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Technical Correspondence

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ON SOLID-STATE PA MATCHING NETWORKS

☐ I would like to pass along some observations I've made which are of interest to builders of solid-state Class C hf transmitters.[1] I have found that the use of such matching networks as the commonly recommended L and T,[2] as well as any other network with an inductor or series LC as the input element,[3] will inevitably result in improper circuit operation. The circuit will exhibit poor collector efficiency, spurious output, or a high transistor failure rate, unless one of these conditions is met: (1) the output transistor is very rugged (in which case it won't fail, but the other conditions will remain); (2) the transistor output capacitance is 100 pF or higher; (3) a Zener diode is connected across the transistor (more about this later); or (4) the network is modified in a manner I will describe.

Let's see what causes the problem. Although there is an optimum resistive impedance for a transistor to "see" (approximately $V_{CC}^2/2P_O$),[4] the transistor does not present this or any other impedance. Rather, it acts much as a simple on-off switch. At the instant the transistor is turned off, current flowing through the rf choke is dumped into the circuit elements. The dominant circuit presented to this current is parallel resonant, with L being the network input inductor and C the transistor output capacitance, C_O. C_O is in parallel with stray circuit capacitance. This circuit "rings" at its resonant frequency, which is not necessarily related to the operating frequency.

Fig. 1 shows the schematic of a typical 40-meter, 2-watt-output amplifier. Fig. 2A is a photo of the oscilloscope waveform at the collector of Q1. The presence of 70-volt, 50-MHz ringing at the collector may be readily seen. I was able to obtain this picture only because the particular transistor was exceptionally rugged — several devices were destroyed in the attempt. Although this condition could be detected with a wavemeter coupled loosely to the collector circuit, it can only be observed with the aid of a wide-bandwidth scope. The instrument used to obtain these photos has a 250-MHz bandwidth.

A photo of the waveform at the load is shown in Fig. 2B. Distortion may be reduced by filtering, but — assuming the transistor is not destroyed — collector efficiency will be less than optimum. Typical efficiency will be on the order of 40 to 60 percent, rather than the 70 to 80 percent obtained from a well-designed amplifier stage.

An advanced circuit-analysis computer program was used to investigate the circuit of Fig. 1, assuming perfect inductors, capacitors, source, load and a good model of the 2N3866 transistor. The graphical results of this analysis are shown in Fig. 3. Because of the use of perfect components, frequency and amplitude of the simulated waveform vary slightly from the real waveforms shown in Fig. 2. The striking similarity to Fig. 2 and the presence of ringing in the simulation verify that the phenomenon is *not* a spurious oscillation in the usual sense, nor is it due to stray capacitance or inductance or poor circuit layout. *It is inherent in the use of this type of network!*

A capacitor connected from the collector to ground or, preferably, from collector to emitter, will solve the problem if it approximately resonates with the input inductor at the operating frequency. The capacitor will reduce collector-voltage swing to less than 30 volts with a 12-volt supply. The effect on the Q of common networks will be negligible and only slight readjustment of the variable capacitor(s) will restore the correct match.

A Zener diode connected across the collector will sometimes solve the problem, but not because of Zener action! A typical 33-volt, 1-watt Zener diode has a capacitance of 200 to 800 pF, depending on the amount of reverse bias. This is generally sufficient to prevent the ring in the first place.

This letter has been necessarily brief but I hope it will enable the reader to take advantage of these matching networks without wondering — as I did for a long time — why sometimes they work and sometimes they don't. — *Roy W. Lewallen, W7EL, 5470 S.W. 152 Ave., Beaverton, OR 97005*

Fig. 1 — Schematic diagram of the 7-MHz Class C amplifier used to examine the oscillation problem.

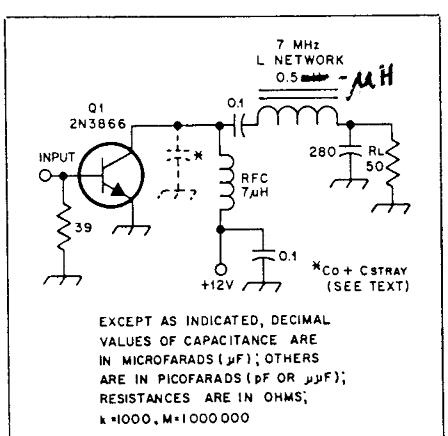
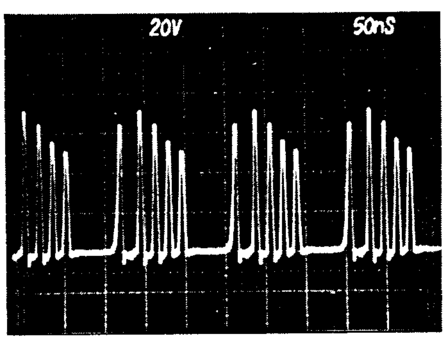
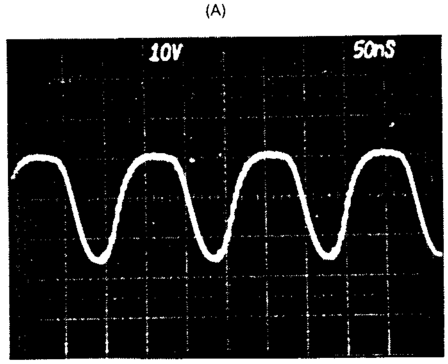


Fig. 2 — Photos of the actual waveforms obtained with the amplifier. Operation was observed with a high-speed oscilloscope. At A, collector waveform; at B, waveform at the output.



(A)



(B)

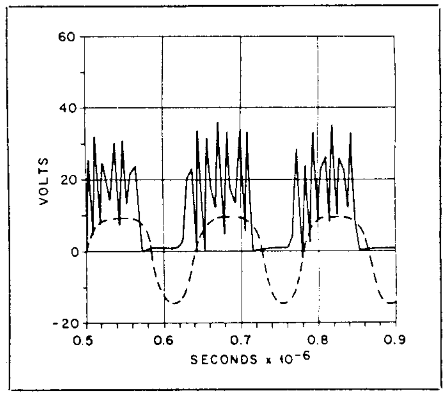


Fig. 3 — When the circuit of Fig. 1 was analyzed on a computer, the waveforms shown were predicted. The solid line indicates how the computer expected the waveform at the collector to look. Expected output waveform is shown by the dotted line.

Footnotes

[1] Strictly speaking, the Class C amplifiers used by amateurs may be better described as Class D, as they are typically driven to saturation. In fact, this is the reason for the problem described here. However, such operation does allow high collector efficiency. For a more detailed discussion of this topic, see Sokal and Sokal, "Class E — A New Class of High-Efficiency Tuned Single-Ended Switching Power Amplifiers," *IEEE Journal of Solid-State Circuits*, Vol. SC-10, No. 3, June, 1975.

[2] Hayward and DeMaw, *Solid State Design for the Radio Amateur*, ARRL, 1977, pp. 52-53.

[3] *The Radio Amateur's Handbook*, 54th Edition, 1977, ARRL, p. 161.

[4] Hayward and DeMaw, p. 24.