SINGLE-ENDED SWITCHING-MODE TUNED AMPLIFIERS

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Summary

Voltage and current waveforms cannot be specified independently and no configuration of linear circuit elements can provide both continuous current and continuous voltage waveforms while obtaining an output power. At least one of the waveforms must contain an abrupt step.

Switching-mode tuned power amplifiers are ideally 100 percent efficient. One of these types, the class-E amplifier, in addition reduces switching losses by eliminating the voltage-current product at one switching transition. The class-E amplifier was suggested by N. O. Sokal and A. D. Sokal [1] and analyzed by F. H. Raab [2].

The Sokals originally suggested a nearly rectangular set of waveforms as "ideal" with respect to both power-output capability and minimum switching loss. Several class-E like amplifiers are known [3], [4] but each of them has at least one abrupt jump in the voltage or current waveform.

The considerations presented here have been carried out on tuned power amplifiers but they are valid for high-efficiency tuned power oscillators, too [5].

A new power-equation of a loss free switch

An ideal switch means that it has zero "on" resistance, infinite "off" resistance and zero switching times between the "on" and "off" states. In practice, the switch is almost without loss and its resistance may be absorbed into the network connected to the switch.

The switch operates cyclically at the output frequency, at a chosen duty ratio determined by the driver. The new general power-equation is:

$$\sum_{k=1}^{\infty} k^2 P_k = \frac{T}{8\pi^2} S\Delta$$

where:

P_k is the real power of the harmonics at the switch,
Δ is the jump of current or voltage at the switching instant,
S is the slope of voltage or current at the same time.

When there is a jump at both transitions of the switch, the $S\Delta$ terms must be summed.

This equation is generally valid, and does not depend on the network connected to the switch. The derivation of the equation is too long to be presented here, it was published earlier [6].

Applications

1. General Class-E amplifier with perfect harmonic suppression.
Stipulations:

The output matching network is linear and free of loss and there is no rear harmonic power.

Since no power is generated at harmonic frequencies and there is no loss,

$$P_1 = -P_{out}$$
$$P_2 = 0$$
$$P_3 = 0 \ldots$$

The negative sign of P_{out} indicates the power supply of the amplifier circuit.

Using the general power-equation:

$$P_{out} = -\frac{T}{8\pi^2} S\Delta$$

2. In the Sokals' Class-E amplifier:

$$\Delta = -0.6988 I_{max}$$

$$S = 11.08 \frac{V_{max}}{T}$$

Therefore

$$P_{out} = -\frac{T}{8\pi^2} S\Delta = 0.0981 V_{max} I_{max}$$

in agreement with previously published results.

3. In Raab's Class-F amplifier:

$$\Delta_1 = -\Delta_2 = -V_{max}$$

$$S_1 = -S_2 = 2\pi \frac{I_{max}}{T}$$

Therefore

$$P_{out} = -\frac{T}{8\pi^2}(S_1\Delta_1 + S_2\Delta_2) = \frac{1}{2\pi} V_{max} I_{max}$$

is in perfect agreement with the result published.

References

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