July 14, 1959 G. I. KLEIN 2,895,107

PULSED MAGNETRON INSTABILITY DETECTOR

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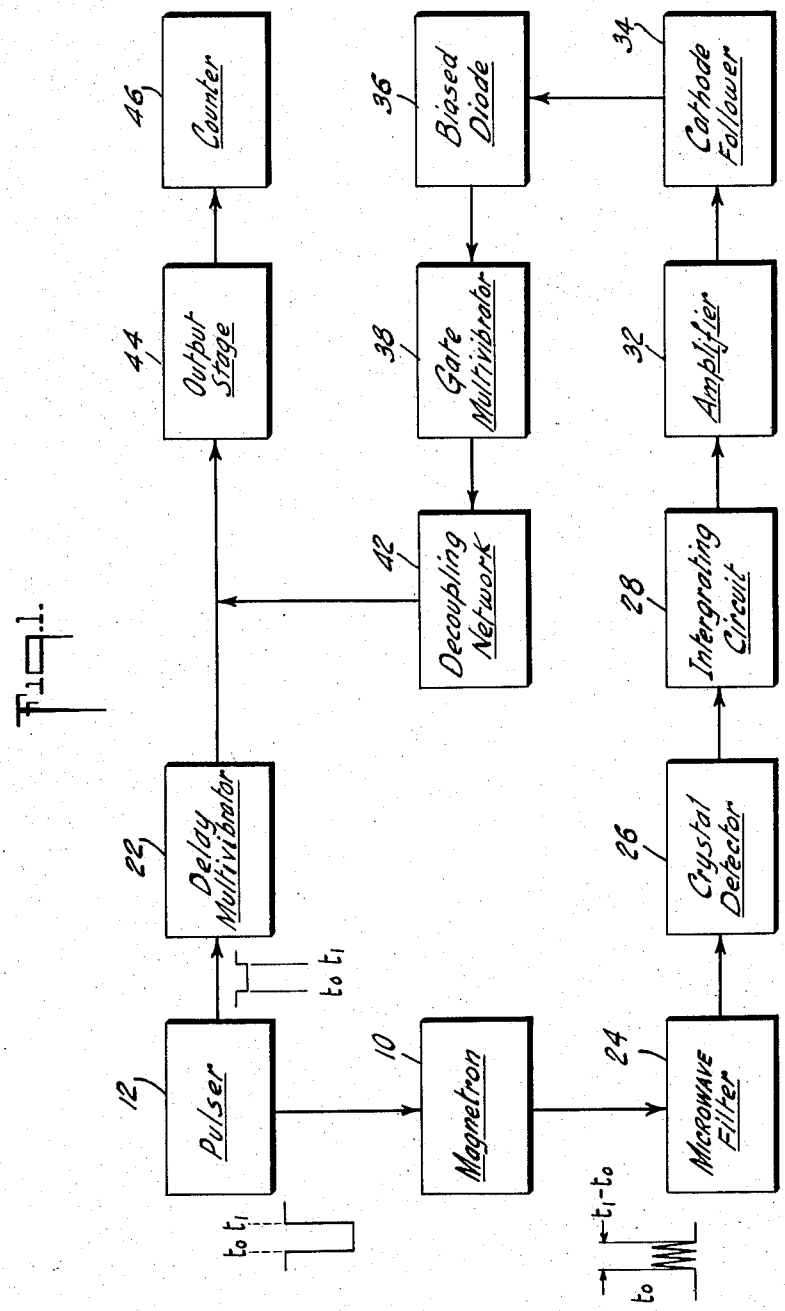


Fig. 1.

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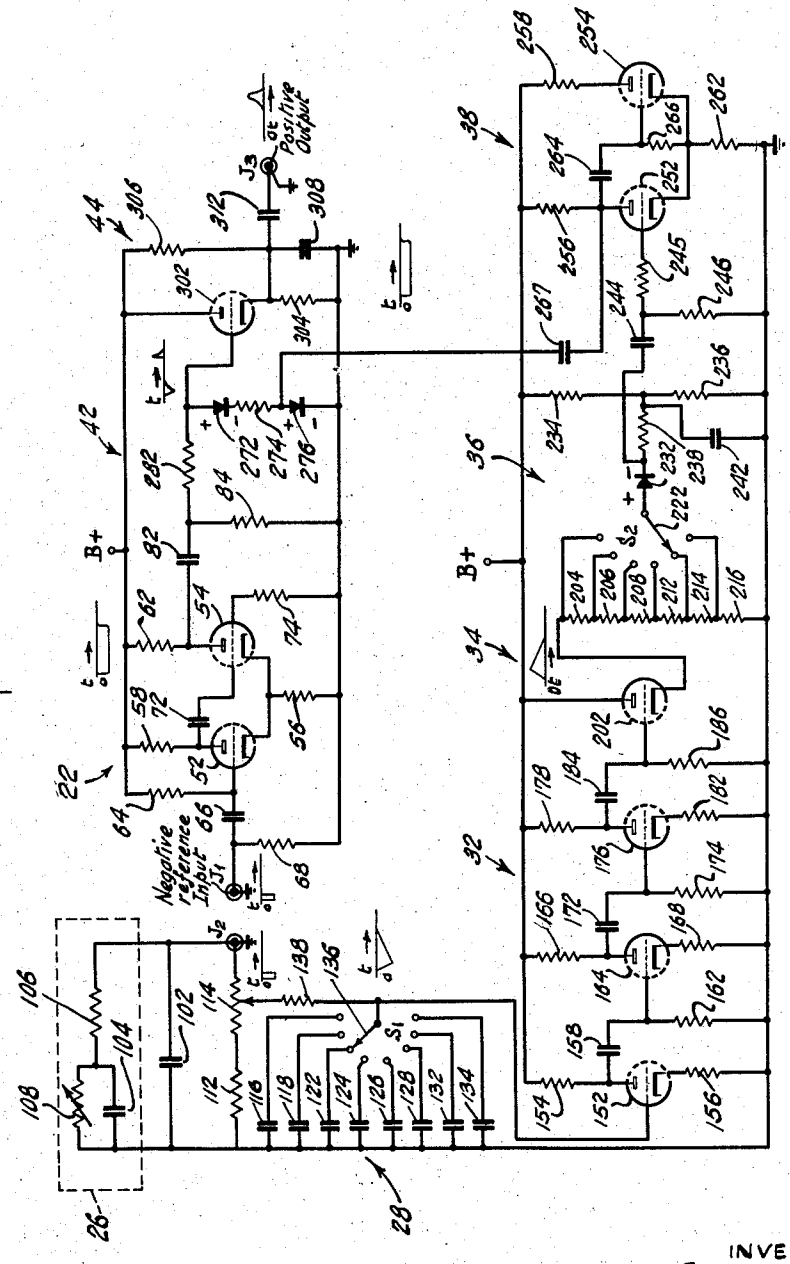
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Fig. 2.



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2,895,107

PULSED MAGNETRON INSTABILITY DETECTOR

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7 Claims. (Cl. 331—87)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention concerns a pulsed magnetron instability detector circuit and more particularly, a pulsed magnetron instability detector circuit for providing quantitative information on the useful energy content in radio frequency pulses generated by a pulsed microwave magnetron tube or its equivalent.

Pulsed microwave magnetrons hereinafter referred to as magnetrons, are subject to many forms of malfunction or instability that all result in the loss of useful radio frequency output power. The existence of instability in a magnetron, the prevalence of a particular form of instability, and the percentage of applied voltage pulses during which the prevalent form of instability is manifested is a complicated function of the electrical characteristics of the magnetron, the electrical conditions to which it is subjected, and the type of circuitry employed for pulse modulation of the magnetron. All forms of magnetron instability are characterized by the loss of radio frequency output power within the desired frequency band. Information on power loss is of prime importance in the quest for improved operating results.

The types of instability that are encountered in the operation of pulsed magnetrons include arcing, moding, and misfiring. Arcing is characterized by a voltage breakdown from anode to cathode due to the formation of a conducting path of ionized gas. Moding is characterized by oscillation in the magnetron at an undesired frequency produced by a spurious electron space charge configuration that is sustained by circuit operating conditions. Since this usually results in an electromagnetic field pattern in the magnetron resonant circuits that is quite different than that for which the magnetron output coupling section is designed, only a very small fraction of the microwave power generated in the magnetron is transmitted to the transmission line. Misfiring is characterized by the absence of oscillation in the magnetron; it results when the voltage-current characteristic of the magnetron and the voltage-current characteristic of the magnetron driving circuit do not coincide at any point to sustain oscillations. No anode current flows in the magnetron when the magnetron misfires.

Techniques available in the present state of the art for studying instability in magnetrons involve the use of instruments that provide only qualitative information. The interpretation of the qualitative information is dependent upon the experience and judgment of the operator. For example, one such technique entails visual counting of flicks on a cathode ray tube screen when evaluating a pulsed magnetron for instability due to arcing. At best, both the technique and the results obtained are crude. There is no technique or detector available in the present state of the art that can provide quantitative information on magnetron performances. Specifically, there is no method or apparatus that provides quantitative information on instability in magnetrons by analyzing a sample of the radio frequency output pulses from a magnetron to evaluate useful energy content.

This invention marks a departure from the prior art in that it provides a method and apparatus for providing quantitative data that directly evaluate the stability of magnetrons. This invention samples the radio frequency output pulses of a magnetron, properly analyzes each pulse, and classifies each pulse according to how much of its energy content is in the desired frequency band. Each radio frequency pulse generated by the magnetron under test is processed through a narrow bandpass filter. The filter blocks all radio frequency energy not generated in the desired voltage mode of oscillation within the magnetron. Each pulse or any fraction of a pulse passed by the filter is detected and its envelope is integrated to measure the energy content. A counter registers the number pulse periods during which a magnetron does not generate as much or more than a particular quantity of radio frequency energy in the desired frequency band. The instability detector circuit may be adjusted to vary the level of the aforesaid particular quantity of radio frequency energy.

An object of this invention is to provide a pulsed magnetron instability detector circuit.

A further object is to provide a pulsed magnetron instability detector circuit for affording accurate quantitative information on instability in magnetrons.

A further object is to provide a pulsed magnetron instability detector circuit for affording accurate quantitative information on instability in magnetrons and for affording quantitative information on the useful energy content of radio frequency pulses generated by magnetrons.

A further object is to provide a pulsed magnetron instability detector circuit for providing quantitative information on malfunction of a magnetron which information is useful as a guide in the development of electronic and microwave circuitry utilizing magnetrons.

A further object is to provide a pulsed magnetron instability detector circuit for simplifying the establishment of test specifications for the stability of magnetrons and for investigations of magnetron starting phenomena.

A further object is to provide a pulsed magnetron instability detector circuit for sampling the output microwave energy of a magnetron and for counting the number of pulses in the sample whose energy content is below a predetermined level.

A further object is to provide a pulsed magnetron instability detector circuit which is simple, does not rely on the use of particular electronic components or particular lay-out, does not require critical adjustments, and is suitable for operation in the vicinity of high-power pulse equipment.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a block diagram of a preferred embodiment of this invention, and

Fig. 2 is a schematic wiring diagram in accordance with Fig. 1.

Detailed information useful for designing a specimen of the invention shown in Figs. 1 and 2 for particular operating conditions, is available in a thesis entitled "Pulsed Magnetron Instability Detector," submitted by the inventor in June 1953 in partial fulfillment of the requirements for the Degree of Master of Electrical Engineering at the Polytechnic Institute of Brooklyn in New York City.

The embodiment of the invention shown in block diagram form in Fig. 1 comprises two separate channels

connected to a magnetron **10**. The upper or reference channel consists of a delay multivibrator **22**. The delay multivibrator **22** is adapted to be triggered by a sampling of each negative voltage pulse generated by the pulser **12** for application to the cathode of the magnetron **10** under test. The delay multivibrator **22** generates a delayed positive pulse each time it is triggered. The lower channel includes a microwave filter **24** connected in conventional manner to the output end of the magnetron **10**. Since frequencies of spurious voltage modes of oscillation in properly designed magnetrons are separated from the normal or desired frequency by at least 5%, a filter of approximately 2% bandwidth blocks all frequencies corresponding to oscillation in undesired voltage modes. This bandwidth is sufficiently broad to allow for normal operating frequency changes without loss of signal from oscillations in the desired voltage mode. A crystal detector **26** is connected to the microwave filter **24**. The crystal detector **26** receives from the microwave filter **24** the energy generated in the desired voltage mode of oscillation in the magnetron. Energy from other modes is blocked by the filter **24**. An integrating circuit **28** is connected to the detector **26**. The detected radio frequency envelope of energy generated in the desired voltage mode of oscillation only is coupled into the integrating circuit **28**; the latter produces a voltage pulse for each magnetron pulse, whose peak amplitude is proportional to the total energy passing through the microwave filter **24**. The pulse produced by the integrating circuit **28** is conventionally processed by an amplifier **32** connected to the output end of the integrating circuit **28**, and cathode follower **34** connected to the output of the amplifier. The cathode follower presents a high impedance to the amplifier and a low impedance source. A biased diode **36**, normally nonconducting, is connected to cathode follower **34** and generates an output only if the peak amplitude of the integrated pulse exceeds the bias of the biased diode **36**. A gate multivibrator **38** is connected to the output of the biased diode **36** and is triggered if the biased diode **36** conducts to a sufficient extent. The time delay introduced by multivibrator **22** is such that each gating pulse and the corresponding pulse from delay multivibrator **22** overlap. When the gate multivibrator **38** is triggered, it generates a gating pulse of sufficient pulse width and sufficient amplitude for suppressing in a decoupling network **42**, the corresponding pulse generated in the delay multivibrator **22**. If the pulse from the delay multivibrator **22** is suppressed the output stage **44** produces no output pulse for triggering the counter **46**. However, if the gate multivibrator **38** is not triggered to generate a gate pulse for suppressing the pulse of the delay multivibrator **22** the latter causes the output stage **44** to generate a pulse for triggering the counter **46**. The counter **46** is triggered to register each pulse period of the magnetron **10** during which instability reduces the useable radio frequency energy level generated during that pulse period below a predetermined minimum.

The description of the schematic wiring diagram shown in Fig. 2 includes quantitative information on the components, immediately following the description of the components. It is not intended that the quantitative information be interpreted in a limiting sense since the stages may be varied to suit the magnetron operating conditions and equivalents of the stages shown be substituted in accordance with principles well known in the art. The quantitative information supplied is for one particular design of this invention for operation where magnetron pulse widths are from 0.2 to 6.0 microseconds in duration and the pulse repetition rate exceeds 2000 pulses per second. The embodiment as described in detail has been used satisfactorily and successfully under various test conditions within the range designated above. A source of reference potential is indicated on the drawing by the conventional grounding symbol and is referred to throughout this description as ground. Where electronic tubes are shown on the drawings, the heater filaments have been omitted to simplify the drawings. The power supply, not shown, for the heater filaments, not shown, is conventional and is obtainable from electronics circuit designers' handbooks.

The power supply serving as the source of plate supply voltage is not shown because a conventional power supply is suitable. For example, a single VR tube regulated 150 volt power supply with an output of 35 milliamperes is ample for activating all stages of the disclosed circuit. Information for designing a power supply may be obtained from many electronic circuit designers' handbooks. Though the power supply is not shown on the drawing, the terminal to which it is to be connected is indicated by B+.

A fraction of the driving pulse for the magnetron **10** is coupled from the pulser **12** to a delay multivibrator **22** (Fig. 1). The delay multivibrator **22** generates a fixed-width negative pulse (30 microseconds) which is differentiated to provide a positive spike at the trailing end. The multivibrator **22** is a cathode-coupled one-shot multivibrator. It includes a normally conducting vacuum triode **52** (½12AU7) and a normally nonconducting vacuum triode **54** (½12AU7). The cathodes of both vacuum triodes **52** and **54** are commonly connected to a cathode bias resistor **56** (3 kilohms), the opposite end of the cathode bias resistor **56** being connected to ground. Plate load resistor **58** (20 kilohms) and 62 (20 kilohms) are connected between the source of plate supply voltage B+ and the plates of the vacuum triodes **52** and **54**, respectively. A grid limiting resistor **64** (1 megohm) is connected between the source of plate supply voltage B+ and the control grid of vacuum triode **52**. Negative trigger pulses for the multivibrator **22**, having a fraction of the amplitude of the magnetron driving pulses, are derived from the pulser **12** (Fig. 1) and are coupled into the junction between series-connected condenser **66** (.01 microfarad) and resistor **68** (1 kilohm), both of which are connected between the control grid of vacuum triode **52** and ground. A condenser **72** (.0025 microfarad) connects the plate of vacuum triode **52** and the control grid of vacuum triode **54**. A resistor **74** (220 kilohms) connects the control grid of the vacuum triode **54** to ground. The long time constant of resistor **64** and condenser **66** prevents changes in the grid voltage of vacuum triode **52** during the interval during which it is cut off. In order for the grid circuit of the vacuum triode **52** not to have any effect upon the pulse-width output of delay multivibrator **22**, condenser **66** is caused to charge through a low impedance **68**. If condenser **66** were to charge through the high impedance of the pulser **12** during the cutoff period of vacuum triode **52**, such action would raise the grid potential of vacuum triode **52** by some fixed voltage dependent upon the ratio of the impedance of the pulser **12** to resistor **64** and would reduce the pulse width.

A differentiating circuit comprising a condenser **82** (10 micromicrofarads) in series with a resistor **84** (500 kilohms), is connected between the plate of vacuum triode **54** and ground. Each time multivibrator **22** is triggered by a negative pulse (0.2–6 microseconds, 2 volts minimum) a corresponding negative pulse (30 microseconds, 70 volts) of constant pulse-width is generated at the plate of the normally nonconducting vacuum triode **54**. The generated negative pulse, shown above the delay multivibrator in Fig. 2, is differentiated to produce a negative voltage spike across resistor **84** corresponding to the leading edge of the negative pulse and a positive voltage spike across resistor **84** corresponding to the trailing edge (both spikes having 0.2 microsecond pulse width, 35 volts amplitude). Only the positive voltage spike is active to trigger the output circuit under those conditions when permitted to do so by the other or radio frequency channel of the detector

circuit. By feeding a narrow spike from differentiator **82, 84** to the circuit **42** instead of the very much wider pulse from multivibrator **52, 54**, the likelihood of counter **46** being triggered by noise is minimized.

Microwave pulse energy generated by the magnetron **10** is coupled into a conventional microwave filter **24**; filter **24** blocks all energy except that at the frequency corresponding to the desired voltage mode of oscillation in magnetron **10**. Information on microwave filter design is obtainable from volume 9 of the Massachusetts Institute of Technology Radiation Laboratory Series by Ragan, published by McGraw-Hill. A properly designed magnetron generates microwave energy at a frequency corresponding to the desired pi mode and at frequencies corresponding to spurious modes of oscillation but the frequency of energy generated in the pi mode differs by at least 5% from the frequency of the closest spurious voltage mode of oscillation. The microwave filter **24** is readily designed according to known principles for approximately 2% bandpass which is suitable for blocking microwave energy at all frequencies corresponding to all spurious modes of oscillation in the magnetron **10**. The 2% bandpass is sufficiently broad to allow for normally operating frequency changes without loss of microwave energy corresponding the desired mode of oscillation.

A crystal detector **26** (IN23B) is connected to the output of the microwave filter **24**. The crystal mount, not shown, is arranged to produce detected pulses of negative polarity. The input signal to the radio frequency channel is a sample or fraction of the pulsed microwave energy generated by the magnetron **10**. Before these pulses can be integrated to analyze their energy content they must be detected to produce video pulses whose shapes are proportional to the envelopes of the modulated radio frequency. This detection is accomplished by means of the crystal detector **26**. The crystal detector **26** is a microwave silicon crystal of the type employed as a mixer in the input to a superheterodyne receiver of a radar system. A coaxial cable is used for connecting the crystal mount and the input end of the integrating circuit **28**. Since normal coaxial cable lengths of 2 to 5 feet are short compared to the wavelengths of the highest frequencies composing the detected pulses, the coaxial cable capacitance indicated by **102** on the drawing is considered to be lumped (about 75 micromicrofarads) at the input to the integrator circuit. When the microwave energy is present, the equivalent capacity **104** of the equivalent circuit of crystal detector **26** and the shunt capacity **102** provided by the connecting coaxial cable both charge rapidly through the low forward resistance **106** of the crystal detector **26**. However, at the termination of the last radio frequency cycle of the pulse the voltage of the equivalent capacity **104** of the crystal detector **26** causes resistor **108** to assume its high back value on the order of 10,000 ohms or higher. As a result, the crystal capacity **104** and the cable capacity **102** cannot discharge rapidly through resistor **108**.

The integrator circuit **28** includes a voltage divider having a fixed resistor **112** (200 ohms) and a potentiometer **114** (100 ohms) connected in series and comprising a low load resistance to maintain the discharge time-constant at a value sufficiently low to prevent distortion of the pulse shape. The voltage developed across the cable capacity **102** is applied across the voltage divider. Potentiometer **114** provides for varying the input signal to the succeeding stages (e.g. by 30%). A carbon potentiometer **114** and a carbon resistor **112** are used instead of wound elements because the signals are pulses as narrow as 0.2 microsecond and which have very high frequency components (5 megacycles). Any changes in the amplitude of a magnetron output microwave pulse due to mode instability is accompanied by a shift in frequency to a point outside the bandpass of the microwave filter **24** whereby the pulse does not reach the detecting crystal **26**. Arcing and misfiring result in a complete absence of microwave energy output for the duration of the instability. Therefore, the microwave energy incident upon the crystal is either at full value or zero. Therefore, it is not critical for the output voltage from the crystal detector **26** to bear a linear relationship with respect to input peak power in order to obtain a proper analysis of the energy content of the input signal. The crystal detector output voltage is either at full amplitude or at zero. The duration of the full amplitude pulse is a measure of the microwave energy generated in the desired voltage mode of oscillation. There is no need for analyzing intermediate pulse amplitudes. The crystal operating region is a compromise (0.5 volt peak output obtained by incident power of about .2 milliwatt), i.e. the voltage is sufficiently low so as to be available from most microwave crystals yet is high enough to simplify problems encountered in shielding the circuit from external sources of noise, such as high power pulse generators and magnetron modulators, and a change in peak input power of 10% results in a 5% change in peak output voltage.

The integrator circuit **28** further includes a series of condensers **116** (690 micromicrofarads), **118** (1040 micromicrofarads), **122** (1610 micromicrofarads), **124** (2530 micromicrofarads), **126** (3910 micromicrofarads), **132** (9200 micromicrofarads), **134** (13,800 micromicrofarads); the condensers are connected between ground and the respective terminals of a multi-position selector switch **136** serving as a pulse-width switch. The contactor of the multi-position selector switch **136** is connected to one end of a limiting resistor **138** (10 kilohms) connected at its other end to the tap of the potentiometer **114** and is also connected to the input end of amplifier **32**; high value resistor **138** is provided to prevent loading of the detector by the integrating circuit. The range of sizes of condensers are provided in order that the integrator **28** be useful over a range of pulse widths (.02 to 6 microseconds) with approximately the same value of power incident upon the crystal detector. The condensers switched into the integrator cover the band in discrete ranges, each covering a 1.5 to 1 band in pulse width. The peak output voltage is small (about 0.02 volt). The amplifier **32** amplifies the pulses produced by the integrating circuit (1500 to 1). The width of the pulses before integration in the integrating circuit **28** vary depending upon the characteristics of the magnetron under test (0.2 to 6.0 microseconds). The amplifier **32** is a three-stage resistance-capacitance coupled triode amplifier. The first stage of the amplifier **32** includes a vacuum triode **152** (½12AT7), a plate load resistor **154** (2 kilohms) connected directly between the plate of the vacuum triode **152** and the source of plate supply voltage B+ and a cathode bias resistor **156** (50 ohms). A coupling condenser **158** (.001 microfarad) and grid-leak resistor **162** (1 megohm), in series, are connected between the plate of the vacuum triode **152** and ground. The second stage of the amplifier **32** includes a vacuum triode **164** (½12AT7), a plate-load resistor **166** (2 kilohms) connected between the plate of the vacuum triode **164** and the source of plate supply potential B+, and a cathode bias resistor **168** (50 ohms) connected between the cathode of the vacuum triode **164** and ground. The control grid of vacuum triode **164** is connected to the junction between the coupling condenser **158** and the grid-leak resistor **162**. A coupling condenser **172** (.001 microfarad) and a grid-leak resistor **174** (1 megohm), in series, are connected between the plate of the vacuum triode **164** and ground. The third stage of the amplifier **32** includes a vacuum triode **176** (½12AT7), a plate-load resistor **178** (10 kilohms) connected between the plate of the vacuum triode **176** and the source of plate supply potential B+ and a cathode bias resistor **182** (33 ohms) connected between the cathode of vacuum triode **176**

and ground. Its control grid is connected to the junction between condenser 172 and resistor 174. A coupling condenser 184 (.001 microfarad) and a grid-leak resistor 186 (1 megohm), in series, are connected between the plate of the vacuum triode 176 and ground.

A cathode follower threshold circuit 34 is connected to the amplifier 32; it includes a vacuum triode 202 (½12AT7) whose plate is connected directly to the source of plate supply potential B+, and a voltage dividing resistance connected between the cathode of the vacuum triode 202 and ground. The voltage dividing resistance comprises series-connected resistors 204 (667 ohms), 206 (476 ohms), 208 (357 ohms), 212 (278 ohms), 214 (222 ohms), and 216 (2 kilohms). Terminals of a multiposition threshold switch 222 are connected to the cathode and to the junction of each pair of adjacent resistors comprising the cathode resistance of cathode follower stage 34.

A biased diode 36 is connected to the contactor of threshold switch 222 and includes a crystal diode 232 (IN39) and a voltage divider for biasing the diode 232 to a fixed threshold level. The gate multivibrator 38 is triggered if the threshold is exceeded. The voltage divider includes a pair of series-connected resistors 234 (70 kilohms) and 236 (5 kilohms) connected between the source of plate supply potential B+ and ground. A high-valued resistor 238 (10 kilohms) is connected between the tap of the voltage divider and the cathode of diode 232. A bypass condenser 242 is connected across the resistor 236 of the voltage divider. The diode 232 conducts only when the potential at its anode end exceeds the bias voltage provided by the voltage divider.

A gate multivibrator is connected to the biased diode 36; it is a single-shot cathode-coupled multivibrator which when triggered generates a negative pulse of sufficient amplitude (70 volts) and duration (60 microseconds) to suppress with certainty the positive reference pulse derived from differentiation of the output of the delay multivibrator 22. The gate multivibrator 38 includes a vacuum triode 252 (½12AU7) and a vacuum triode 254 (½12AU7). Plate load resistors 256 (100 kilohms) and 258 (4 kilohms) are connected between the plates of the vacuum triodes 252 and 254, respectively, and the source of plate supply potential B+. The cathode bias resistor 262 (1500 ohms) is connected between the commonly connected cathodes of the vacuum triodes 252 and 254 and ground. The plate of vacuum triode 252 is coupled to the control grid of the vacuum triode 254 by means of a condenser 264 (50 micromicrofarads). Grid-leak resistor 266 (900 kilohms) is connected between the control grid and cathode of vacuum triode 254. In the absence of a trigger pulse, vacuum triode 254 is operating at zero bias and is conducting because its grid is returned to its cathode through resistor 266. Vacuum triode 252 is cut off until there is a positive trigger pulse. A positive trigger pulse applied to the grid of vacuum triode 252 is required for triggering the multivibrator 38.

The control grid of vacuum triode 252 is coupled to the biased diode by means of a coupling condenser 244 (.01 microfarad) in series with a resistor 245 (100 kilohms). A resistor 246 (500 kilohms) is connected between the junction of condenser 244 and resistor 245 and ground. Condenser 244 and resistor 246 are designed for proper pulse width (60 microseconds) output.

When the diode 232 conducts, diode current serves to charge the coupling condenser 244 (0.01 microfarad), raising the potential on the control grid of vacuum triode 252. The latter conducts and its plate voltage falls, thereby coupling a negative pulse to the grid of vacuum triode 254. Reduction of the plate current of this stage of vacuum triode 254 completes the regenerative feedback; this continues until vacuum triode 254 is cut off and vacuum triode 252 is conducting. The capacitor 264 then discharges through resistor 266, resistor 262, and conducting vacuum triode 252, until the voltage at the grid at vacuum triode 254 again is raised to the point where vacuum triode 254 can conduct and cause regeneration to establish quiescent conditions.

The threshold circuit which includes the biased diode 36 and the cathode circuit of the cathode follower stage 34 permits an operator to preset the percentage of full pulse energy at the correct frequency that must be generated in order that the counter 46 not be triggered. The threshold circuit serves to determine the threshold quantity of signal energy generated in the desired voltage mode of oscillation and passing through the microwave filter 24, below which threshold quantity of signal energy the counter 46 is caused to register.

The decoupling network 42 is provided for combining the pulse generated by the delay multivibrator 22 and the gate multivibrator 38, if any; it functions as an anticoincidence device. The decoupling network 42 includes, in series, a crystal diode 272 (IN39) in series with a resistor 274 (200 kilohms) and a crystal diode 276 (IN39). A resistor 282 (100 kilohms) is connected between the differentiating circuit at the output end of the delay multivibrator 22 and the decoupling network 42. A condenser 267 couples the plate of vacuum triode 252 to decoupling network 42. The decoupling network 42 combines pulses from the delay multivibrator 22 and the gate multivibrator 38 for coupling into output stage 44 without any interaction between the multivibrator stages. The diode 272 isolates the gate multivibrator 38 from the negative spike pulses corresponding to the leading edges of negative pulses produced by the delay multivibrator 22, while resistor 274 and diode 276 act as a clipper to limit the positive pulses. Germanium diodes are used in this grid network because they are compact and rugged, have low shunt capacities (approximately 1 micromicrofarad), have low forward resistance (285 ohms maximum), and do not require heat or power.

The output stage 44 comprises a vacuum triode 302 (½12AU7) connected as a cathode follower and including a cathode bias resistor 304 (4 kilohms) connected between the source of plate supply potential B+ and ground. The cathode bias resistor 304 comprises part of a voltage divider for biasing the vacuum triode 302 beyond cutoff. The other part of the voltage divider is the resistor 306 (47 kilohms) connected between the source of plate supply potential B+ and the cathode end of cathode bias resistor 304. A bypass condenser 308 (500 micromicrofarads) is connected across the cathode bias resistor 304. The charging current of the grid-cathode capacitance (1.6 micromicrofarads) of vacuum triode 302 produces a spurious positive feedthrough (0.6 volt) when the tube is cut off. Since the spurious feedthrough is short in duration (0.5 microsecond) as compared to the normal signal (5 microseconds), the bypass condenser 308 connected across the cathode resistor 304 is used to bypass the spurious feedthrough and while it partially bypasses the normal signal output, it does not seriously affect it. Through the use of the bypass condenser 308 the ratio of normal signal output to residual feedthrough is made very high. A coupling condenser 312 (0.02 microfarad) connected to the cathode of the vacuum triode 302 is used to couple the output developed in the cathode follower output stage 42 to a conventional electronic decade counter, not shown.

In operation, the missing radio frequency pulse detector circuit described when employed with a filter of approximately 2% bandpass, provides a positive output pulse to trigger an electronic decade counter each time a driving pulse is applied to the magnetron 10 under test, and the output energy within the bandpass of the filter is less than that of a normal pulse by some preset percentage. First the pulse-width switch 136 is set to the range that includes the pulse-width being employed for driving the magnetron 10. This selects the proper time constant for the integrating circuit 28. Then the

threshold switch 222 is set to zero position and the input level potentiometer 114 is set to the approximate center of its range. By means of a variable microwave attenuator (not shown) in the transmission line between the magnetron 10 and the crystal detector 26 the input signal is reduced below the threshold level so that the electronic counter records the full repetition rate of the trigger pulses. Then, by adjusting the input level potentiometer 114 as a fine control, the input to the radio frequency channel is adjusted to the threshold at which the counter records the full repetition rate. Then the threshold switch 222 is set to the desired operating position corresponding to the desired minimum energy content of each radio frequency pulse. The counter will then be triggered for all pulses whose energy content is less than that determined by the setting of the threshold switch 222. In other words, the counter will register for all generated pulses whose useful energy content is less than that of a normal pulse by a percentage selected through the use of switch 222. The missing radio frequency pulse detector circuit provides a quantitative information on magnetron malfunction. The quantitative information can be utilized as a guide in the development of electronic and microwave circuitry utilizing magnetron tubes. This circuit simplifies the establishment of test specifications for the stability of pulsed magnetrons, and aids materially in investigations of tube starting phenomena.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

I claim:

1. An instability detector circuit adapted for coupling to a magnetron and which is suitable for use in the vicinity of high power pulse equipment and its pulsing means, said detector circuit comprising; a first single-pulse generating means adapted to be coupled to the magnetron pulsing means for sampling a predetermined fraction of each of the magnetron driving pulses and for generating a pulse of predetermined pulse width for each magnetron driving pulse; differentiating means coupled to the output end of said first single-pulse generating means to provide a narrow reference pulse coincident with the trailing edge of each pulse generated by said first single-pulse generating means, whereby the reference pulse is spaced by a predetermined interval from the corresponding driving pulse and whereby there is minimum likelihood of coincidence between the narrow reference pulse and interference energy from said high power pulse equipment in the vicinity and consequently minimum likelihood of modification of a significant number of the reference pulses by interference energy; a microwave filter adapted to be coupled to the output end of the magnetron for sampling a predetermined fraction of the microwave energy in a predetermined frequency band in each pulse generated by the magnetron; detector means coupled to said filter; integrating means coupled to said detector means for separately integrating the energy from said microwave filter for each magnetron pulse respectively; threshold means coupled to the output end of said integrating means; a second single-pulse generating means coupled to the output end of said threshold means and triggered each time said threshold means becomes conductive to generate a gating pulse of predetermined amplitude and many times greater width than said reference pulse; said first single pulse generating means delaying each reference pulse by an interval such that each reference pulse occurs between the leading and trailing edges of a corresponding gating pulse; anticoincidence means coupled to the output ends of said differentiating means and said second single-pulse generating means for providing an output pulse for each reference pulse not attended by a gating pulse; means coupled to the output end of said anti-coincidence means to provide an indication of the degree of instability in the magnetron.

2. An instability detector circuit adapted for coupling to a magnetron and which is suitable for use in the vicinity of high power pulse equipment and its pulsing means, said detector circuit comprising; first means adapted to be coupled to the magnetron pulsing means for sampling a predetermined fraction of each of the magnetron driving pulses and for generating one delayed reference pulse of very narrow pulse width for each magnetron driving pulse, whereby there is minimum likelihood of coincidence between reference pulses and interference energy from said high power pulse equipment in the vicinity and consequently minimum likelihood of modification of a significant number of the reference pulses by interference energy; second means adapted to be coupled to the output end of the magnetron for sampling and summing up a predetermined fraction of the microwave energy in a predetermined frequency band in each pulse generated by the magnetron and for generating a gating pulse of predetermined pulse width and much wider than the reference pulses for each magnetron driving pulse during which the microwave energy generated by the magnetron within the selected frequency band exceeds a predetermined minimum; said first means delaying each reference pulse by an amount such that the leading and trailing edges of each gating pulse occur respectively before and after the corresponding reference pulse; third means coupled to the output ends of said first and second means for accepting the reference pulses and the gating pulses and for generating pulses whose number are related to the number of reference pulses, that are attended by gating pulses and the number of reference pulses that are not attended by gating pulses; and means coupled to the output end of said third means and responsive to the pulses therefrom for providing an indication of the degree of instability in the magnetron.

3. A circuit adapted for detecting instability in a magnetron and which is suitable for use in the vicinity of high power pulse equipment comprising: means for generating magnetron driving pulses adapted to be coupled to the magnetron; a first single-pulse generating means coupled to said means for sampling a predetermined fraction of each of the magnetron driving pulses and for generating a pulse of predetermined pulse width for each magnetron driving pulse; differentiating means coupled to the output end of said first single-pulse generating means to provide a narrow reference pulse coincident with the trailing edge of each pulse generated by said first single-pulse generating means, whereby the reference pulse is spaced by a predetermined interval from the corresponding driving pulse and whereby there is minimum likelihood of coincidence between the narrow reference pulse and interference energy from said high power pulse equipment in the vicinity and consequently minimum likelihood of modification of significant number of the reference pulses by interference energy; a microwave filter adapted to be coupled to the output end of the magnetron for sampling a predetermined fraction of the microwave energy in a predetermined frequency band in each pulse generated by the magnetron; detector means coupled to said filter; integrating means coupled to said detector means for separately integrating the energy from said mircowave filter for each magnetron pulse respectively; threshold means coupled to the output end of said integrating means; a second single-pulse generating means coupled to the output end of said threshold means and triggered each time said threshold means becomes conductive to generate a gating pulse of predetermined amplitude and many times greater width than said reference pulse; said first single pulse generating means delaying each reference pulse by an interval such that each reference pulse occurs between the leading and trailing edges of a corresponding gat-

ing pulse; anticoincidence means coupled to the output ends of said differentiating means and said second single-pulse generating means for providing an output pulse for each reference pulse not attended by a gating pulse; means coupled to the output end of said anticoincidence means to provide an indication of the degree of instability in the magnetron.

4. A circuit adapted for detecting instability in a magnetron and which is suitable for use in the vicinity of high power pulse equipment comprising; first means for generating magnetron driving pulses adapted to be coupled to the magnetron; second means coupled to said first means for sampling a predetermined fraction of each of the magnetron driving pulses and for generating one delayed reference pulse of very narrow pulse width for each magnetron driving pulse, whereby there is minimum likelihood of coincidence between reference pulses and interference energy from said high power pulse equipment in the vicinity and consequently minimum likelihood of modification of a significant number of the reference pulses by interference energy; third means adapted to be coupled to the output end of the magnetron for sampling and summing up a predetermined fraction of the microwave energy in a predetermined frequency band in each pulse generated by the magnetron and for generating a gating pulse of predetermined pulse width and much wider than the reference pulses for each magnetron driving pulse during which the microwave energy generated by the magnetron within the selected frequency band exceeds a predetermined minimum; said first means delaying each reference pulse by an amount such that the leading and trailing edges of gating pulse occur respectively before and after the corresponding reference pulse; fourth means coupled to the output ends of said second and third means for accepting the reference pulses and the gating pulses and for generating pulses whose number are related to the number of reference pulses that are attended by gating pulses and the number of reference pulses that are not attended by gating pulses; and means coupled to the output end of said fourth means and responsive to the pulses therefrom for providing an indication of the degree of instability in the magnetron.

5. An anticoincidence circuit comprising: two diodes, a resistor connecting the cathode of one diode and the anode of the other diode, a second resistor connected at one end to the anode of said one diode, a source of positive pulses coupled between the other end of said second resistor and the cathode of said other diode whereby current flows through said resistors during each positive pulse therefrom, a source of negative pulses shunting said other diode, the negative pulses being of an amplitude such that when a positive and a negative pulse from said sources are coincident, the positive pulse is suppressed in said circuit.

6. An instability detector circuit adapted for coupling to a magnetron and its pulsing means, said detector circuit comprising; a first single-shot multivibrator adapted to be coupled to the magnetron pulsing means for sampling a fraction of each of the magnetron driving pulses and for generating a pulse of predetermined pulse width for each magnetron driving pulse; differentiating means coupled to the output end of said first multivibrator to provide a reference pulse coincident with the trailing edge of each pulse generated by said first multivibrator; a microwave filter adapted to be coupled to the output end of the magnetron for sampling a predetermined fraction of the microwave energy in a predetermined frequency band in each pulse generated by the magnetron; detector means coupled to said filter; an integrator circuit; adjustable voltage divider means coupling said integrating circuit to said detector means; means coupled to the output end of said integrator circuit for amplifying the output of said integrator circuit; a second single-shot multivibrator for generating a gating pulse of predetermined amplitude and pulse width when triggered; a biased diode coupling the output end of said amplifier means to second multivibrator; the width of each pulse generated by said first multivibrator being such that every gating pulse and the corresponding reference pulse overlap; voltage summation means including in series a first unidirectional conducting means, a resistor, and a second unidirectional conducting means; a current limiting resistor connected between the output end of said differentiating means and said first unidirectional connecting means; a coupling condenser connected between the output end of said second multivibrator and the junction between said resistor and said second unidirectional conducting means of said voltage summation means; output amplifier means connected at its input end across said voltage summation means and producing an output pulse only when a reference pulse from said differentiating means, not attended by a gating pulse from said second multivibrator, is applied to said voltage summation means, and a counter connected to said output amplifier means for counting pulses from said output amplifier means to provide a quantitative measurement of instability in the magnetron.

7. A circuit adapted for detecting instability in a magnetron comprising; means for generating magnetron driving pulses adapted to be coupled to the magnetron; a first single-shot multivibrator coupled to said means for sampling a fraction of each of the magnetron driving pulses and for generating a pulse of predetermined pulse width for each magnetron driving pulse; differentiating means coupled to the output end of said first multivibrator to provide a reference pulse coincident with the trailing edge of each pulse generated by said first multivibrator; a microwave filter adapted to be coupled to the output end of the magnetron for sampling a predetermined fraction of the microwave energy in a predetermined frequency band in each pulse generated by the magnetron; detector means coupled to said filter; an integrator circuit; adjustable voltage divider means coupling said integrating circuit to said detector means; means coupled to the output end of said integrator circuit for amplifying the output of said integrator circuit; a second single-shot multivibrator for generating a gating pulse of predetermined amplitude and pulse width when triggered; a biased diode coupling the output end of said amplifier means to second multivibrator; the width of each pulse generated by said first multivibrator being such that every gating pulse and the corresponding reference pulse overlap; voltage summation means including in series a first unidirectional conducting means, a resistor, and a second unidirectional conducting means; a current limiting resistor connected between the output end of said differentiating means and said first unidirectional connecting means; a coupling condenser connected between the output end of said second multivibrator and the junction between said resistor and said second unidirectional conducting means of said voltage summation means; output amplifier means connected at its input end across said voltage summation means and producing an output pulse only when a reference pulse from said differentiating means, not attended by a gating pulse from said second multivibrator, is applied to said voltage summation means; and a counter connected to said output amplifier means for counting pulses from said output amplifier means to provide a quantitative measurement of instability in the magnetron.

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