

Half-wave Quasi-root-mean-square Rectifier

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The rectifying characteristics of the half-wave quasi-rms rectifier, which has the feature between those of the peak detector and the average detector, have been investigated. The approximation to the true rms value for the different input waveforms depends on the ratio of the values of two resistors in the circuit, and curves showing this dependence are obtained. This investigation has been made to substantiate the basis for the quasi-rms rectifying circuit with a wide dynamic range.

Introduction

Among complaints on the various sources of environmental pollutions, the largest percentage is caused by the sound noise. The minimum constituents for the sound level meter employed in the sound measurements, are made of a microphone, a step-attenuator, a weighting network, an amplifier, a rectifier, and an indicating meter. Also, there are international and national standards for the sound level meters. In the following, the characteristics of the half-wave approximate root-mean-square rectifier are discussed considering the requirements imposed by the standards.

Approximate root-mean-square (quasi-rms) rectifier circuits

The sound signal which is received by the microphone and amplified through the amplifier is an alternating current or voltage consisting of many frequency components with fluctuating magnitude. For the indication of such intensity, the root-mean-square (rms) value or effective value is preferable for the most of the cases, but a device with thermal principle usually employed for this indication has slow response and is not suitable for the rapidly fluctuat-

ing signal. Also, the moving-iron type meter and the electrodynamic type meter employed in the power line circuit are not adaptable for the sound frequencies. In most of the sound level meters, the full-wave approximate rms (quasi-rms) rectifier circuit, as shown in Fig. 1, is commonly employed. But with this circuit, the working dynamic range is limited to under 20 dB because of the diminishing rectifying sensitivity, at lower levels of signals, of the semiconductor

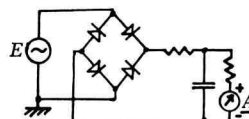


Fig. 1. Full-wave quasi-rms rectifier.

diodes. The fluctuations of levels of the environmental sound are much greater than 20 dB, and the frequent change-overs of step-attenuator are required in the actual measurements. To eliminate this inconvenience, an investigation has been made to develop a quasi-rms rectifier which has a dynamic range of 60 dB or more. However, in such a rectifier, the full-wave circuit as shown in Fig. 1 can not be adopted because of the requirement for grounding one side of each rectifier, and therefore the half-

wave type circuit must be employed to meet the above requirement.

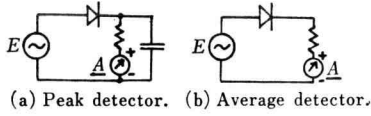


Fig. 2. Half-wave rectifiers.

The half-wave rectifier circuits shown in Fig. 2 (a) and Fig. 2 (b) are what are called a peak detector and an average detector respectively, and the dc outputs from these rectifiers do not indicate the rms values of input voltages with different waveforms. The circuit of Fig. 3 (a) is a half-wave quasi-rms rectifier and has a characteristic between those of the peak and average detec-

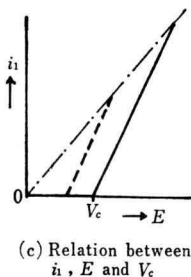
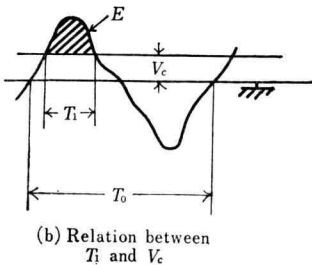
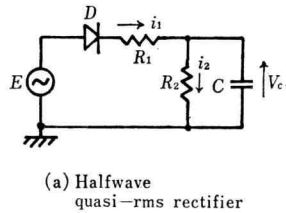


Fig. 3. Half-wave quasi-rms rectifier.

tors. In the following, the approximation to the true rms values of the input voltage by utilizing the dc output, i.e., the condenser terminal voltage V_c , is investigated.

In the circuit of Fig. 3 (a), the current i_1 through R_1 flows only when the input voltage E is greater than the condenser terminal voltage V_c which is assumed to be kept constant because of the large time constant with respect to the period of the input waveform, the current i_2 through R_2 is always flowing under the same assumption and since the total charge by i_1 is equal to the total discharge by i_2 , we may obtain equation (1) assuming ideal rectification by the diode, thus:

$$\int_{T_1} \frac{E - V_c}{R_1} dt = \frac{V_c}{R_2} T_0 \quad (1)$$

In equation (1), the left hand side integration is made only for the duration T_1 when E is greater than V_c and T_0 is the period of the waveform as indicated in Fig. 3 (b). Fig. 3 (c) shows the relation between i_1 , E and V_c . For a different size of the input voltage, the value of V_c shifts accordingly as shown by the dotted line in the figure, but the equation (1) always holds.

For a definite waveform, if a value of V_c is assumed, the duration T_1 for $E > V_c$ can be determined as shown in Fig. 3 (b), and then the integration of the left side of equation (1) can be carried out. Rewriting equation (1), we have

$$\frac{R_1}{R_2} = \frac{\int_{T_1} (E - V_c) dt}{V_c T_0} \quad (2)$$

From equation (2), the ratio R_1/R_2 to produce the assumed V_c for the given waveform is determined.

In the case of sinusoidal waveform, E can be represented as $E_m \cos t$ if the period of

the wave is taken to be 2π , and the duration T_1 becomes θ_1 , as shown in Fig. 4. In this figure, the relation between V_c and θ_1 , is expressed by the following equation.

$$V_c = E_m \cos \frac{\theta_1}{2} \quad (3)$$

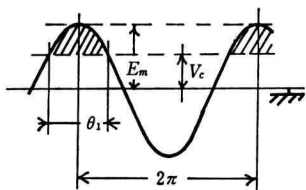


Fig. 4. V_c and θ_1 for sinusoidal wave.

After the integration of equation (2), and taking into account of equation (3), and considering the fact that the rms value E_{rms} is equal to $E_m/\sqrt{2}$ in this case, the relation between R_1/R_2 and V_c/E_{rms} can be obtained as follows,

$$\frac{R_1}{R_2} = \frac{\tan\left(\cos^{-1} \frac{V_c}{\sqrt{2} E_{rms}}\right) - \cos^{-1} \frac{V_c}{\sqrt{2} E_{rms}}}{\pi} \quad (4)$$

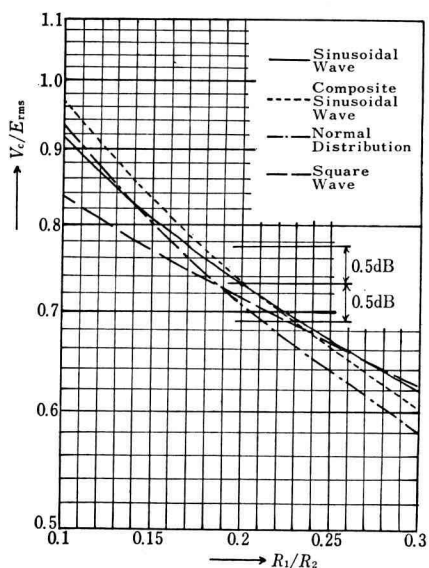


Fig. 5 (a). Calculated relations between V_c/E_{rms} and R_1/R_2 , (1).

which is plotted in Fig. 5 (a). In the similar manner, the corresponding relations for square, triangular and tone burst waveforms have been calculated and shown in Figs. 5 (a) and 5 (b). In the latter waveform, N stands for the ratio between the period and the duration of tone as shown in Fig. 5 (b).

When the input voltage has the random waveform, but its probability distribution of magnitude is known, the relation between V_c/E_{rms} and R_1/R_2 can be calculated by means of the table of probability functions. The result for the case of normal distribution is plotted in Fig. 5 (a).

In the recommendation by the International Electrotechnical Commission (IEC) for the sound level meter, there is an article about the indication which states that the composite signal made of two sinusoidal signals which produce equal readings on the indicating meter but with different frequencies of non-harmonic relation, must give a reading 3 dB greater than that caused by each sinusoidal signal. This statement cor-

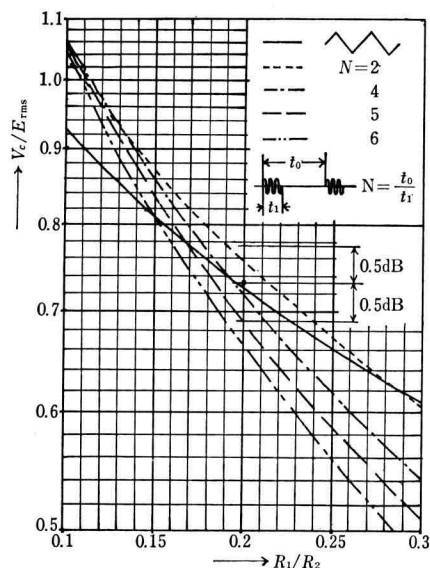


Fig. 5 (b). Calculated relations between V_c/E_{rms} and R_1/R_2 , (2).

responds to the rms indication of the sound level meter. The above composite signal is expressed as equation (5),

$$\begin{aligned} E &= E_m \cos 2\pi f_1 t + E_m \cos 2\pi f_2 t \\ &= 2E_m \cos \pi (f_1 + f_2) \cos \pi (f_1 - f_2), \end{aligned} \quad (5)$$

where E_m is the magnitude of each component and f_1 and f_2 are frequencies. The waveform of this signal is shown in Fig. 6 for the case of $f_2 = 0.8f_1$.

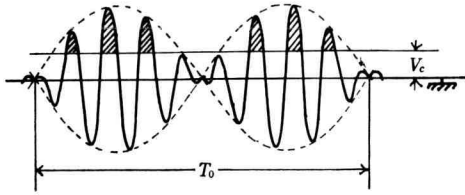


Fig. 6. Waveform of composite sinusoidal wave.

When the input voltage has this waveform, following relation must hold in the quasi-rms rectifier circuit.

$$\begin{aligned} &\frac{\text{Sum of the shaded area in Fig. 5}}{R_1} \\ &= \frac{V_c}{R_2} T_0, \end{aligned} \quad (6)$$

where

$$T_0 = \frac{2}{f_1 - f_2}$$

The calculations of the shaded area for different values of V_c have been carried out by the OKI 4300-type computer installed at Ikutoku Technical College and, since E_{rms} for the composite wave is equal to E_m in equation (5), the relation between V_c/E_{rms} and R_1/R_2 has been obtained. This relation is plotted on Fig. 5 (a) and it is known from the position of the crossing of this line and the line for sinusoidal signal, that the value of 0.2 for the ratio R_1/R_2 satisfies the re-

quirements for the composite signal in the IEC recommendation. In Figs. 5 (a) and 5 (b), it is seen that the deviations from the correct rms values for other waveforms are less than ± 0.5 dB except for the case of tone burst wave with $N > 5$ in the quasi-rms rectifier when R_1 is set to $0.2 R_2$.

The measured relations of V_c/E_{rms} and R_1/R_2 are shown in Fig. 7. Because of the forward barrier voltage drop and the non-linear forward resistance of the rectifying diode, there are some differences between the calculated and the measured values, but it is seen that the range of deviations among different waveforms are similar in the both cases.

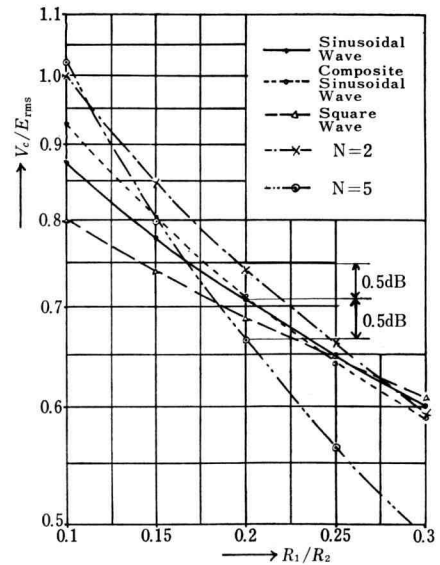


Fig. 7. Measured relations between V_c/E_{rms} and R_1/R_2 .

From the above calculations and measurements, it can be justified in saying that the half-wave quasi-rms rectifier with the ratio R_1/R_2 of 0.2 is suitable for most of the sound measurements. Also, employing two half-wave rectifiers, an equivalent full-wave

circuit can be constructed for the sound level meter.

Transient response of the Quasi-rms rectifier

When a signal input is suddenly applied to the quasi-rms rectifier of Fig. 3 (a), the condenser C is charged through R_1 . The equivalent charging time-constant is larger than the dc time-constant CR_3 , where R_3 stands for the parallel combination of R_1 and R_2 . If C is small, the charge-up time becomes fast, but the so-called rectifier ripple voltage appears on V_e when the input frequency is low. Then the assumption of the constant V_e in the previous calculations is violated.

According to the IEC recommendation on the transient behaviour of the sound level meter, test must be made with a pulse of sinusoidal signal having a frequency of 1000 Hz and a duration of 0.2 sec. For this input, the maximum reading on the meter should be 1 ± 1 dB less than the reading for a steady signal of the same frequency and amplitude.

In the measurements of actual quasi-rms

rectifier circuits, it has been found that the size of C must be smaller than $30 \mu\text{F}$ to conform to the above transient requirement, with R_1 of 2 kohms and R_2 of 10 kohms. The final determination of C should be made considering the effects from the other circuit elements and the moving part of the indicating meter, which influence the overall transient response.

Conclusions

The features of the half-wave quasi-rms rectifier have been made clear in the above investigations and it may be said that its approximation to the true rms values is sufficient for most of the sound measurements. Replacing the semiconductor diode by a rectifying circuit comprised of a MOS-type field effect transistor and an operational amplifier, and with some modifications in the circuit arrangements, a quasi-rms rectifier which has the dynamic range of 70 dB has been realized.*

* A paper about this circuit was presented at "the 1973 Electrical and Electronic Measurement and Test Instrument Conference" sponsored by IEEE in May, 1973.