

- [54] ADJUSTABLE TIME CONSTANT
OPERATING CIRCUIT
- [76] Inventor: **Bernard Katz**, 33 Phillip Pl.,
Irvington, N.J. 07111
- [22] Filed: **Feb. 23, 1972**
- [21] Appl. No.: **228,636**
- [52] U.S. Cl. **328/127, 307/229, 328/128**
- [51] Int. Cl. **G06g 7/18**
- [58] Field of Search **307/229, 230, 340;**
328/127, 128; 235/197, 183; 333/19

[56] **References Cited**

UNITED STATES PATENTS			
3,258,699	6/1966	Harenberg, Jr.	328/127
3,274,552	9/1966	Harmon et al.	328/127
3,549,903	12/1970	Lowdenslager	328/127 X
3,646,393	2/1972	Tarr	328/127
3,675,137	7/1972	Raphael	328/127
3,701,059	10/1972	Nyswander	307/240 X

OTHER PUBLICATIONS

Korn & Korn Electronic Analog Computers 2nd Ed.
McGraw Hill, page 13.
Electronic Analog Computers, (D.C. Analog Comput-
ers) by Korn & Korn, McGraw Hill page 415, 1956.

Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—B. P. Davis

[57] **ABSTRACT**

Apparatus for adjusting the time constant of an oper-
ating circuit including an operational amplifier is dis-
closed in accordance with the teachings of the present
invention wherein switch means are provided to peri-
odically interrupt the resistive feedback path of a dif-
ferentiating circuit or the resistive input path of an in-
tegrating circuit. The time constant of the operating
circuit is dependent upon the duration of each peri-
odic interruption.

6 Claims, 3 Drawing Figures

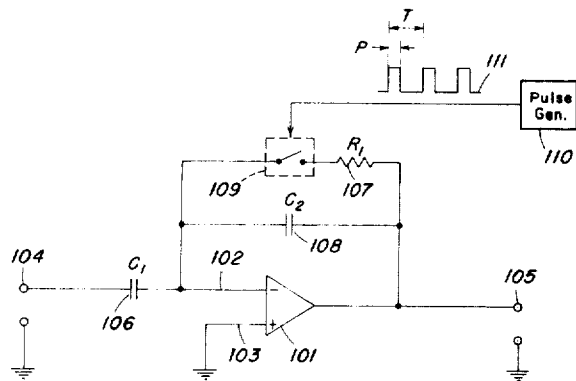


Fig. 1.

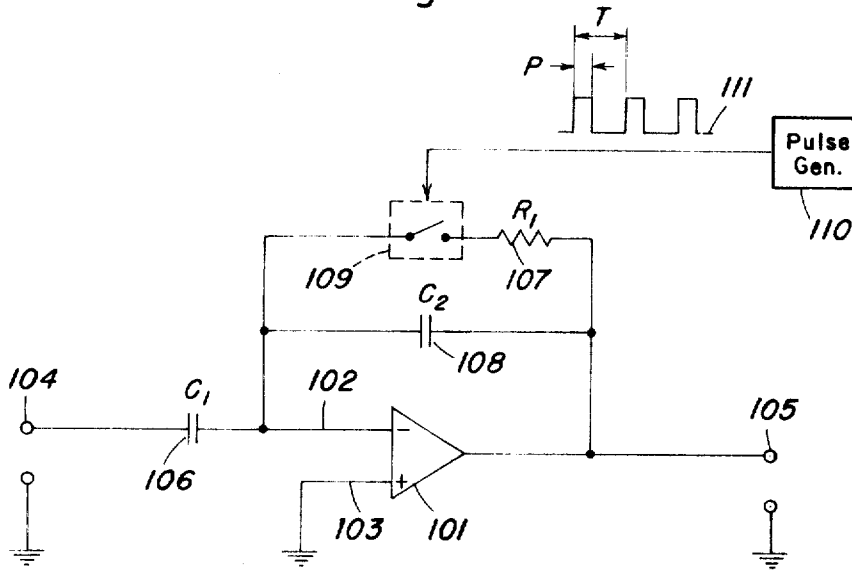
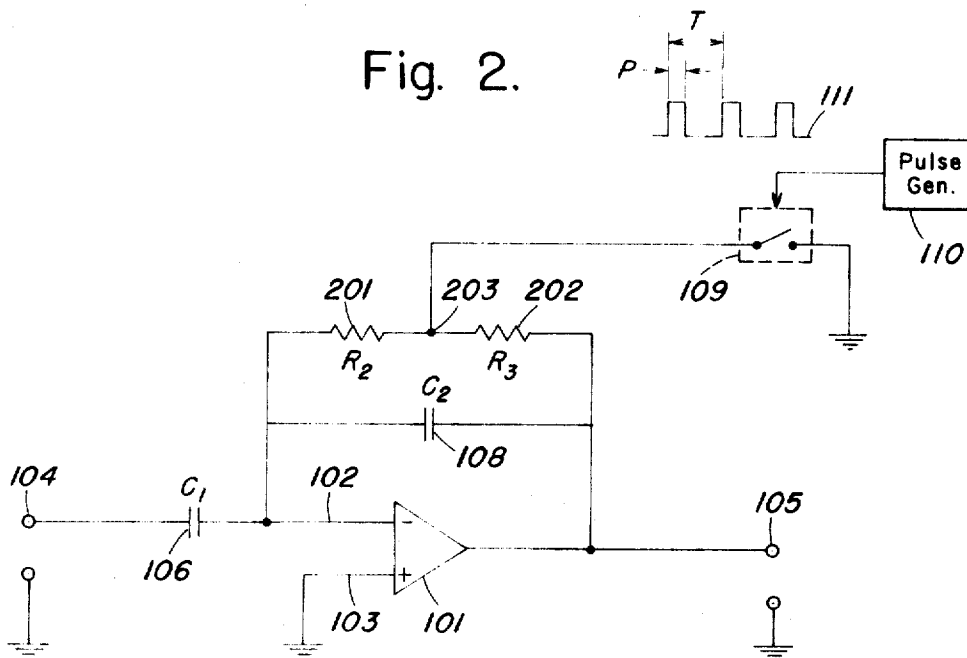


Fig. 2.



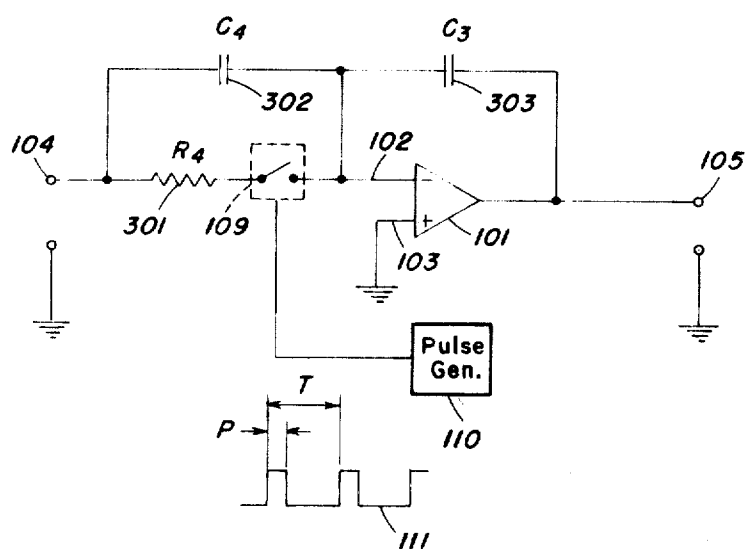


Fig. 3.

ADJUSTABLE TIME CONSTANT OPERATING CIRCUIT

This invention relates to operating circuits employing operational amplifying means and, more particularly, to apparatus for adjusting the time constant of an operational amplifier differentiating circuit and an operational amplifier integrating circuit.

A conventional resistance-capacitance circuit exhibits, in one configuration, differentiating properties which may be advantageously utilized to provide an output signal proportional to the derivative of an input signal applied thereto. In a second configuration, the resistance-capacitance circuit provides integrating properties whereby an output signal is proportional to the integral of the input signal. As is understood, the respective time constants of these circuits is equal to the product of the resistance and the capacitance thereof. The time constant is determinative of the proportional relationship between the input and output signals. Unfortunately, the simple resistance-capacitance circuits exhibit desirable differentiating or integrating properties only under certain limiting conditions.

The operational amplifier, however, with its attendant high gain and high input impedance admits of a practical differentiating or integrating circuit. Accordingly, the output signal produced by a differentiating circuit comprised of an operational amplifier including an input capacitance means and a feedback resistance means is proportional to the derivative of the input signal applied thereto. The proportionality constant or gain of this differentiating circuit is equal to the time constant thereof, i.e., the product of the feedback resistance and the input capacitance. The foregoing is equally applicable to an integrating circuit comprised of an operational amplifier having an input resistance means and a feedback capacitance means. It is desirable in some applications of the operational amplifier differentiating or integrating circuit to vary the time constant and, correspondingly, the gain of the circuit. The techniques heretofore utilized by the prior art to vary the time constant of the differentiating circuit employ a single variable feedback resistor or alternatively, a plurality of fixed resistors each operable to be selectively connected into the feedback circuit. Similarly, the time constant of an integrating circuit has previously been varied by utilizing a single variable input resistor or a plurality of switchable input resistors. These techniques, however, are extremely susceptible to extraneous noise which has a deleterious effect on the operation of the differentiating or integrating circuit. In addition, the aforescribed techniques usually require a plurality of electrical contacts and their accompanying leakage capacitance characteristics.

Therefore, it is an object of the present invention to provide an operating circuit admitting of an adjustable time constant.

It is another object of the present invention to provide improved apparatus for adjusting the time constant of a differentiating circuit and an integrating circuit.

It is a further object of the present invention to provide apparatus for adjusting the time constant of a differentiating or integrating circuit without introducing undesirable noise signals.

Various other objectives and advantages of the invention will become clear from the following detailed description of exemplary embodiments thereof and the novel features will be particularly pointed out in connection with the appended claims.

In accordance with one embodiment of this invention, a differentiating circuit including an operational amplifier is provided wherein the time constant of said differentiating circuit is adjusted by periodically interrupting the resistive feedback channel of said circuit, such that the effective time constant of the differentiating circuit is dependent upon the duration of interruption. In another embodiment hereof, the time constant of an integrating circuit is varied by periodically interrupting the resistive input channel thereof.

The invention will be more clearly understood by reference to the following detailed description of exemplary embodiments thereof in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic drawing of a first embodiment of the differentiating circuit of the present invention;

FIG. 2 is a schematic drawing of another embodiment of the differentiating circuit of the present invention; and

FIG. 3 is a schematic drawing of the integrating circuit of the present invention.

Referring now to the drawings wherein like reference numerals are used throughout, and in particular to FIG. 1, there is illustrated a differentiating circuit comprised of operational amplifying means 101, capacitance means 106 and resistance means 107. Operational amplifying means 101 may comprise a conventional operational amplifier well known to those skilled in the art including an inverting input terminal 102, a non-inverting input terminal 103 and an output terminal 105. The operational amplifying means 101 admits of a conventional differentiating circuit configuration wherein capacitance means 106 is coupled to inverting input terminal 102 and feedback resistance means 107 provides an electrical channel from output terminal 105 to inverting input terminal 102. The non-inverting input terminal 103 of operational amplifying means 101 is preferably coupled to a reference potential such as ground potential.

It is understood by those skilled in the art that the capacitive input of the operational amplifier differentiating circuit provides undesirable susceptibility to random noise. Accordingly, the noise responsive characteristics of the circuit illustrated in FIG. 1 may be greatly improved by providing a further resistance means in series with input capacitance means 106. Alternatively, filter capacitance means 108 may be connected in parallel relationship with feedback resistance means 107. Those skilled in the art will recognize filter capacitance means 108 as a conventional high frequency "stop."

The conventional differentiating circuit of FIG. 1 is modified by the addition of switch means 109 connected in series relationship with feedback resistance means 107 and adapted to assume a first or second state. Hence, switch means 109 may comprise the armature of a conventional relay circuit. If desired, the switch means 109 may comprise a conventional field effect transistor or a silicon controlled switching device or other switching transistor. Accordingly, the switch means 109 is adapted to assume a first state whereby feedback resistance means 107 is interconnected be-

tween output terminal 105 and input terminal 102. Conversely, the switch means 109 is adapted to assume a second state whereby the electrical channel including the feedback resistance means 107 is interrupted. Pulse generating means 110 is coupled to switch means 109 and is adapted to provide a periodic pulse signal thereto for controlling the state assumed by switch means 109. If switch means 109 comprises a relay circuit, pulse generating means 110 may be connected to the energizing coil thereof; and if switch means 109 comprises a switching transistor pulse generating means 110 may be connected to the control electrode thereof. The frequency of the applied pulses should be high with respect to the frequency of an input signal applied to input terminal 104. In addition, pulse generator means 110 may include means to vary the time duration of each periodically generated pulse for a purpose soon to become apparent.

The operation of the apparatus illustrated in FIG. 1 will now be described. For purposes of explanation, it will initially be assumed that switch means 109 admits of its first state and activating pulses are not supplied thereto by pulse generating means 110. Thus, if the reactive impedance of filter capacitance means 108 exceeds both the reactive impedance of capacitance means 106 and the resistance of feedback resistance means 107 then the output signal produced at terminal 105 in response to an input signal provided at terminal 104 may be represented as $E_{out} = -R_1 C_1 (dE_{in}/dt)$ where R_1 is equal to the resistance of feedback resistance means 107, C_1 is equal to the capacitance of input capacitance means 106 and E_{in} represents the voltage of the signal supplied to terminal 104. This equation is manifested for all frequencies below the "stop" frequency, i.e., until the reactive impedance X_{C2} of filter capacitance means 108 is equal to the resistance R_1 of feedback resistance means 107.

At frequencies above the "stop" frequency, the reactive impedance X_{C2} of filter capacitance means 108 becomes less than the resistance R_1 of feedback resistance means 107. A relation between any frequency above the "stop" frequency and the "stop" frequency itself may be shown to be:

$$f/f_{stop} = (1/X_{C2})/(1/X_{C2stop}) = X_{C2stop}/X_{C2} = R_1/X_{C2}$$

It may thus be observed that at very high frequencies, the effect, of feedback resistance means 107 is negligible in comparison to the effect of the filter capacitance means 108.

If, now, pulse generating means 110 provides high frequency pulses admitting of a frequency that greatly exceeds the "stop" frequency (in practice, the "stop" frequency may be, say, 10 Hz and the pulse frequency may be 5,000 Hz) and having a period equal to T and a pulse duration equal to P , then feedback resistance means 107 is provided in the feedback circuit for a time P during each period T . Since the resistance R_1 of feedback resistance means 107 is much greater than the reactive impedance X_{C2} of filter capacitance means 108 at the pulse frequency of 5,000 Hz, it is apparent that the output signal produced at terminal 105 will exhibit an insignificant high frequency ripple component. In fact, the ripple component is a function of the ratio between the "stop" frequency and the pulse frequency, or $10/5,000 = 0.2$ percent. However, it should be intuitively appreciated that the alternate insertion and removal of feedback resistance means 107 by the opera-

tion of switch means 109 results in a time averaged multiplying effect on the resistance R_1 of the feedback resistance means. Consequently, if the signal provided at terminal 104 admits of a frequency below the "stop" frequency, the effective value of R_1 may be expressed as $(T/P) R_1$. The output signal produced at terminal 105 in response to an input signal provided at terminal 104 may be represented as $E_{out} = T/P R_1 C_1 dE_{in}/dt$. Thus, it is seen that switch means 109 is operable to adjust the time constant of the differentiating circuit illustrated in FIG. 1 by the factor T/P .

Another embodiment of the present invention is illustrated in FIG. 2 which comprises operational amplifier 101, input capacitance means 106, feedback resistance means 201 and 202, and switch means 109. Feedback resistance means 201 and 202 are connected in series relationship forming a common junction 203 therebetween. Hence, a feedback resistance circuit comprised of feedback resistance means 201 connected in series with feedback resistance means 202 is provided. The common junction 203 is selectively coupled to a reference potential such as, for example, ground potential, by switch means 109. The switch means 109 is operably coupled to pulse generating means 110 and, therefore, is identical to the switch means aforescribed with respect to FIG. 1. It is observed that the configuration illustrated in FIG. 2 is similar to the configuration in FIG. 1 wherein the feedback resistance means 107 of the latter has been replaced by series connected feedback resistance means 201 and 202.

The operation of the embodiment illustrated in FIG. 2 will now be described. When switch means 109 assumes its first state the common junction 203 is provided with reference potential such as ground. Whereas pulse generating means 110 provides activating pulses 111 for switch means 109 resistance means 201 is effectively coupled between input terminal 102 and input terminal 103 which is also provided with ground, and resistance means 202 is effectively coupled between output terminal 105 and input terminal 103 during each activating pulse interval P . Conversely, resistance means 201 and 202 provide a feedback resistance circuit during each interval $T-P$. Accordingly, when switch means 109 assumes its second state, the current from terminal 104 to input terminal 102 is substantially equal to the current from output terminal 105 to input terminal 102 because input terminal 102 will not conduct current to the operational amplifier 101, and

$$C_1 dE_{in}/dt = 1/(R_2 + R_3) \cdot E_{out}(T-P)/T.$$

Solving this equation for the output voltage E_{out} ,

$$E_{out} = -T/(T-P) (R_2 + R_3) C_1 dE_{in}/dt$$

where R_2 and R_3 represent the resistance of resistance means 201 and 202 respectively. Since the switch means 109 assumes its first and second states at the frequency of the pulses 111, it is apparent that the feedback resistance means comprised of series connected feedback resistance means 201 and 202 is alternatively inserted and removed from the feedback circuit in a manner analogous to that previously described with respect to FIG. 1. Accordingly, the operation of switch means 109 results in a time averaged multiplying effect on the resistance $R_2 + R_3$ of the series connected feedback resistance means. It is apparent that in the previously described embodiment, the multiplying factor was a function of the pulse duration P . However, in the

presently described embodiment the multiplying factor is a function of the "guard" time $T-P$. Consequently, the output voltage E_{out} may be represented by the aforementioned equation:

$$E_{out} = -T/(T-P) (R_2 + R_3) C_1 dE_{in}/dt.$$

It is now readily apparent that the effective time constant of the differentiating circuit illustrated in FIG. 2 is adjusted by the factor $T/(T-P)$.

It should be understood by those skilled in the art that the pulses 111 supplied to switch means 109 are adapted to selectively activate the switch means whereby said switch means assumes its first or second state in accordance with the sense of pulses 111. Consequently, pulse generating means 110 may be specifically designed to produce positive or negative activating pulses. It will be recognized, therefore, that switch means 109 may respond to an applied activating pulse to assume its second state. In addition, pulse generating means 110 may include further means to vary the duty cycle P of the pulses 111 generated thereby such that the effective time constant of the differentiating circuit may be correspondingly varied.

Referring now to FIG. 3, there is illustrated an integrating circuit having a variable time constant comprised of operational amplifying means 101, input resistance means 301 and feedback capacitance means 303. The operational amplifying means 101 has been described hereinabove. Accordingly, further description thereof is not deemed necessary. Input resistance means 301 is coupled via series connected switch means 109 to inverting input terminal 102 of operational amplifying means 101. Feedback capacitance means 303 interconnects the output terminal 105 and inverting input terminal 102. An additional capacitance means 302 is optionally connected in parallel relationship with the series connection of input resistance means 301 and switch means 109 and may be omitted if desired. Switch means 109 is identical to the afore-described switch means of FIG. 1. Accordingly, the switch means is coupled to pulse generating means 110, the latter being adapted to supply a periodic pulse signal having a period T and a pulse duration P .

It is recognized that the integrating circuit of FIG. 3 may be analyzed in accordance with principles of superposition. Thus, when switch means 109 assumes its second state, the input resistance channel to inverting input terminal 102 is interrupted. Consequently, the illustrated circuit functions as an inverting amplifier having a gain equal to $-C_3/C_4$, where C_3 is the capacitance of feedback capacitance means 303 and C_4 is the capacitance of additional capacitance means 302. It should be appreciated that, if $C_3 = C_4$, the resulting inverting amplifier comprises a unity gain amplifier. However, when switch means 109 assumes its first state, input resistance means 301 is connected to inverting input terminal 102. If the reactive impedance X_{C4} of additional capacitance means 302 exceeds the resistance R_4 of input resistance means 301, then the output signal produced at terminal 105 in response to an input signal E_{in} provided at terminal 104 may be represented as $E_{out} = -1/R_4 C_3 \int E_{in} dt$. This equation obtains for all frequencies until the reactive impedance X_{C4} of additional capacitance means 302 is equal to the resistance R_4 of input resistance means 301. It may now be appreciated that the alternate insertion and removal of input resistance means 301 by the operation of

switch means 109 results in a time averaged multiplying effect on the resistance R_4 of the input resistance means. The output signal produced at terminal 105 in response to an input signal provided at terminal 104 may thus be represented as $E_{out} = -T/P R_4 C_3 \int E_{in} dt$. Hence, switch means 109 is operable to adjust the time constant of the illustrated integrating circuit by the factor T/P .

Although not illustrated herein, it should be readily appreciated that the input resistance means coupled to operational amplifying means 101 may assume a configuration analogous to that displayed by the feedback resistance means of the differentiating circuit of FIG. 2. Analysis of the integrating circuit modified in this manner is similar to the analysis set forth hereinabove with respect to FIG. 2 and need not here be provided.

While this invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be obvious to those skilled in the art that the foregoing and various other changes and modifications in form and details may be made without departing from the spirit and scope of the invention. It is therefore intended that the appended claims be interpreted as including all such changes and modifications.

What is claimed is:

1. In a differentiating circuit including the combination of an operational amplifier exhibiting relatively high input impedance and gain characteristics, an input capacitance means providing an input channel to an input terminal of said operational amplifier and feedback resistance means providing an electrical channel between an output terminal of said operational amplifier and said input terminal thereof, apparatus for adjusting the time constant of said differentiating circuit, comprising:

switch means coupled to said feedback resistance means and adapted to selectively interrupt said electrical channel upon the activation of said switch means, said feedback resistance means including first and second resistance means connected in series relationship and said switch means including a switching device connected to the junction formed by said first and second series connected resistance means, said switching device being operative to interrupt said electrical channel for a portion P of each periodic interval of time T such that said effective time constant of said differentiating circuit is adjusted by the factor $T/T-P$; and

energizing means coupled to said switch means for providing an activating signal to activate said switch means at periodic intervals of time, whereby the effective time constant of said differentiating circuit is dependent upon said periodic intervals, said energizing means generating a periodic signal having a duration P and a period equal to T .

2. The combination of claim 1 wherein said switching device is adapted to supply a reference potential to said junction during said portion P of each periodic interval of time T .

3. In a differentiating circuit including the combination of an operational amplifier exhibiting relatively high input impedance and gain characteristics, an input capacitance means providing an input channel to an input terminal of said operational amplifier and feed-

back resistance means providing an electrical channel between an output terminal of said operational amplifier and said input terminal thereof, apparatus for adjusting the time constant of said differentiating circuit, comprising:

switch means coupled to said feedback resistance means and adapted to selectively interrupt said electrical channel upon the activation of said switch means; and

energizing means coupled to said switch means for providing an activating signal to activate said switch means at periodic intervals of time, whereby the effective time constant of said differentiating circuit is dependent upon said periodic intervals, said energizing means including pulse generating means for providing a periodic pulse signal characterized by a duration P and a period T .

4. In a differentiating circuit including the combination of an operational amplifier exhibiting relatively high input impedance and gain characteristics, an input capacitance means providing an input channel to an input terminal of said operational amplifier and feedback resistance means providing an electrical channel between an output terminal of said operational amplifier and said input terminal thereof, apparatus for adjusting the time constant of said differentiating circuit, comprising:

switch means coupled to said feedback resistance means and adapted to selectively interrupt said electrical channel upon the activation of said switch means;

filter means coupled to said feedback resistance means; and

energizing means coupled to said switch means for providing an activating signal to activate said

switch means at periodic intervals of time, whereby the effective time constant of said differentiating circuit is dependent upon said periodic intervals.

5. In an integrating circuit including the combination of an operational amplifier exhibiting relatively high input impedance and gain characteristics, input resistance means providing an input channel from an input means to said integrating circuit to an input terminal of said operational amplifier, and feedback capacitance means interconnecting an output terminal of said operational amplifier with said input terminal thereof, the improvement in apparatus for adjusting the time constant of said integrating circuit comprising:

switch means connected to said input resistance means for selectively interrupting said input channel upon an activation thereof;

capacitor means connected between said input means and said input terminal of said operational amplifier to thereby reside in parallel with said interconnected resistance and switch means; and

means for applying an energizing signal to said switch means to activate said switch means at periodic intervals of time, said integrating circuit manifesting an effective time constant which is a function of said periodic intervals.

6. The combination of claim 5 wherein said switch means comprises a switching device connected in series relationship with said input resistance means and said means for applying an energizing signal generating pulses having a duration of P and a period equal to T , said switching device being operative to interrupt said input channel for a portion $T-P$ of each periodic interval of time T such that said effective time constant of said integrating circuit is adjusted by the factor T/P .

* * * * *

40

45

50

55

60

65