Use your handheld calculator for a quick and better approximation of rectifier ripple voltage

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Abstract

You do not necessarily have to use a circuit simulator such as Spice for an acceptable estimate of the ripple voltage produced by a rectifier with a reservoir capacitor. All you need is a simple handheld calculator with an "Ans-key".

When given a simple rectifier circuit with a reservoir capacitor (figure 1), it is a standard practice to calculate the ripple voltage by linearizing the problem. The approximation thus obtained is the better as the ripple voltage gets smaller. However, the ripple voltage shouldn't be smaller than required for a given application as too small a ripple voltage would result in very high peak currents in the diode(s) of the rectifier and the preceding circuit. High peak currents may cause unnecessary difficult to cure emc-problems. In short, ripple voltages aren't always small.

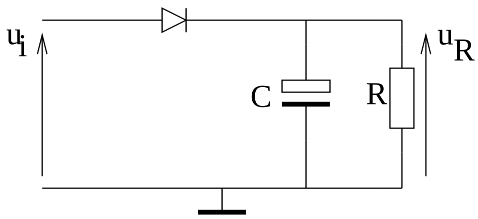

Figure 1: Linearizing

In figure 2 on the next page, a linear approximation of the voltage over C or R is shown. Notice that the discharging time is taken equal to the period of the input sine wave which is only approximately true for small ripple voltages. This drawing also might misleadingly suggest the voltage across the reservoir capacitor can change instantaneously, which of course is physical impossible. Anyway, if the amplitude of the input sine wave is $U_{I,P}$, τ the time constant RC and T the period of the input sine wave, the peak-to-peak value of the output ripple voltage given by linearizing is $U_{R,AC,PTP} = U_{I,P} \times \dfrac{T}{\tau}$.
For $\tau = 0.1\,\mathrm{s}$, T=20 ms and $U_{I,AC,P} = 20\,\mathrm{V}$ this gives $U_{R,AC,PTP} = 4\,V$.

One might think of using a circuit simulator such as Spice to check things but if you don't have a Spice-version at your desk a simple handheld calculator with an "Ans-key" such as the Casio FX-82MS is all you need.

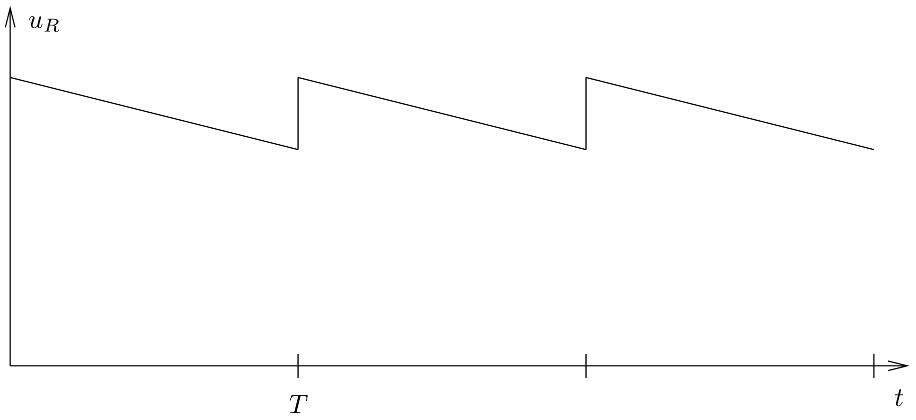

Figure 2: Linearizing

From figure 3, the following equations can be derived:

$$U_{I,P}e^{\frac{-t_1}{\tau}} = U_{I,P} - U_{R,AC,PTP} \tag{1}$$

$$U_{I,P}sin\left(\omega t_2\right) = U_{I,P} - U_{R,AC,PTP} \quad \text{or} \quad U_{R,AC,PTP} = U_{I,P}\left(1 - e^{\frac{-t_1}{\tau}}\right) \tag{2}$$

$$t_1 = t_2 + \frac{3T}{4} \tag{3}$$

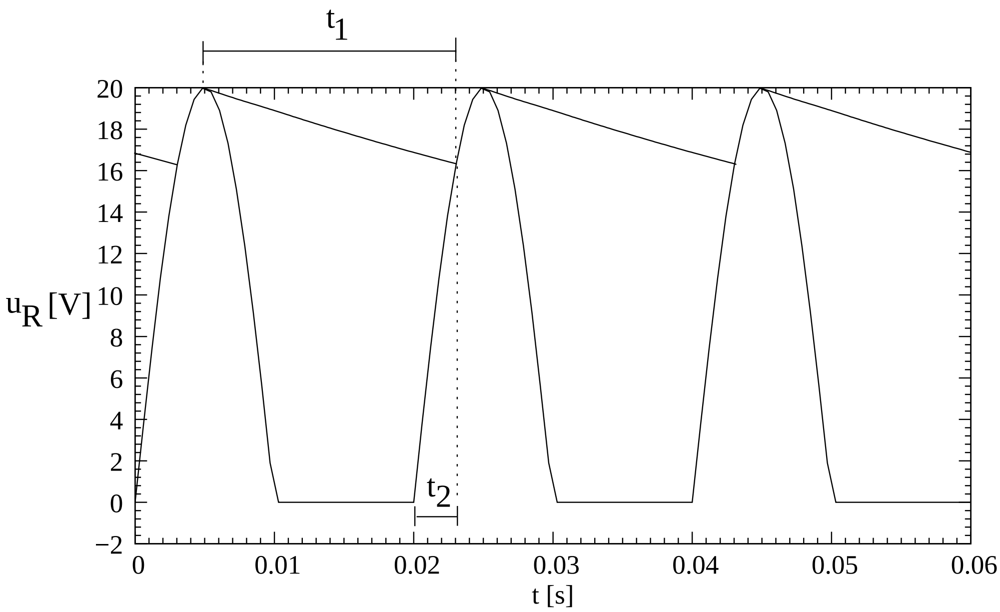

Figure 3: A better approximation

	$U_{R,AC,PTP}$ [V]		
$\tau\,[ms]$	Linear	Iterat.	Spice
100	4	3.32	3.16
50	8	5.90	5.63
25	16	9.75	9.31

Table 1: Comparison of three methods to determine $U_{R,AC,PTP}$

Rearranging equations 1, 2 and 3 gives the time t_1 the capacitor needs to discharge:

$$t_1 = \frac{3T}{4} + \frac{\operatorname{asin}\left(e^{-\dfrac{t_1}{\tau}}\right)}{\omega} \tag{4}$$

Equation 4 is easily solved iteratively by means of a handheld calculator with an "Ans-key". Be sure your calculator is in "rad-mode" and enter an initial guess for t_1, any numerical value between 15 ms en 20 ms will do e.g. 18 ms:

$$18 \quad \text{EXP} \quad (-) \quad 3 \quad =$$
$$15 \quad \text{EXP} \quad (-) \quad 3 + \sin^{-1} \quad (\text{e}^{\text{x}} \quad (\quad (-) \quad \text{Ans} \quad \div \quad 0.1) \quad) \quad \div \quad (\quad 2 \quad \times \quad \pi \quad \times \quad 50)$$

Press the "=-key" a few times until the display no longer changes digits. On my Casio I got 18.14012782 ms. Entering this value in equation 2 gives $U_{R,AC,PTP}$=3.32 V.

Just to have an idea of the accuracy of the method presented, I "spiced" a half wave rectifier with a 1N4007 for some values of τ as can be seen in table 1. This shows indeed that the method presented above is better than the linear approximation method.

Even for high values of $U_{R,AC,PTP}$ this method gives an acceptable approximation even though the time constant for charging the reservoir capacitor is not taken into account.

Notice that for a full wave rectifier with reservoir-C the only thing that changes is equation 3 i.e. $\frac{3T}{4}$ becomes $\frac{T}{4}$

As a final note: in order to determine C for a given R and a wanted value of $U_{R,AC,PTP}$ one shouldn't linearize the problem nor use the iterative method mentioned above. In this case t_2 can be determined directly from equations 1,2 and 3. The value of C is obtained easily:

$$C = -\frac{\dfrac{3T}{4} + \frac{1}{\omega}\operatorname{asin}(a)}{R \cdot \ln(a)}, \quad a = \frac{U_{I,P} - U_{R,AC,PTP}}{U_{I,P}} \tag{5}$$