Dec. 18, 1956 R. C. MACHLER 2,774,277

SYSTEMS FOR SPECTROCHEMICAL ANALYSIS

Filed Nov. 5, 1952 2 Sheets-Sheet 1

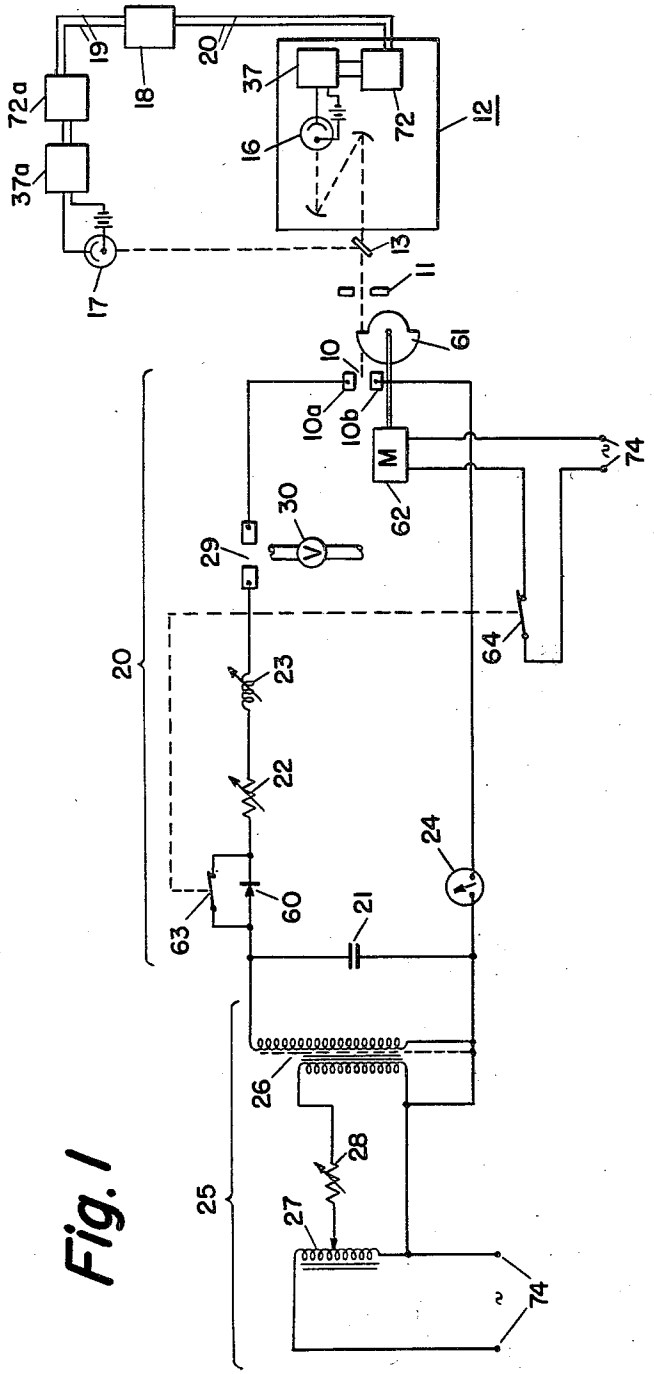
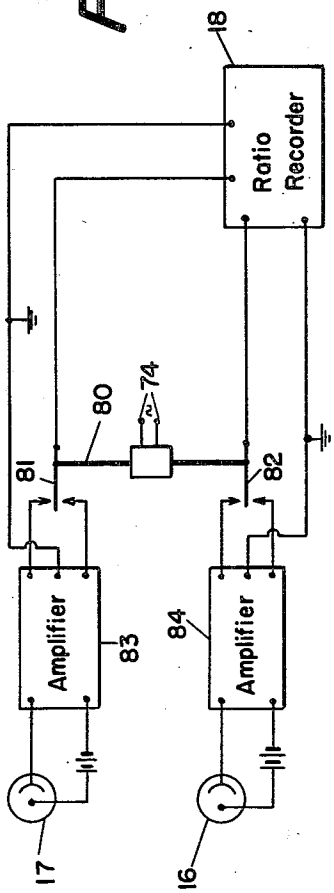


Fig. 1

Fig. 2



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SYSTEMS FOR SPECTROCHEMICAL ANALYSIS

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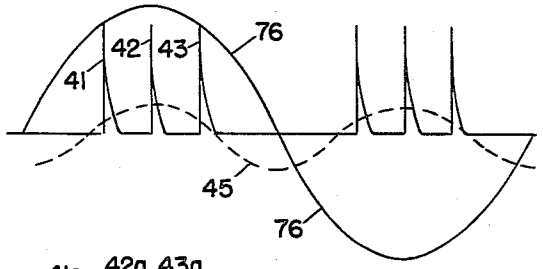


Fig. 3

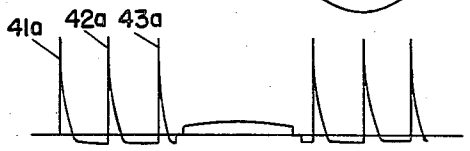


Fig. 4

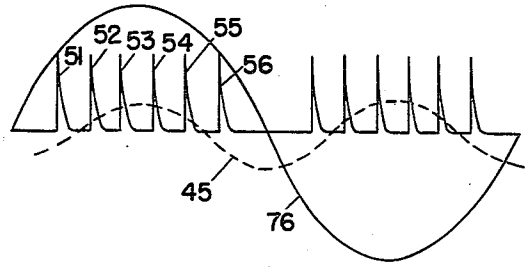


Fig. 5

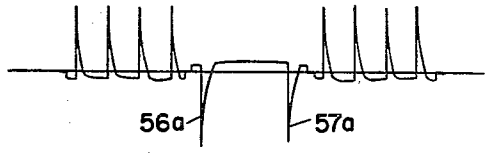


Fig. 6

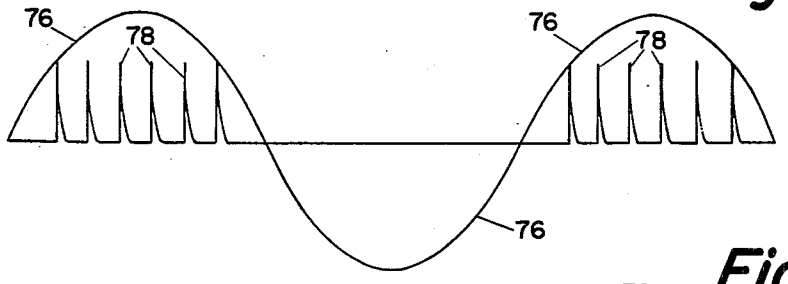


Fig. 7



Fig. 8

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SYSTEMS FOR SPECTROCHEMICAL ANALYSIS

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Application November 5, 1952, Serial No. 318,807

9 Claims. (Cl. 88—14)

This invention relates to systems, such as those for spectrochemical analysis, which include pulse amplifiers of the alternating current type having in the output circuit a synchronous rectifier and has for an object the provision of systems in which there is avoided variation in the direct current output of the alternating current amplifier and rectifier due to phase shift of the synchronous rectifier.

This invention is particularly applicable to systems utilized in spectrochemical analyses of various compositions where a spectrum will be produced by a spark discharge and where a radiation-responsive device has an output corresponding with the intensity of a selected line or lines of the spectrum produced from the composition. The repetition rate of the spark discharge is controlled in manner such that the energies in successive discharges remain substantially constant within narrow limits. With each spark discharge a pulse is produced by a radiation-responsive device such as a phototube, the intensity of which is measured with reference to the intensity of a selected line or band of the spectrum.

Such measuring systems are preferably of the type disclosed in Williams, Jr. Patent No. 2,522,976. Reference may also be had to the article entitled "Electrically Balanced Controller for Flight Testing and Spectroscopy" by Albert J. Williams, Jr. et al. which appears in AIEE Transactions, volume 65, 1946, pages 205–208, for details of such a ratio-measuring system.

It has been found desirable, as more fully explained in copending application Serial No. 157,541, filed April 22, 1950, for "Pulse Amplifier System for Spectrographic Analysis" by Albert J. Williams, Jr., issued May 19, 1953 as patent No. 2,638,811, to include preamplifiers in ratio-measuring systems of said Williams' patent No. 2,522,976 and of said publication in order to utilize signals from low intensity lines of the spectrum. However, direct-current amplifiers, if used, would increase the "dark current" signals to the same degree as the signals due to the fainter lines of the spectrum. Hence, the signal-to-noise ratio would not be improved. Alternating current amplifiers improve the signal-to-noise ratio by elimination of the dark current signal, but with alternating current amplifiers it is necessary to rectify the output thereof for application to the ratio-measuring network. However, rectifiers of either the diode type or of the semi-conductor type do not have sufficiently linear characteristics to meet the exacting requirements of the spectrographic application. More particularly, the non-linearity of such types of rectifiers produces an apparent change in ratio at different signal levels not due to change in relative intensities of the lines of the spectrum under the observation but due solely to the non-linearity of the rectifiers.

Synchronous rectifiers of the mechanical type have linear response characteristics, but due to the fact that such synchronous rectifiers operate with switching contacts, they have been found to be subject to slight phase shifts during operation; that is, like switching operations may occur at different times in the cycle of the alternating current used to drive them. These shifts in phase of the synchronous rectifier have been enough to introduce unwanted signals. More specifically the shifts in phase of the synchronous rectifiers have produced a change in the ratio due solely to said shift of phase, and not to a change in the ratio of intensity of the lines under observation.

It is the principal purpose of the present invention to provide compensation for systems including an alternating current amplifier and a synchronous rectifier wherein the system is compensated for the inherent phase shift of the synchronous rectifier and more particularly to provide a system which allows a substantial tolerance in the phasing of the synchronous rectifier without introducing signals due to shifts in phase of the synchronous rectifier without regard to the number of spark discharges within a given cycle. While systems of the type disclosed and claimed in the aforementioned copending application have been successful in avoiding the introduction of signals due to shifts in phase of the synchronous rectifier when a relatively few number of spark discharges take place during a cycle, such systems have left something to be desired when many discharges, for example more than six pulses of radiant energy for each half cycle, are produced. When more than a few pulses of radiant energy are produced in each half cycle, some of the resulting voltage pulses will be reversed by the synchronous rectifier and will subtract from the direct current output signal of the amplifier-rectifier. This is undesirable. Thus, in accordance with the present invention there is provided means for applying to the input circuit of the amplifier-rectifier radiant energy pulses during alternate half cycles only of an alternating current supply voltage.

In carrying out the invention in one form thereof, there is provided a spectrometer system having a source of radiant energy operable over a range of selected repetition rates and a phototube responsive to a selected band of the spectrum of the radiant energy for producing radiant energy pulses at a selected repetition rate. There is further provided an amplifier having an input circuit including said phototube and an output circuit in which there appears an output signal including amplified pulses corresponding to those applied to the input circuit. There is further provided a synchronous rectifier in the output circuit and means for applying to the input circuit radiant energy pulses during alternate half cycles only of an alternating current reference voltage, to insure unipolarity of the rectified amplified pulses throughout said range of selected repetition rates, and means including the reference voltage for operating the synchronous rectifier to produce switching operations at a predetermined time in the cycle of said reference voltage.

Further in accordance with the invention, there is provided a system for measuring the relative intensities of radiant energy produced over a range of selected repetition rates comprising phototubes respectively viewing the radiant energy, a D. C. ratio recorder for comparing the output of one phototube relative to the other, and an A. C. amplifier disposed between each phototube and the ratio recorder, each amplifier having an input circuit for application thereto of groups of pulses at a selected repetition rate and an output circuit in which there appears an output signal including amplified pulses corresponding to those applied to the input circuit. The system further includes a synchronous rectifier means of the mechanical type in each output circuit, means for simultaneously applying to each input circuit radiant energy during alternate half cycles only of an alternating-current reference voltage to insure unipolarity of the rectified amplified pulses throughout the range of selected repetition rates, and means for operating the synchronous rectifier means to produce switching operations at a predetermined time in the cycle of the reference voltage.

Further in accordance with the invention, the means for applying to the input circuit radiant-energy pulses during alternate half cycles only of an alternating-current reference voltage may comprise a half-wave rectifier in series circuit with the source of radiant energy or it may comprise a rotary light shutter disposed adjacent the spark electrodes forming the analytical gap.

Further in accordance with the invention, the synchronous rectifier means may be of the mechanical double reed vibrator type, one reed being disposed respectively in each of the output circuits of the amplifiers and both of the reeds simultaneously producing the switching operations at a predetermined time.

For a more detailed understanding of the invention and for further objects and advantages thereof, reference is to be had to the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 diagrammatically illustrates a preferred embodiment of the invention;

Fig. 2 diagrammatically illustrates a modification of the invention applicable to the embodiment shown in Fig. 1; and

Figs. 3–8 are graphs useful in explanation of the problems to be solved and the manner of their solution by the invention.

Referring to Fig. 1 as exemplary of a spectrometer system utilizing the invention, light pulses from the analytical gap or source **10** are admitted through entrance slit **11** of spectrometer **12** in which a prism or grating produces a spectrum having emission lines characteristic of the material to be analyzed, which material is included in electrodes **10***a* and **10***b* or introduced into the spark gap **10** between them. As the particular nature of the spectrometer is not here of interest, it is not further described. It may be of any conventional type suitable for use in spark spectrographic analysis.

Similar to the spectrometer system disclosed in aforesaid copending application Serial No. 157,541, the spectrometer **12** directs upon phototubes **16** and **17** the selected lines or bands of the spectrum. Phototube **16** may be considered as the analyzing phototube whereas phototube **17** may be considered as the reference phototube. For purposes of clarity, insofar as possible, like parts in the present application have been designated with the same reference characters as the aforesaid copending application. In the spectrometer **12** of the present application, Fig. 1, there is interposed in the optical path adjacent entrance slit **11** a clear polished quartz light-splitter in the form of a plate **13** which transmits radiant energy to analyzing phototube **16** and reflects radiant energy to reference phototube **17**. The purpose of the light splitter **13** will be later pointed out. As disclosed in said copending application, the radiation-responsive devices **16** and **17** are preferably photomultipliers and these have been connected in a ratio measuring circuit for operation of a ratio recorder **18** in accordance with the relative values of the intensity of the reference radiant energy and the radiant energy corresponding with the constituent of the substance being analyzed. Accordingly, in Fig. 1 the ratio recorder **18** is illustrated as having one input circuit **19** from phototube **17** and a second input circuit **20** from phototube **16**.

In the aforementioned copending application Serial No. 157,541, it was pointed out that because of the "dark current," that is, the current flow during the absence of an output from the radiation source, direct current amplifiers do not improve the signal-to-noise ratio where the signal, of course, is a measure of the intensity of the respective spectral lines and the dark current is the "noise." Accordingly, to provide needed amplification for the measurement of the fainter spectral lines and at the same time to improve the signal-to-noise ratio, alternating-current amplifiers are particularly advantageous. The output of such an alternating-current amplifier is then converted to direct current for application to ratio measuring networks of the type shown in said Williams, Jr. Patent No. 2,522,976.

It was further pointed out in said copending application Serial No. 157,541 that the use of alternating-current amplifiers of the type generally available are not suitable for use in spectrographic analysis for the reason that undesirable signals are introduced, which signals are not due to ratio differences between the selected spectral lines or bands. Accordingly, in said copending application Serial No. 157,541 there was disclosed and is included here by reference a pulse amplifier system including a compensated pulse amplifier having a feedback circuit including circuit elements having impedance characteristics which are materially different for low and high-frequency components of the applied pulses for so modifying the amplifier characteristics as to produce a substantially uniform level of signal between groups of pulses in avoidance of spurious signals which would otherwise be introduced by change in phase operation of the rectifier in the regions in which said substantially uniform signal level has been established. Similar amplifiers **37**, **37***a* and synchronous contact rectifiers **72**, **72***a* illustrated in Fig. 1 of said copending application Serial No. 157,541 have been illustrated schematically in Fig. 1 of this application by blocks designated by corresponding reference characters. The synchronous rectifiers **72**, **72***a* may be of the polarized vibrator type, the construction of which is disclosed in copending application Serial No. 725,465, filed by Albert J. Williams, Jr., issued October 14, 1952 as U. S. Patent No. 2,614,188 (and also disclosed in Belgian Patent No. 479,515). The vibrators **72**, **72***a* may be either of the normally closed or the normally open type, but preferably of the latter type.

The reference cell **17**, while it may receive radiant energy from only a single line of the spectrum, preferably and as illustrated in Fig. 1, receives radiant energy from a selected band of the total radiation of the excited specimen as more fully disclosed in copending application Serial No. 156,763, filed April 19, 1950, Patent No. 2,734,418 issued February 14, 1956, for "Spectrometer Systems" by John H. Enns. The reference band effectively viewed by the reference photocell is undispersed radiation and embraces the principal radiation from the constituents of the specimen yet is limited by the response characteristic of the receiver alone or in combination with an optical filter to exclude the non-representative radiation due to components of the ambient atmosphere or due to specimen components of appreciably different excitation characteristics. In this connection, it is to be noted that it is desirable to have the radiant energy reaching the reference channel of the ratio recorder **18** considerably attenuated with respect to the light actually passing through the clear polished quartz plate **13** to the analyzing cell **16** of the spectrometer because the latter cell is viewing only a single line which contains very little radiant energy while the photocell **17** in the reference channel is viewing substantially all of the radiant energy. Thus, as the two have an extremely large ratio, it is difficult to adjust the ratio recorder to obtain a reasonable on-scale reading unless the radiation viewed by the reference channel is attenuated. Such attenuation is obtained relatively automatically by utilizing the clear polished quartz plate **13** as it is only a partial reflector, that is, it reflects only from about four to ten per cent of the incident light while a large portion of the light passes through the quartz plate to the analyzing cell **16** of the spectrometer, the foregoing division of the radiation from the energy source being the desired division.

This invention is particularly concerned with spectrometer systems utilizing multiple pulses, that is, groups of pulses produced in each half cycle of a reference voltage. The manner of producing multiple pulses is more fully explained in Enns Patent No. 2,456,116. Briefly, the source or analyzing gap **10** is included in a high-frequency

discharge circuit **20** including a capacitor **21**, a resistor **22** and inductor **23**, and preferably a radio-frequency ammeter **24**. The low-frequency charging circuit **25** includes a voltage step-up transformer **26** supplied from a suitable source of alternating-current supply **74**. To adjust the charging voltage for the capacitor **21**, an adjustable autotransformer **27** of the "Variac" type is utilized in conjunction with an adjustable series resistance **28**. The conventional 60-cycle alternating-current source of supply may be utilized, the sine waveform **76** being illustrated in Figs. 3–8. Variation of the voltage applied to the transformer **26** will predetermine, other things remaining constant, the number of sparks which jump the gap **10** each half cycle or alternate half cycle of the low-frequency supply voltage. A control gap **29** is included in series with the analytical gap **10** to stabilize operation thereof, a stream of air being directed across the control gap as by means of a flow pipe **30** of insulating material.

As fully explained in said Enns patent, when the voltage rises across the capacitor **21**, it will attain a magnitude at which a spark will jump across the control gap **29**, whereupon the energy stored in the capacitor **21** will be dissipated as an oscillatory high-frequency discharge in the discharge circuit **20** including the analytical gap **10**. The voltage across capacitor **21** will be quickly restored to zero. However, the capacitor again starts recharging at a rate determined by the time constant of the charging network and therefore may again receive a charge adequate to produce a spark at the control gap **29** to initiate a further high-frequency discharge. The charging and discharging cycle repeats in each half wave of waveform **76** of the reference voltage **74** a number of times depending upon the setting of the control gap **29**, the time constant of the charging circuit **25**, and the available secondary voltage of the transformer **26**. As described above, the spark breakdowns of the analytical gap **10** have ranged from 1 to 20 per half cycle of the reference voltage.

In Fig. 3 there has been illustrated the sine wave **76** of the reference voltage **74** of 60 cycles per second as well as three pulses **41**, **42** and **43** of radiant energy directed to the spectrometer **12** as a result of three discharges across gap **10** during the positive half cycle of the reference voltage **74**. During the negative half cycle of that voltage, there will again be three further discharges. As indicated by the broken line 120-cycle sine wave **45**, it will be observed that the three pulses of radiant energy occur during the positive half cycles of a 120-cycle sine wave **45**. Under such conditions, it will be desirable to have the synchronous rectifiers **72**, **72***a*, Fig. 1, (disclosed in detail in aforementioned copending application Serial No. 157,541) operate at 120 cycles per second. With synchronous rectifiers **72**, **72***a* operating at 120 cycles per second, there will be obtained operation of the amplifier-rectifier combinations of Fig. 1 according to the waveform including the resulting voltage pulses **41***a*—**43***a* illustrated in Fig. 4.

While the foregoing operation is satisfactory if only a single pulse or a small number of pulses are produced in each half cycle of the reference voltage **74** (illustrated as sine wave **76** in Figs. 3, 5 and 7) if numerous pulses, for example as many as six pulses of radiant energy **51**—**56** are produced in each half cycle of the reference voltage **74** (illustrated as sine wave **76** in Figs. 3, 5 and 7), it will be seen from Fig. 6 that two of the resulting voltage pulses **56***a* and **57***a* will be reversed by the synchronous rectifier **72**, **72***a* and will subtract from the direct-current output signal of the amplifier-rectifiers.

Operation according to the waveforms illustrated in Figs. 5 and 6 is undesirable and in accordance with the present invention there is provided means for applying to the input circuits of the amplifiers radiant energy pulses during alternate half cycles only of the alternating-current reference voltage **74**. The alternate half-wave operation may be performed in various ways. For example, as shown in Fig. 1, the high-frequency discharge circuit **20** may include a half wave rectifier **60** which serves to limit the discharge current through the gaps **10** and **29** only to the half wave corresponding with the polarity of connection of the rectifier **60** in the discharge circuit. Alternatively, the half-wave operation may be accomplished by providing a rotary shutter (approximately 180° disc) **61** in the light path between the source or gap **10** and the phototubes **16** and **17**, operated by a synchronous motor **62** supplied from source **74**, the half-wave shutter **61** blocking from the phototubes alternate half cycles of radiant energy, thus performing the equivalent function of the half-wave rectifier **60** in the electrical circuit of gap **10**. While in Fig. 1 both the half-wave rectifier **60** and the half-wave shutter **61** have been illustrated, it will be noted that there has been provided a rectifier shunting switch **63** and a motor circuit switch **64**. Both switches **63** and **64** are mechanically coupled together for simultaneous operation to open and closed positions. Thus, when motor switch **64** is closed to energize motor **62** to provide half-wave source operation by means of half-wave shutter **61**, the switch **63** also will be closed, thereby shorting out of the electrical circuit of gap **10** the half-wave rectifier **60**. Similarly, when switches **63** and **64** are in open position, half-wave rectifier **60** will be effective in the electrical circuit of gap **10** to produce half-wave source operation, and, accordingly, motor **62** will be deenergized thereby preventing rotation of the half-wave shutter **61**. It is to be understood that suitable provision is to be made to insure that when switch **64** is in open position with motor **62** deenergized, the half-wave shutter **61** will be at rest in a position such that it will not block the pulses of radiant energy being directed from gap **10** to entrance slit **11**.

By thus limiting the radiant energy pulses to either the positive or to the negative half cycles of the reference voltage wave **76**, the synchronous mechanical rectifiers **72**, **72***a* of Fig. 1 may be operated at 60 cycles; for example, from the same source of alternating-current supply as supply **74** having sine waveform **76**, Fig. 7, and the switching of the rectifiers may be phased for operation with respect to the reference voltage wave **76** to eliminate the possibility of radiant energy pulses which, in turn, may produce signal pulses at the amplifier which, if present, would be reversed by the rectifiers **72**, **72***a* in diminution of the direct-current output signals. As may be seen in Fig. 8, the switching of the synchronous rectifiers takes place at the point of alternation of reference voltage wave **76**. Thus, with operation according to the waveform illustrated in Fig. 8 there is avoided the possibility of inaccuracies due to change in the direct-current output signal which would result in a change from the operation with some pulses, at times, subtracting from the direct-current output, and at other times due to mechanical rectifier phase shift, not subtracting therefrom. There is further avoided the need for a high degree of phase stability since by including the rectifier **60** in the discharge circuit, the synchronous rectifiers **72**, **72***a* can shift in phase over a substantial period of time without the possibility of the improper operation above discussed in connection with Figs. 5 and 6. There may then be as many radiant energy pulses **78** as desired during alternate half cycles of voltage **74** represented by waveform **76**, but none of the resulting voltage pulses **79** will be reversed by rectifiers **72**, **72***a* because their switching operations even with some phase shift occur substantially during the inactive half cycles.

It is, of course, possible to have phase shift occur between the synchronous rectifier **72** contained in the measuring channel and synchronous rectifier **72***a* contained in the reference channel which would lead to inaccuracies in the system unless the amplifiers contained in the reference channel and in the measuring channel are compensated, for example, in accordance with the compensation described in aforesaid copending application Serial No. 157,541. However, to avoid the need of utilizing com-

pensated amplifiers, there may be substituted for the two separate synchronous rectifiers 72, 72*a* of Fig. 1 a vibrator 80, Fig. 2, utilizing two reeds 81, 82 operated from a common drive energized by source 74. By utilizing the common vibrator drive of Fig. 2 with two reeds 81, 82 attached thereto, reed 81 serving to rectify the output of the reference channel and reed 82 rectifying the output of the measuring channel, the phase shift produced in both channels will be identical since being derived from a common vibrator 80 and the effects of any phase shift will cancel. This, of course, assumes that both halves of the vibrator respectively including reeds 81 and 82 will vary identically in their vibrating characteristics such as the make or break time of the vibrator contacts. Thus, by utilizing a common vibrator 80, as illustrated in Fig. 2, the amplifiers 83 and 84 need not be of the aforementioned compensated type but may be of a well-known type voltage amplifier characterized by high gain, stabilized by feedback and having relatively uniform response throughout the audio spectrum, for example, such as Ballantine decade amplifier Model 220.

It is to be understood that the amplifier-rectifier circuit of Fig. 2 may be utilized with the source circuit of Fig. 1 and that the half-wave source operation may be obtained as in Fig. 1 by either the use of the half-wave rectifier 60 or the half-wave rotary light shutter 61. It is further to be understood that, while it is not necessary, the common vibrator 80 may also be used with compensated amplifiers such as 37 and 37*a* of Fig. 1.

While preferred embodiments of the invention have been illustrated, it is to be understood, of course, that further modifications may be made within the spirit and scope of the appended claims.

What is claimed is:

1. In combination, a spectrometer system having a source of radiant energy operable over a range of selected repetition rates and a phototube responsive to a selected band of the spectrum of said radiant energy for producing radiant-energy pulses at a selected repetition rate, an amplifier having an input circuit including said phototube and an output circuit in which there appears an output signal including amplified pulses corresponding with those applied to said input circuit, a synchronous rectifier in said output circuit, means for applying to said input circuit radiant-energy pulses during alternate half cycles only of an alternating-current reference voltage to insure unipolarity of the rectified amplified pulses throughout said range of selected repetition rates, and means including said reference voltage for operating said synchronous rectifier to produce switching operations at a predetermined time in the cycle of said reference voltage.

2. The combination according to claim 1 wherein said means for applying to said input circuit radiant-energy pulses during alternate half cycles only of an alternating-current reference voltage comprises a half-wave rectifier in series with said source of radiant energy.

3. The combination according to claim 1 wherein said means for applying to said input circuit radiant-energy pulses during alternate half cycles only of an alternating-current reference voltage comprises a rotary light shutter.

4. A system of measuring the relative intensities of radiant energy produced over a range of selected repetition rates comprising phototubes respectively viewing said radiant energy, a D. C. ratio recorder for comparing the output of one phototube relative to the other, a pair of A. C. amplifiers, one disposed between each phototube and said ratio recorder and each amplifier having an input circuit for application thereto of groups of pulses at a selected repetition rate and an output circuit in which there appears an output signal including amplified pulses corresponding with those applied to said input circuit, synchronous rectifier means of the mechanical type in the respective output circuits, means for simultaneously applying to the respective input circuits radiant-energy pulses during alternate half cycles only of an alternating current reference voltage to insure unipolarity of the rectified amplified pulses throughout said range of selected repetition rates, and means for operating said synchronous rectifier means to produce switching operations at a predetermined time in the cycle of said reference voltage.

5. A system according to claim 4 wherein said synchronous rectifier means is of the mechanical double reed vibrator type, one reed being disposed respectively in each of said output circuits and both of said reeds simultaneously producing the switching operations to avoid phase shift effects.

6. A system according to claim 4 wherein said means for applying to said input circuit radiant-energy pulses during alternate half cycles only of an alternating current reference voltage comprises a half-wave rectifier in series with said source of radiant energy.

7. A system according to claim 4 wherein said means for applying to said input circuit radiant-energy pulses during alternate half cycles only of an alternating current reference voltage comprises a rotary light shutter.

8. In combination, a spectrometer having a source of radiant energy operable over a range of selected repetition rates and a phototube responsive to a selected band of the spectrum of said radiant energy for producing radiant-energy pulses at a selected repetition rate, an amplifier having an input circuit including said phototube and an output circuit in which there appears an output signal including amplified pulses corresponding with those applied to said input circuit, said amplifier including compensating means for making substantially uniform the output signal level between groups of said pulses, a synchronous rectifier in said output circuit, means for applying to said input circuit radiant-energy pulses during alternate half cycles only of an alternating-current reference voltage to insure unipolarity of the selected amplified pulses throughout said range of selected repetition rates, and means including said reference voltage for operating said synchronous rectifier to produce its switching operations during the time said output signal level is maintained substantially uniform in avoidance of production of spurious output signals due to small shifts in phase in operation of said rectifier.

9. A system of measuring the relative intensities of two selected spectral bands produced over a range of selected repetition rates comprising phototubes respectively viewing said spectral bands, a D. C. ratio recorder for comparing the output of one phototube relative to the other, a pair of A. C. amplifiers, one disposed between each phototube and said ratio recorder and each amplifier having an input circuit for application thereto of groups of pulses at a selected repetition rate and an output circuit in which there appears an output signal including amplified pulses corresponding with those applied to said input circuit, each said amplifier including compensating means for making substantially uniform the output signal level between groups of said pulses, synchronous rectifier means of the mechanical type in each said output circuit, means for simultaneously applying to each said input circuit radiant-energy pulses during alternate half cycles only of an alternating-current reference voltage to insure unipolarity of the rectified amplified pulses throughout said range of selected repetition rates, and means for operating said synchronous rectifier means to produce switching operations during the time said output signal level is maintained substantially uniform in avoidance of production of spurious output signals due to small shifts in phase in operation of said rectifier.

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