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[54] AMPLITUDE MODULATED RF GENERATOR FOR QUADRUPOLE MASS ANALYZER

2 Claims, 1 Drawing Fig.

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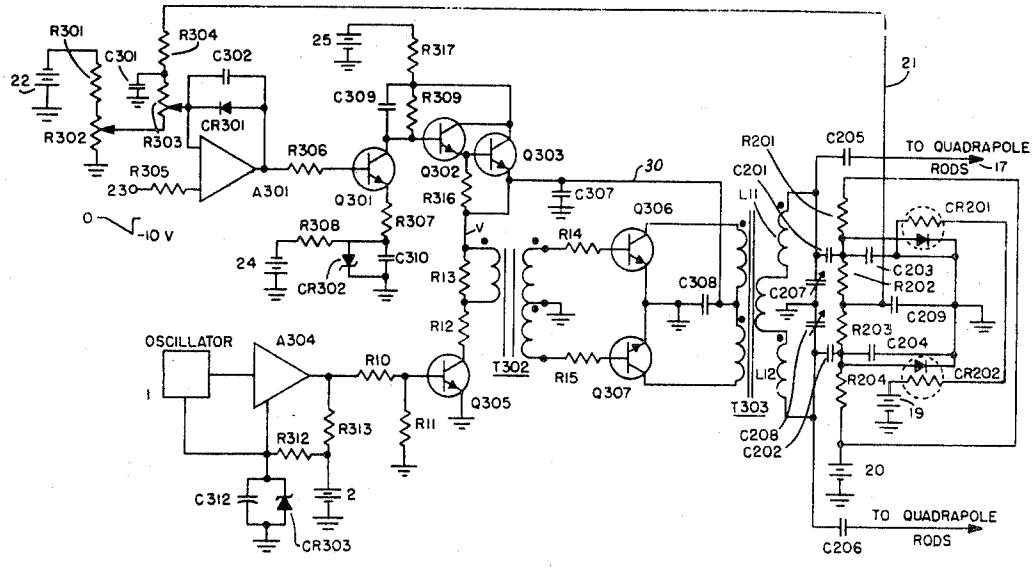
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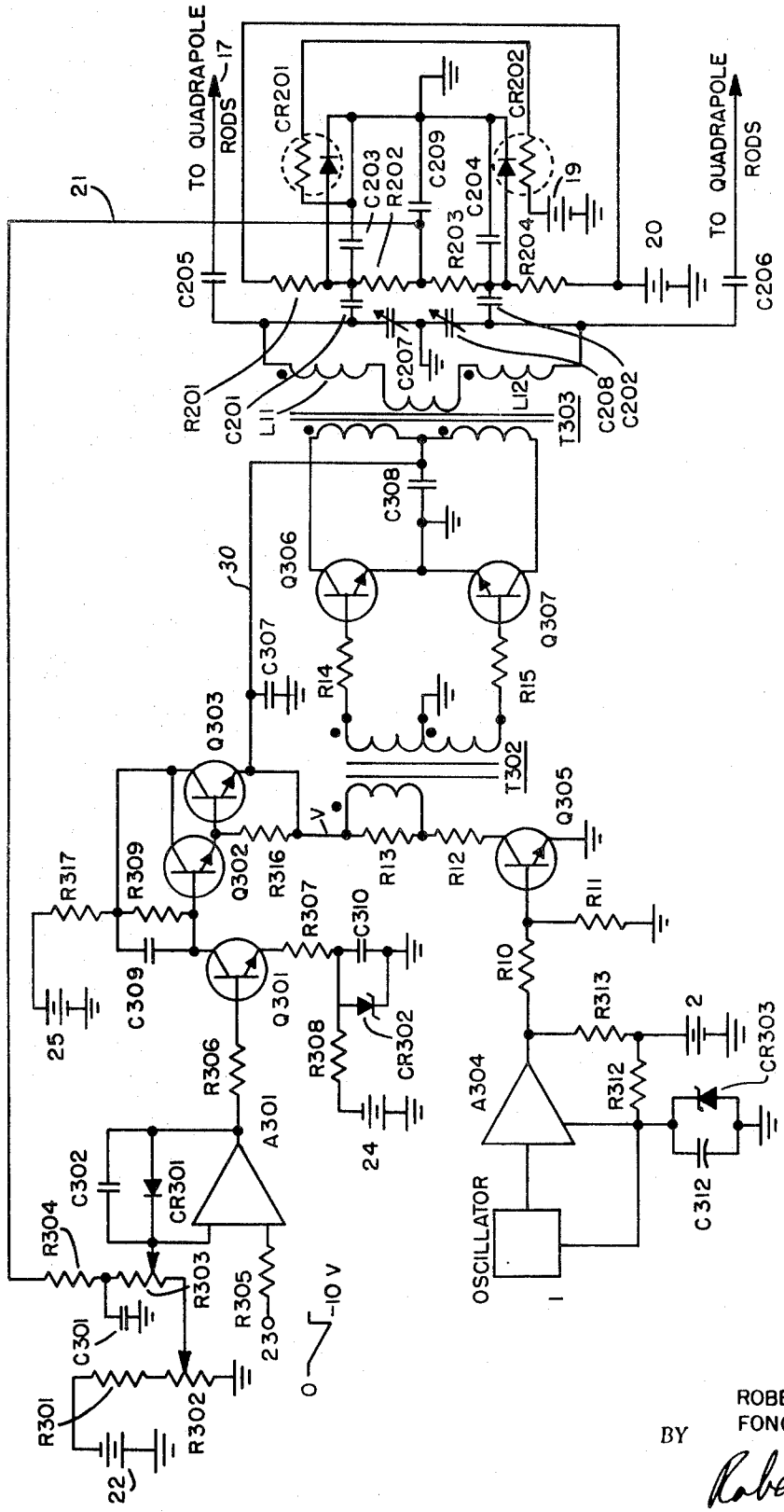
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ABSTRACT: An improved radio frequency (RF) generator for use with a quadrupole mass analyzer is disclosed wherein a ramp of RF at constant frequency is provided by developing a difference signal between the output of the circuit and a control ramp input. The error signal is modulated by the desired frequency supplied from an oscillator and amplified by a push-pull arrangement. The amplified signal is applied to a series resonant tuned circuit which directly supplies the quadrupole rods.





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AMPLITUDE MODULATED RF GENERATOR FOR QUADRUPOLE MASS ANALYZER

This invention relates to a radiofrequency generator for use in a quadrupole mass analyzer.

Quadrupole mass analyzers have been described in the prior art, particularly in U.S. Pat. No. 2,939,952 to Wolfgang Paul et al. In that patent, a controlled varying voltage is used in conjunction with a fixed frequency signal to perform a mass spectrum analysis. Such analyzers may be used in measuring the composition of chemical substances and are primarily comprised of an ionizer, a quadrupole section, and an ion detector. Generally, the substance to be analyzed is introduced into the ionizer as a vapor at low pressure. A portion of the atoms or molecules which make up the chemical substance are ionized by electron bombardment or other means, and these ions are then accelerated and focused into the quadrupole section as an ion beam. The ion beam is filtered by permitting only those ions having specific values of charge-to-mass ratio to pass through the quadrupole section. Those ions which are able to pass through the quadrupole section are then collected by the ion detector which may be an electron multiplier or a Faraday Cup.

The output current produced by the ion detector is a measure of the number of atoms or molecules in the ion beam which have a particular charge-to-mass ratio. The specific detected charge-to-mass ratio is determined by the values of the scanned or controlled varying RF voltage and the related DC voltage which voltages are applied to the electrodes of the quadrupole section. The RF and DC voltages applied to the rods at any given time determine the mass number of the ions being passed by the filter and the ion detector current indicates the ion abundance at that mass number. A display of the quantitative abundance of such detected ions as a function of atomic mass may be conveniently presented on conventional display instruments such as oscilloscopes, X–Y recorders, or strip chart recorders.

It will be appreciated that precise voltage and frequency control of the radiofrequency applied to the mass analyzer is required to obtain maximum resolution. The present invention provides an electronic circuit for providing a fixed frequency ramp of radiofrequency voltage for the filter of a quadrupole mass analyzer.

In brief, the invention provides a series resonant tuned circuit connected to the quadrupole rods supplying opposite phase radiofrequency ramps. The output of the tuned circuit is continuously detected and compared with a control ramp voltage. An error signal is generated which is amplified and utilized to control the amplitude of the signal applied to the tuned circuit. The feedback loop described provides precise amplitude control of the radiofrequency applied to the quadrupole rods.

It is an object of the present invention to provide a simplified radiofrequency generator for a quadrupole mass analyzer.

A further object of the present invention is the provision of a radiofrequency generator having a series resonant tuned circuit which enables the required high voltage to be applied to the rods of the quadrupole filter section.

Another object of the present invention is the provision of a radiofrequency generator for a quadrupole mass analyzer having precise radiofrequency amplitude control throughout the range of radiofrequency amplitudes required.

These as well as further objects and advantages of the present invention will become apparent to those skilled in the art from a reading of the specification with reference to the accompanying drawings in which:

the single FIGURE is a schematic diagram of the preferred embodiment of the radiofrequency generator in accordance with the invention.

In the FIGURE, numeral 1 denotes an oscillator which may be a crystal oscillator producing a square wave output at a frequency of 2.8 MHz. The output of oscillator 1 is connected to the input of an amplifier A304 which provides current amplification.

Voltage supply for the oscillator is provided from bias source 2 via resistor R312. Resistor R312, capacitor C312 and zener diode CR303 provide bias voltage regulation for the oscillator as well as for amplifier A304.

The output of amplifier A304, developed across load resistor R313, is connected to the base of transistor Q305 via resistor R10. Resistor R10 develops base current for transistor Q305. Shunt resistor R11 stabilizes the base voltage for transistor Q305 ensuring that the transistor will be rendered nonconductive when the output of A304 switches to 0 volts.

Transistor Q305 is thus rendered alternately conductive and nonconductive at the oscillator output frequency. The amplitude of the output of transistor Q305 is established by the voltage at point V. More particularly, the collector of transistor Q305 is connected to point V via the series connection of R12 and R13. The primary winding of transformer T302 and capacitor C307 are connected across R13. The configuration just described presents a low impedance drive for the transformer. When transistor Q305 is nonconductive, the impedance seen by transformer T302 is R13. When transistor Q305 is conductive, the impedance seen by transformer T302 is R12 in parallel with R13. Transistor Q305 thus functions as an electronic switch. Resistor R13 also serves to dissipate the energy stored in the primary of transformer T302 when transistor Q305 is nonconductive.

In the preferred embodiment, the primary winding of transformer T302 has 20 turns while each of the portions of the center tapped secondary winding has five turns. This results in one-eighth of the voltage at point V being developed across each portion of the center tapped secondary winding. The secondary winding is connected to the bases of push-pull amplifier transistors Q306 and Q307 via current limiting resistors R14 and R15. The push-pull output at the collectors of transistors Q306 and Q307 is connected across the center tapped primary winding of transformer T303. In the preferred embodiment, each portion of this center tapped primary winding consists of 12 turns while the secondary winding has eight turns. Capacitor C308 is connected between the center tap of the primary winding of transformer T303 and ground to provide RF bypass. It will be noted that the potential of point V is also applied to the center tap of the primary winding of transformer T303 via lead 30.

It has been found that the push-pull stage must be effectively bypassed for low amplitude radiofrequency voltage. At low radiofrequency amplitude, the difference signal at point V is, of course, at a very low amplitude. Distortions in the push-pull amplifier at crossover degrade the small amplitude error signal. The application of the error signal via lead 30 thus ensures a driving signal for the tuned circuit throughout the amplitude range of the ramp of radiofrequency.

The secondary winding of transformer T303 is connected to two series resonant tuned circuits. The desired voltage output for the quadrupole mass analyzer is 2,400 volts peak-to-peak. The tuned circuits are employed to increase the voltage at the secondary winding of transformer T303 to the desired level.

The first tuned circuit includes inductor L11, adjustable capacitor C207, fixed capacitor C201 and the inherent capacitance of one pair of quadrupole rods themselves. The second tuned circuit includes inductor L12, adjustable capacitor C208, fixed capacitor C202 and the inherent capacitance of the other pair of quadrupole rods. The output of each of the tuned circuits is connected to the rods of the quadrupole mass analyzer via respective DC blocking capacitors C205 and C206 (numeral 17 denotes the lead from C205 to the quadrupole rods).

The amplitude of the output thus generated is detected and fed back to a comparator circuit which sweeps the amplitude of the voltage output supplied to the rods through the desired amplitude range. More particularly, capacitors C201 and C203 constitute a capacitive voltage divider. Diode CR201 clamps the voltage developed by the divider to ground. Resistor R201 and voltage source 20 provide forward bias for diode CR201 to improve performance of the detector at low

RF voltages. The out-of-phase voltages developed by the detectors are summed at the juncture of resistors R202 and R203 and filtered by capacitor C209.

Each of the diodes CR201 and CR202 are heated for temperature stability as is shown schematically by the resistors within the dotted circle surrounding each diode. Voltage source 19 supplies power for the heating elements.

Capacitor C204 cooperates with capacitor C202 to form a capacitive voltage divider. Diode CR202 clamps the voltage output of the divider to ground. The output of the detector on conductor 21 is a full wave rectified DC level which is connected as one input to differential amplifier A301.

More particularly, resistors R301, R302, R303 and R304 with voltage source 22 comprise an adjustable voltage divider. Adjustable resistor R303 with fixed resistor R304 sets the maximum slope or amplitude change of the RF frequency. Adjustable resistor R302 provides a zero adjustment to set the divider to a voltage level above the ambient noise while resistor R301 sets the range of resistor R302. Capacitor C301 is connected between the juncture of resistors R303 and R304 and ground to provide filtering of any AC ripple on the detected DC level. Input terminal 23 is connected to a ramp voltage source (not shown) which produces the waveform shown in the drawing. This ramp voltage is fed to an input of the differential amplifier A301 via input resistor R305. The output of amplifier A301 is prevented from going positive by clamping diode CR301. Capacitor C302 connected across amplifier A301 provides frequency compensation and stabilization for the amplifier.

The negative polarity output of amplifier A301 representing the difference between the magnitude of the ramp voltage and the DC level at the output of resistor R303, is amplified by transistor Q301. More particularly, the base of transistor Q301 is connected to the output of amplifier A301 via the base resistor R306. A regulated bias supply for this amplification stage is provided by voltage source 24, resistors R307 and R308, zener diode CR302 and capacitor C310. This regulator provides a reference voltage of 12 volts.

The amplified error signal output of amplifier A301 at the collector of Q301 is developed across load resistor R309 and is coupled to a current amplifier which consists of transistors Q302 and Q303 with resistor R316. This connection constitutes the well known Darlington configuration. A battery 25 is connected to the circuit by way of the resistor 317 which leads to the juncture of a capacitor 309 and the resistor 309. The emitter of transistor Q303 is grounded by way of a capacitor C307.

It will be recalled that the RF voltages to be supplied must be equal in magnitude and opposite in phase. This is achieved in the present invention by the switching of the power transistor Q305 having the inductive load T302. At the moment when the transistor switches off, the collector voltage of transistor Q305 increases rapidly to a relative high value determined by:

$$E_f = -L\, di/dt$$

Further amplification of this collector voltage output is provided by the push-pull amplifier. In addition, it will be recognized that, because of the series resonant effect provided by the tuned circuits, only that component of the signal having the fundamental frequency of the oscillator will be amplified: other frequencies will be filtered out. This results in a pure sine wave output. The output voltage is proportional to the Q of the tuned circuit and the higher the Q, the less will be the distortion in the output voltage.

The RF voltage is modulated with a ramp at the point V. The error amplifier A301 forces the output voltage supplied to the quadrupole rods to follow the ramp input at terminal 23.

What is claimed is:

1. A radiofrequency generator for supplying a variable amplitude radiofrequency electrical energy comprising:
- an oscillator for producing a constant frequency output signal;
- switch means connected to said oscillator and responsive to said output signal, said switch means being rendered alternately conductive and nonconductive at said frequency;
- first amplifier means connected to said switch means,
- a series resonant circuit connected to said amplifier for producing an output voltage having a magnitude dependent upon the output of said first amplifier,
- detector means connected to said tuned circuit for producing an electrical signal representing said output voltage;
- means for producing a ramp voltage;
- differential amplifier means having a first input connected to receive said ramp voltage and a second input connected to said detector means for producing an output signal representing the amplitude difference between said ramp and said output voltage;
- means including second amplifier means connected to said differential amplifier and to said switch means for applying said difference signal to said switch means and said first amplifier means whereby the magnitude of said resonant circuit output voltage is a function of said difference signal at said oscillator frequency.

2. A radiofrequency generator comprising:
- means for producing a control signal having a predetermined frequency,
- a resonant circuit for supplying a constant frequency output voltage having variable amplitude,
- means for producing a voltage having a predetermined amplitude change;
- means connected to said voltage producing means and to said resonant circuit for producing a difference signal representing the difference in amplitude between said variable amplitude radiofrequency voltage and said source;
- means including switch means connected to said control signal producing means; to said resonant circuit; and to said difference signal producing means for selectively applying said difference signal to said resonant circuit at said predetermined frequency; whereby the frequency of said output voltage is said predetermined frequency and the amplitude of said output voltage tracks said predetermined amplitude change.