Frequency-Sensitive Switching Circuit

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A frequency-sensitive switching circuit is described which automatically selects between two ranges of an otherwise conventional frequency meter by switching the leak resistor of the integrating circuit. The basis of the unit is a diode pump integrator operated as a nonlinear device to obtain maximum sensitivity. The sensitivity is such that the "on-off" backlash of the switching relay corresponds to less than 1% of the switching frequency.

I. INTRODUCTION

For investigation of atmospheric potential gradients by a radiosonde method,1,2 a frequency meter with automatic range selection was required for accurate telemetering of the sonde signals. In its present application the frequency-sensitive switching circuit selects between two ranges, 0 to 500 cps and 0 to 5000 cps, of an otherwise conventional frequency meter. The range selection is achieved by switching the leak resistor in the integrating network of the frequency meter.

The basis of both the switching circuit and the frequency meter is the diode pump integrator.4 This integrator provides a most convenient way of obtaining an average dc potential from a train of voltage pulses. With certain limitations (normally applied) this potential is approximately a linear function of frequency, enabling the integrator to be used as a frequency meter,5 random counting rate meter,6 or as a device for the demodulation of frequency modulated radio waves.7 However, the utility of the circuit is not limited entirely to linear applications and it is the nonlinear characteristic which is utilized in the switching circuit.

II. DIODE PUMP INTEGRATOR

Figure 1 shows the circuit of the integrator and it is assumed that each incoming pulse is a rectangular pulse as depicted. The amplitude \( E \) and the duration \( T \) of these pulses are standardized.

\[
v = \frac{nC_2R_2}{1+nC_1R_2} \quad (1)
\]

Normally,8,9 the circuit is operated with \( v \ll E \), so that a linear relationship exists where

\[
v = EnC_1R_2. \quad (2)
\]

In both cases the peak to peak ripple voltage is

\[
(E - v)C_1/C_2. \quad (3)
\]

The nonlinear relationship between \( v \) and \( n \), formed by Eq. (1) is shown graphically in Fig. 2. As the values of \( C_2 \) and \( R_2 \) can be chosen arbitrarily a family of curves can be drawn with the product \( R_4C_1 \) as parameter.

\[
2. K. Kreilheimer, Australian J. Sci. 9, 95 (1946).
7. Seeley, Kimball, and Barco, RCA Rev. 6, 269 (1942).
Maximum sensitivity at a specified switching frequency corresponds to a maximum voltage change per cycle at that frequency. As the components $C_1$ and $R_2$ occur in product form in Eq. (1) they can be replaced by $\tau$ where $\tau = R_C C_1$. Hence Eq. (1) becomes

$$v = \frac{E}{1 + n\tau} \text{ (4)}$$

The value of $\tau$ which makes $\partial v/\partial n$ a maximum for a given value of $n$, say $n_0$, is required and since $\partial v/\partial n = g(\tau)$ this maximum will occur when

$$\partial v/\partial \tau|_{n=n_0} = 0. \text{ (5)}$$

Equation (5) is satisfied by the solution

$$\tau = 1/n_0. \text{ (6)}$$

Therefore the maximum value of $\partial v/\partial n$ for a specified frequency is $E/4n_0$ and this maximum exists when the equilibrium voltage $v$ is equal to half the incoming pulse amplitude.

### III. RANGE SWITCHING CIRCUIT

Figure 3 shows a block diagram of the switching circuit designed for use as a range selector in an otherwise conventional frequency meter. The switching circuit consists of a diode pump integrator whose amplified output controls a Schmitt trigger$^{10}$ in which the actual switching relay is incorporated.

With 70-v pulses from the pulse shaping network the maximum value of $\partial v/\partial n$ obtainable when $n_0 = 500$ cps is $70/(4\times500)$ v/cy, so that for a frequency change of 3 cps the integrator output variation is approximately 0.1 v. Because this change is too small to operate a Schmitt trigger directly a dc amplifier (gain factor 60) is connected between the integrator and the trigger.

The trigger design is such that the relay is "on" whenever the input to $V_2$ (Fig. 4) falls below 100 v and "off" when the input rises above 106 v. Backlash in the trigger is essential to prevent hunting and this value of 6 v, corresponding to a 3-cps change of input frequency, i.e., to a variation of less than 1% of the switching frequency, is the minimum that can be employed for satisfactory operation.


The diode pump integrator is connected to the negative supply line at $P$ where the potential of $P$ is such that, with the addition of 35 v across $C_2$ ($E/2$ at 500 cps), the dc amplifier $V_1$ is biased to amplify in its linear region. The anode voltage of $V_1$ can be adjusted, by the potentiometer in the bias line, so that with an input of 500 cps the trigger "fires." A resistor $R_2$, between $V_1$ anode and $V_2$ grid ensures that when $V_1$ is cut off the grid current in $V_2$ is not excessive. Manual control of the trigger can be achieved by the selector switch at $V_2$ grid. The three positions are (1) on, (2) automatic, (3) off.

In the nonlinear integrator itself the value of $C_1$ is determined by the loading on the pulse shaping network and $R_2$ is then determined by Eq. (6) and the switching frequency (500 cps). With $C_2 = 100 C_1$ the ripple voltage is 0.35 v at $Z$ (see Eq. (3)] and 21 v after amplification; so that it is more than three times the backlash of the trigger. To decrease the ripple by increasing $C_2$ means increasing the response time $R C C_2$ by the same factor. However, as the ripple frequency is 500 cps its magnitude can be reduced to 0.6 v at the input to the trigger by $C_3$ connected between $V_2$ grid and earth. The presence of this capacitor introduces another time-constant $R C C_3$ (0.01 sec) but this is negligible compared with $R C C_2$ (0.2 sec).

Once the conditions $C_3 >> C_1$ and $R_2 C_2 >> 1/n_0$ have been satisfied the actual value of $C_2$ is determined by a compromise between the ripple that can be tolerated and the transient response required. In the application for which the present switching circuit was designed the transient response is such that for any suddenly impressed frequency between 0 and 5000 cps the needle on the frequency meter never "hits the stop" while still on the 0 to 500 cps range.

If the time constants of the linear integrator and recording meter are $t_1$ and $t_2$ respectively, this means that $R C < (t_1^2 + t_2^2)$ thus specifying an upper limit for $C_2$. 

FIG. 3. Block diagram of the frequency meter incorporating the frequency-sensitive switch as a range selector.

![Block diagram](image)

FIG. 4. Practical circuit of frequency-sensitive switch (values for switching frequency of 500 cps).
Any drift in the dc amplifier output causes a variation of the switching point. In the present application the actual switching point is not too critical. However after an initial warming up period the drift is less than 5 cps at any time during a 5-hr interval. For more critical conditions the amplifier can be compensated by any of the usual methods for eliminating drift.11

Further applications of the frequency-sensitive switch are contemplated, one of them using a series of switching circuits set at different frequencies to produce an automatic multirange counting rate meter for particle counting.

IV. ACKNOWLEDGMENTS

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Slide Rule for Radiographic Analysis

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A simple slide rule has been developed which will permit a rapid and accurate determination of radiographic sample transmission, of absorption index, \( \mu \), and of the photographic film density corresponding to the direct x-ray beam by means of a single setting of the sliding scale.

In this laboratory, as in many others where micro-radiographic techniques are employed, a considerable amount of time is often required for the determination of film densities, \( D_{\text{direct beam}} \) and \( D_{\text{sample}} \); of sample transmissions, \( t \); and of the absorption index, \( \mu \), as calculated from the microphotometer readings on the radiogram, \( T_{\text{background}} \), \( T_{\text{sample}} \), and \( T_{\text{direct beam}} \). With the usual assumptions that the reciprocity law holds and that the film densities are proportional to exposure for the given density range, the mathematical relationships which are involved in these calculations can be written as follows:

\[
\frac{D_s}{D_d} = \frac{I_s}{I_d} = e^{-\mu m} = t \quad (1)
\]

in which \( I \) and \( I_d \) are incident and transmitted x-ray intensities, respectively, and in which, by definition,

\[
D_s = \log_{10}(T_b/T_s) \quad \text{and} \quad D_d = \log_{10}(T_b/T_d). \quad (2)
\]

Combining these equations, one obtains

\[
t = \frac{\log_{10}T_b - \log_{10}T_s}{\log_{10}T_b - \log_{10}T_d} = e^{-\mu m}. \quad (3)
\]

In these equations \( \mu \) is the mass absorption coefficient and \( m \) is the mass per unit area of the sample.

A slide rule has been designed that permits an easy and rapid determination of the values of \( \mu m \), \( t \), and \( D_d \) by means of a single setting of a sliding scale which is constrained to translate only along its length or perpendicular to this direction over a two-dimensional, stationary scale. A photograph of the instrument is shown in Fig. 1. It has been mounted on a standard two-by-three-foot drafting board of the type which has a straight-edge that is constrained by a string-and-pulley system to remain parallel to the bottom edge of the board.

The design of the scales is illustrated in Fig. 2. The transparent sliding scale \( b \), on which the photometer readings are entered, is logarithmic to base 10. Consequently, the length \( XY \) is proportional to \( D_s \) since

\[
D_s = \log_{10}T_b - \log_{10}T_s
\]

and similarly, the length \( XZ \) is proportional to \( D_d \) since

\[
D_d = \log_{10}T_b - \log_{10}T_d.
\]

Scale \( c \) is linear and is of range 0 to 1. Hence, by projecting the lengths \( XY \) and \( XZ \) onto scale \( c \), as shown in Fig. 2, the ratio \( (XY/XZ) \) is read directly and, by Eq. (3), is equal to the sample transmission, \( t \).

Scale \( a \) is constructed alongside scale \( c \) in such a manner as to give the value of the absorption index, \( \mu m \), that corresponds to the particular value of sample transmission, \( t \), as read directly above on scale \( c \). Hence, scale lengths measured left-to-right on scale \( a \) must be proportional to the value, \( \exp(-\mu m) \), which is equal to \( t \) as defined in Eq. (3).

The lines which project the lengths \( XY \) and \( XZ \) onto scale \( a \) emanate from a point, \( 0' \), directly below zero.