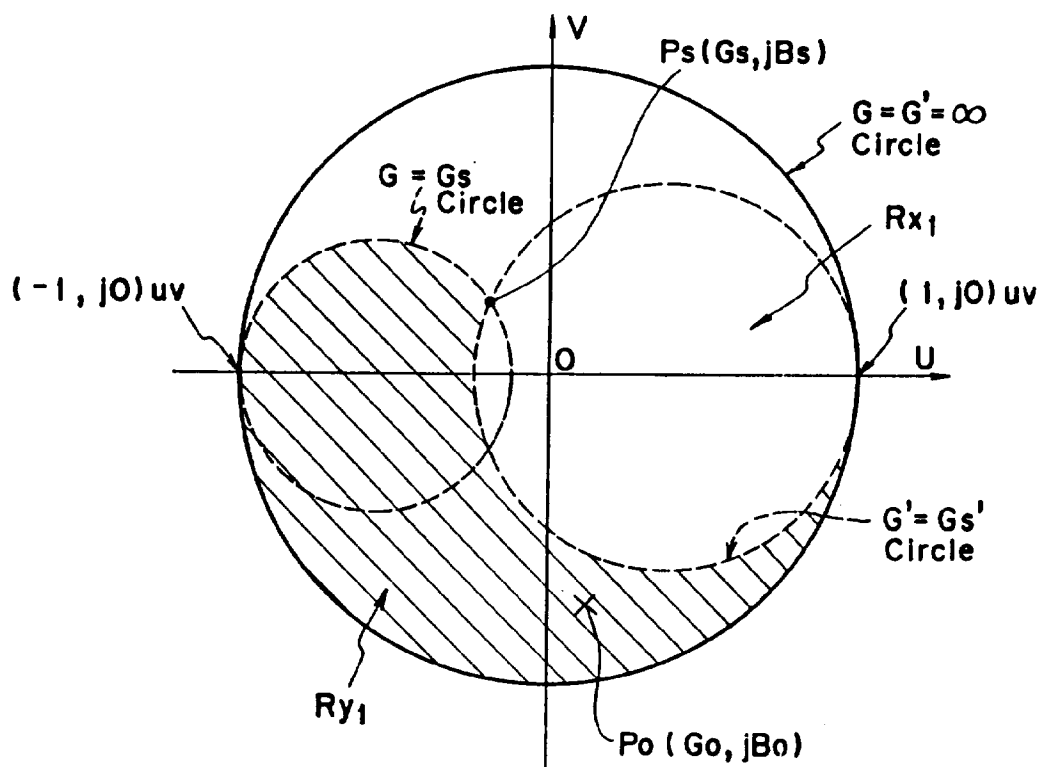


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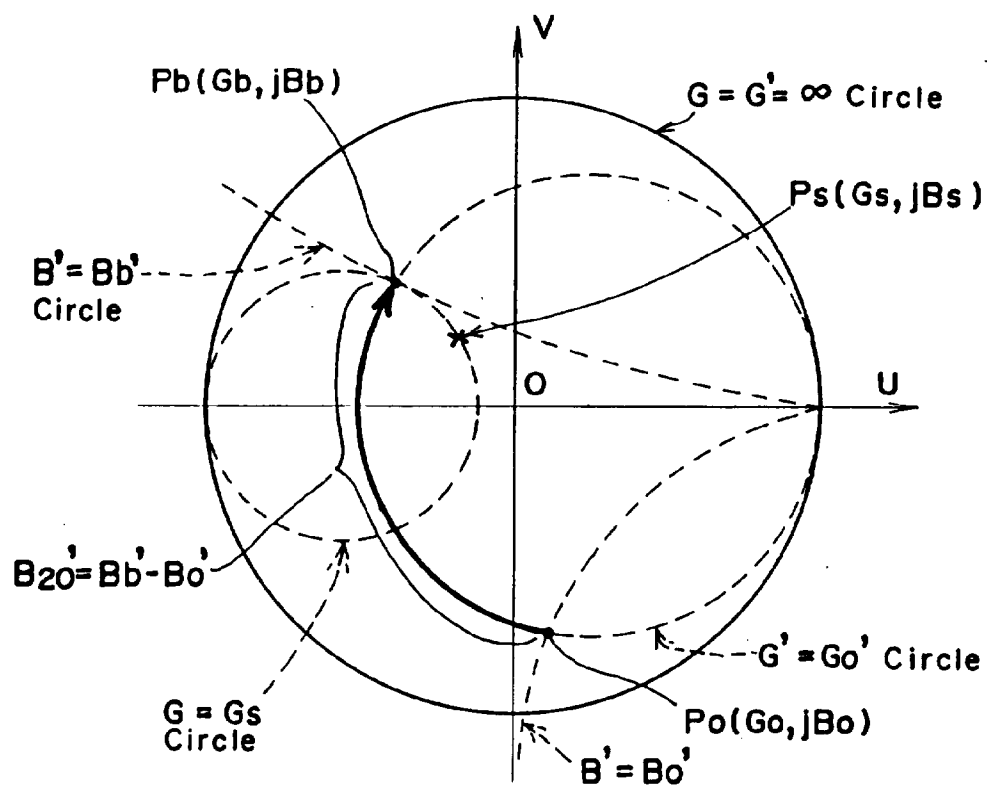


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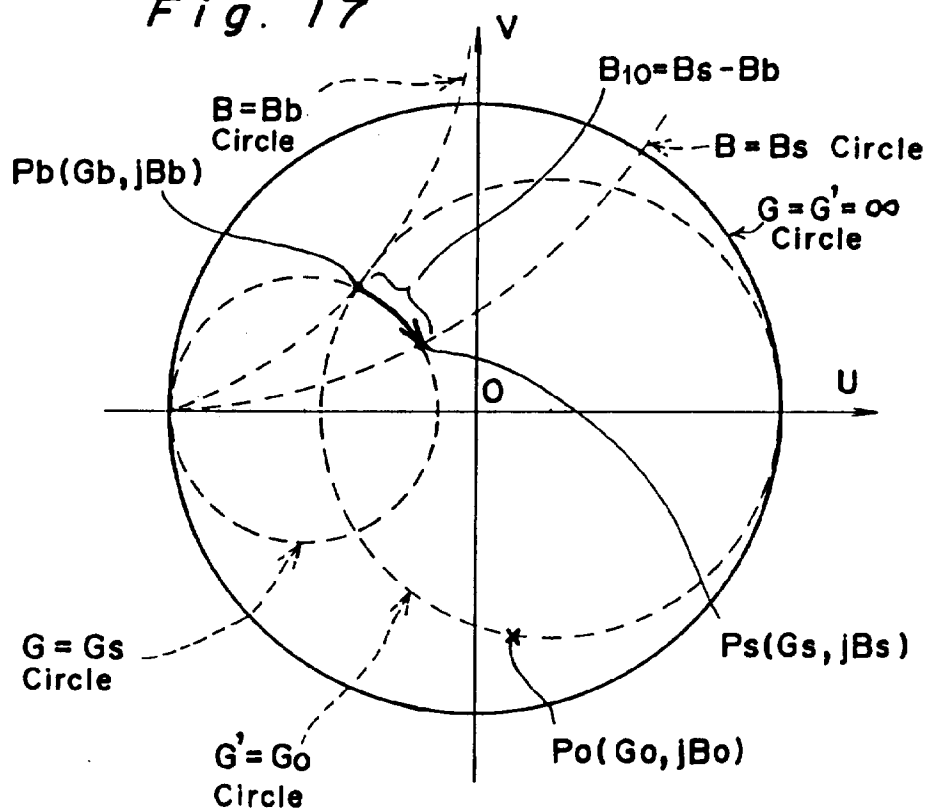


Fig. 18

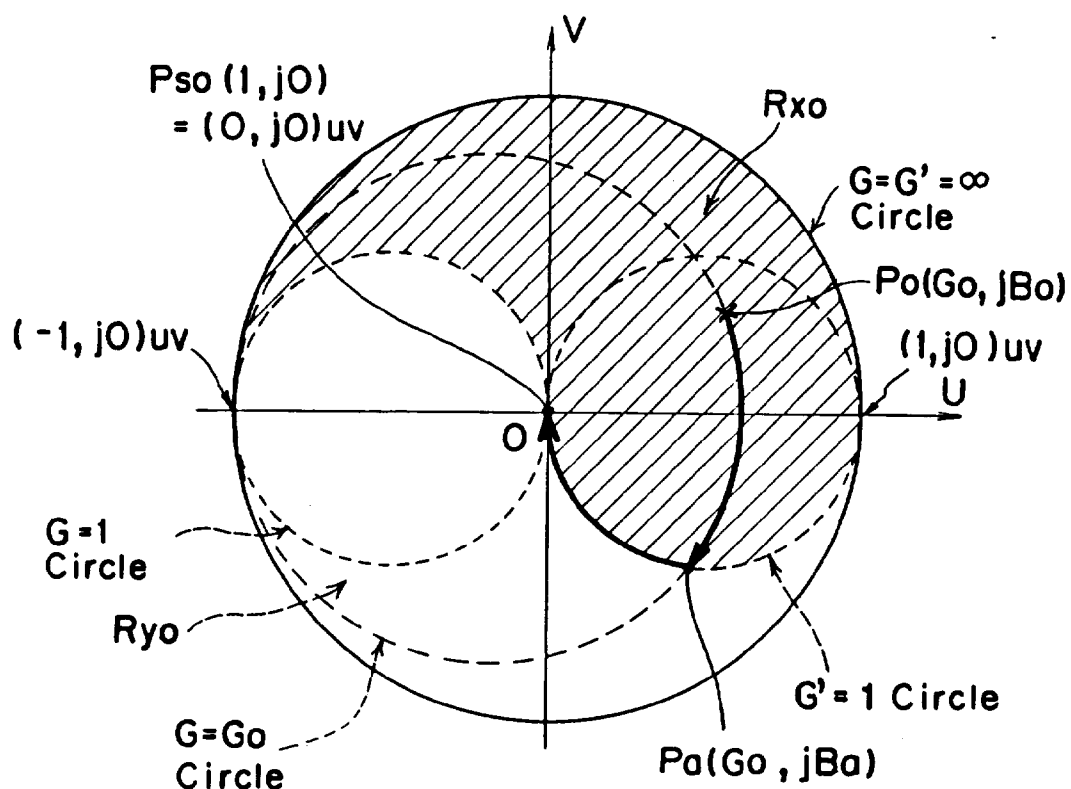


Fig. 19

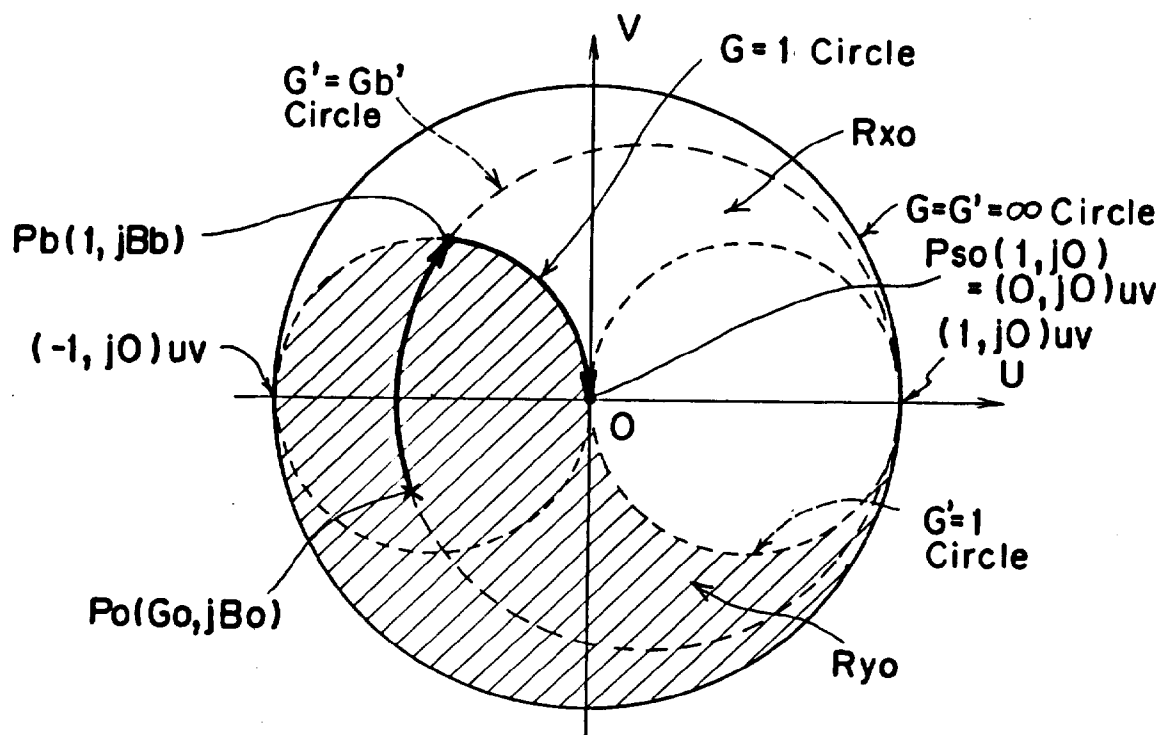


Fig. 20

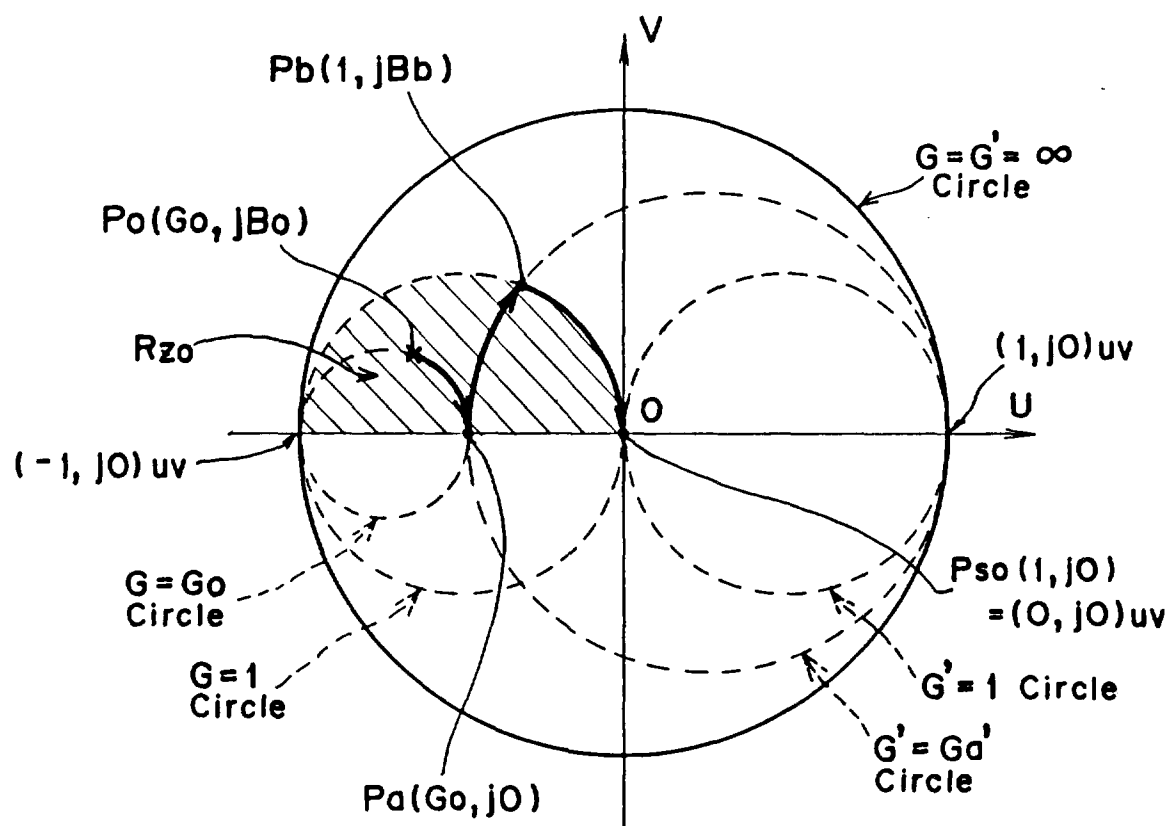


Fig. 21

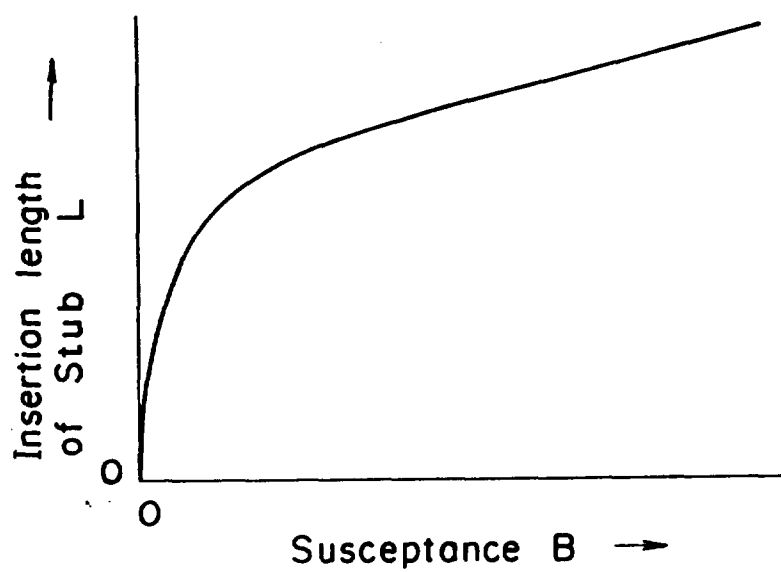


Fig. 22

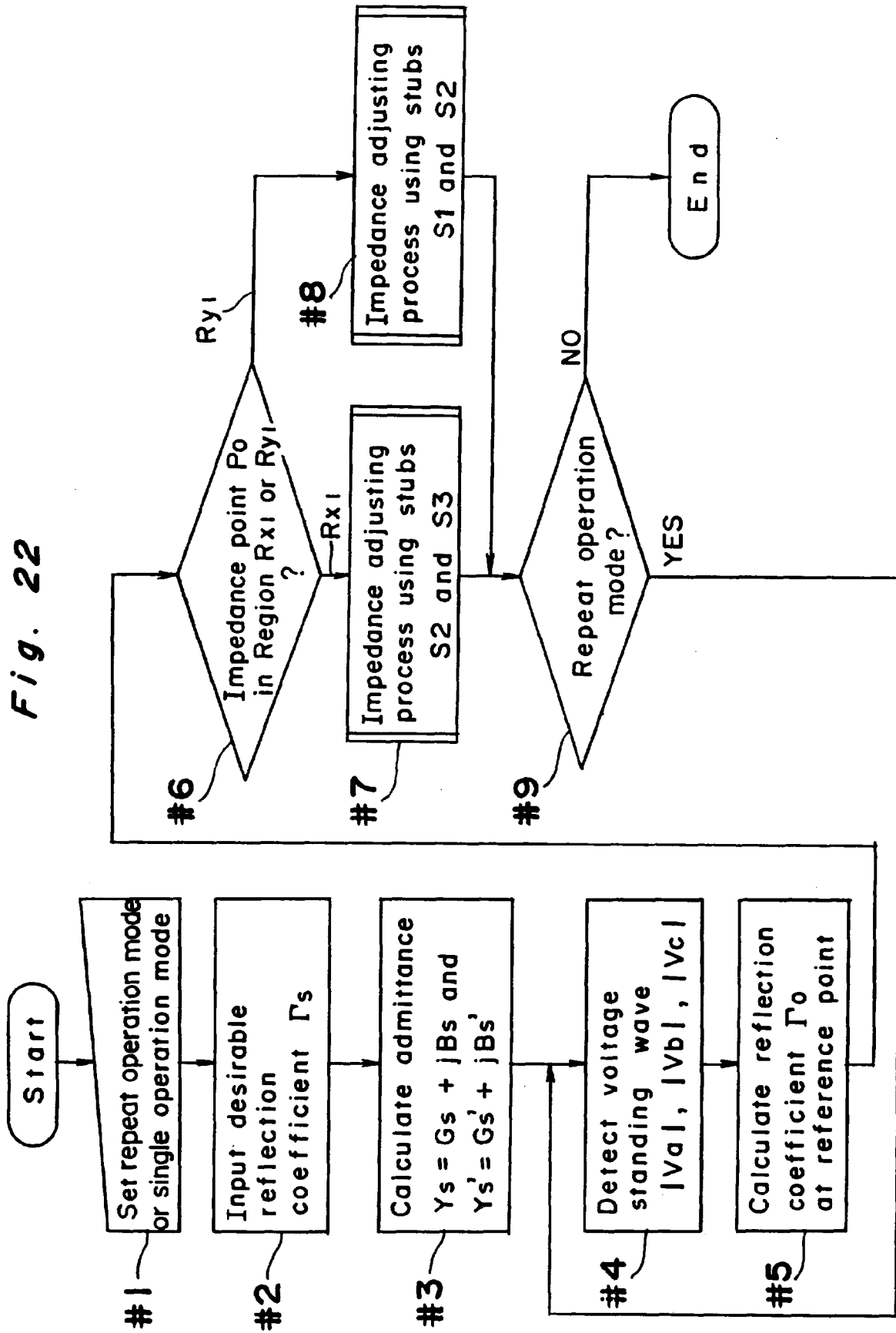


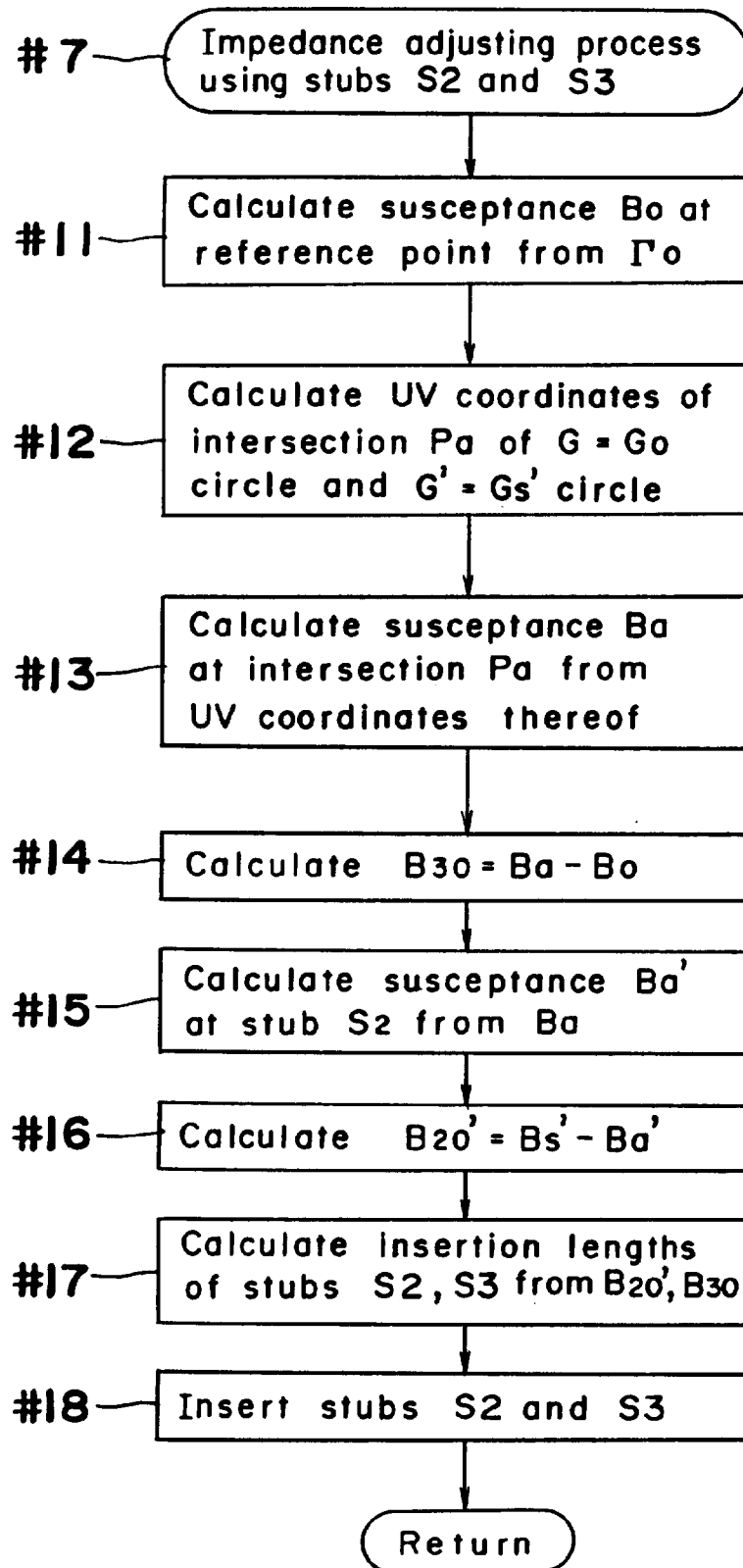
Fig. 23

Fig. 24