Enigmas, etc.

Sinusoidal Wave Output

■ Takashi Ohira

To create a power amplifier with a sinusoidal wave output, a series inductor–capacitor resonator is added to the sawtooth wave generator described in last month's "Enigmas, etc." column (see Figure 1). The resonator enables only the fundamental harmonic wave to flow. Hence, we can write the output current waveform as

$$i(t) = I_P \sin \omega t + I_Q \cos \omega t, \quad (1)$$

where ω denotes the switching angular frequency and $\omega = 2\pi / T$. Coefficients I_P and I_Q represent the sinusoidal in-phase and quadrature components.

The resonator functions not only as a filter but also as a reactor. By carefully adjusting the reactance, we can nullify the transistor's collector voltage at the time of turning it on and thus avoid an undesired surge current and switching power loss. This is called the *zero-voltage-switching* (*ZVS*) condition [1]–[5]. When the reactance is adjusted to meet the ZVS condition, we observe a specific dc-to-RF current proportion. Now, given the dc input current I_{dc}, find the specific I_P among the following candidates:

$$a)\ \pi I_{dc} \quad b)\ \frac{\pi}{2} I_{dc} \quad c)\ \frac{\pi}{3} I_{dc} \quad d)\ \frac{\pi}{4} I_{dc}.$$

Solution to Last Month's "Enigmas, etc." Challenge

Recall the sawtooth-like voltage waveform. Focusing on the time interval $0 < t < T/2$, the shunt capacitor's voltage increases linearly as

$$v(t) = \frac{8V_{dc}}{T} t. \quad (1)$$

According to this voltage, the energy

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

is accumulated in the shunt capacitor. This is consistent with the law of energy conservation because the final right-hand side of (2) refers to the dc energy supplied

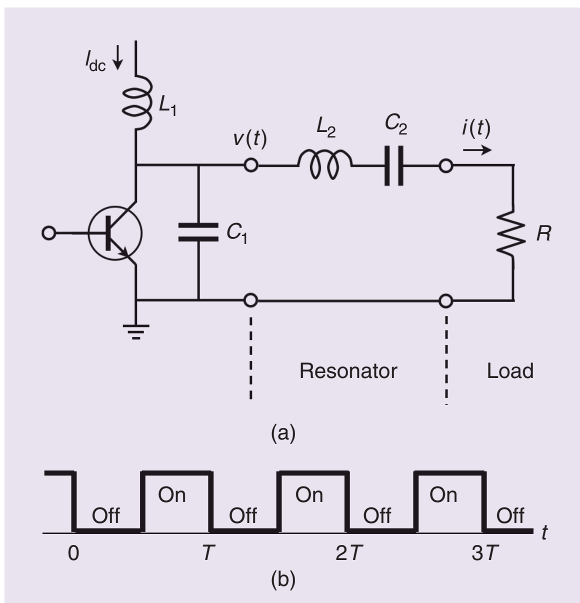

Figure 1. *The switch-mode power amplifier that outputs a sinusoidal wave. (a) The circuit scheme. (b) The base input signal.*

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to the circuit for a period T. In other words, there is no dissipation of power inside the circuit, at least before the transistor turns on. We then recall the dc voltage-to-current relation

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

from last month's solution. Substituting (3) into (2), we obtain

$$U = 8CV_{dc}^2. \quad (4)$$

When the transistor turns on, power dissipation takes place abruptly. The stored energy U instantaneously disappears at the moment when the shunt capacitor is short-circuited by the transistor. This event periodically repeats f times per second, where f stands for the transistor's switching frequency: $f = 1/T$. Therefore, the power dissipation P in question counts

$$P = fU = 8fCV_{dc}^2. \quad (5)$$

We thus conclude that the correct answer to last month's quiz is "d."

The preceding dissipated power P is called *turn-on loss* or *switching loss*, which is undesirable for system applications because it causes excess heat generation and power efficiency degradation. A question may then arise as to whether we can really utilize such a problematic topology for practical RF power amplifiers. The answer is yes if we can convert the energy stored in the shunt capacitor into a sinusoidal wave and effectively redirect it to the output port. A clever idea of how to do that will appear in the next "Enigmas, etc." problem.

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Microwave Bytes *(continued from page 15)*

time was spent performing extensive "fine tuning" on the cascades of balanced modules. The amount of tuning time was something of a closely guarded issue, albeit much discussed internally. Quite apart from the economics of the process, there were tricky documentation issues as well; every unit was strictly speaking a "special" inasmuch as the tuning pad (and/or silver paint) placements were not the same every time; "discretionary wiring," as I once heard a salesman euphemistically describe the process! But it posed some technical questions as well. Most notably, I remember being puzzled as to why we frequently appeared to be doing asymmetrical tuning inside the couplers; surely this would upset the balanced behavior, we frequently asked. Well, the balanced modules did not always have a great VSWR over octave, or even greater bandwidths, and as such would be unbalanced by the imperfect termination looking into the next balanced stage. So I think the asymmetrical tuning was beneficial in restoring, to some extent, this effect.

It's nice to explain some of life's mysteries, albeit 30 years late. Talking of which, I should quote from Kurakawa's seminal paper [4], now 55 years old, concerning the subject: The requirements on the terminations which are connected to the couplers to absorb the transistor reflections are not stringent: VSWR's less than 1.4 should be acceptable. Just a bit optimistic, I would say.

References

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