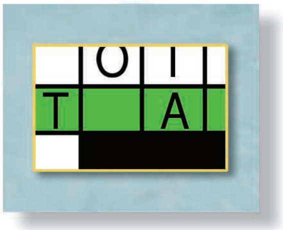

Enigmas, etc.

Turn-On Surge

■ Takashi Ohira

Last month's circuit scheme is shown again in Figure 1. Remember the sawtooth-like waveform, where a surge current flows from the charged capacitor into the transistor every time it turns on. Find how much power dissipation is caused by this surge current. Which of the following is correct? Note that f stands for the switching frequency: $f = 1/T$.

a) fVV_{dc}^2　　c) $4fCV_{dc}^2$

b) $2fCV_{dc}^2$　　d) $8fCV_{dc}^2$

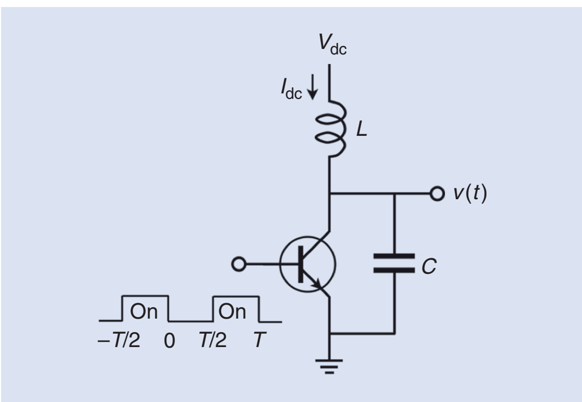

Figure 1. *A switching transistor circuit scheme.*

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Digital Object Identifier 10.1109/MMM.2020.3035933
Date of current version: 11 January 2021

Solution to the January 2021 Puzzle

When voltage V_{dc} is applied to the circuit, the choke coil L conducts current I_{dc}, which charges capacitor C at a constant rate. This makes the output voltage a linearly increasing function of time as

$$v(t) = \frac{1}{C}\int_0^t I_{dc}\,dt = \frac{I_{dc}}{C}t. \quad (1)$$

From this calculation, we notice that C is indispensable to this circuit. If C were removed, $v(t)$ would steeply rise and possibly destroy the transistor when it turns off at $t = 0$.

The choke coil exhibits zero-ohm dc resistance; therefore, the average $v(t)$ for one cycle balances with the dc supply voltage V_{DC}; that is,

$$V_{dc} = \frac{1}{T}\int_0^{\frac{T}{2}} v(t)\,dt = \frac{I_{dc}}{TC}\left[\frac{1}{2}t^2\right]_0^{\frac{T}{2}} = \frac{TI_{dc}}{8C}. \quad (2)$$

Note that the integral is truncated halfway because $v(t)$ vanishes right after the transistor turns on at $t = T/2$. From (2), we can quickly find

$$I_{dc} = \frac{8CV_{dc}}{T}. \quad (3)$$

Figure 2. *The output voltage waveform in the time domain.*

This signifies the dc voltage–current relation of the switching circuit. Reflecting this relation to (1), the output voltage is determined as

$$v(t) = \frac{8V_{\mathrm{dc}}}{T}t \tag{4}$$

during the OFF state $0 < t < T/2$.

Equation (4) indicates that the voltage starts from zero at $t = 0$, linearly increases with t, and reaches its peak,

$$v(T/2) = \frac{8V_{\mathrm{dc}}}{T}\frac{T}{2} = 4V_{\mathrm{dc}}, \tag{5}$$

at $t = T/2$. The voltage is kept at zero during the ON state because the capacitor C is held short-circuited by the transistor. This ON/OFF cycle is periodically repeated in every interval T, as shown in Figure 2. In conclusion, the output voltage waveform resembles a sawtooth. The correct answer to last month's quiz is c).

As the switch-mode operation can achieve an extremely high dc–RF power conversion efficiency, we could exploit this mode in power amplifiers for radio and wireless systems.

As the switch-mode operation can achieve an extremely high dc–RF power conversion efficiency, we could exploit this mode in power amplifiers for radio and wireless systems. However, if we employ the circuit as it is, the described sawtooth-like waveform will cause two serious problems: heavy power loss and strong multiple harmonics (both due to the steep voltage drop down at the turn-on moment). We will explore a viable solution to these problems in forthcoming puzzles.