The Fallacy of the Class-E and the Class-F Amplifier

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Abstract - We show that Class-E and Class-F waveforms cannot be realized by a bipolar junction transistor or by a field effect transistor. The fallacies in previous analyses are presented.

1. Introduction

RF power amplifiers are commonly analyzed by considering their output circuits without regards to the physics of the field effect transistor (FET) or the bipolar junction transistor (BJT) that is utilized. As a result, waveforms have been derived, which cannot be realized by an FET or BJT. Inspection of the transistor curves of the FET or BJT indicate that when the drain or collector voltage is zero the drain or collector current is zero since the curves all start at the origin. The class-F waveforms shown in Fig.1 and the Class-E waveforms shown in Fig. 2 have current flowing for half of the cycle while the voltage is zero and thus cannot be realized by an FET or a BJT.

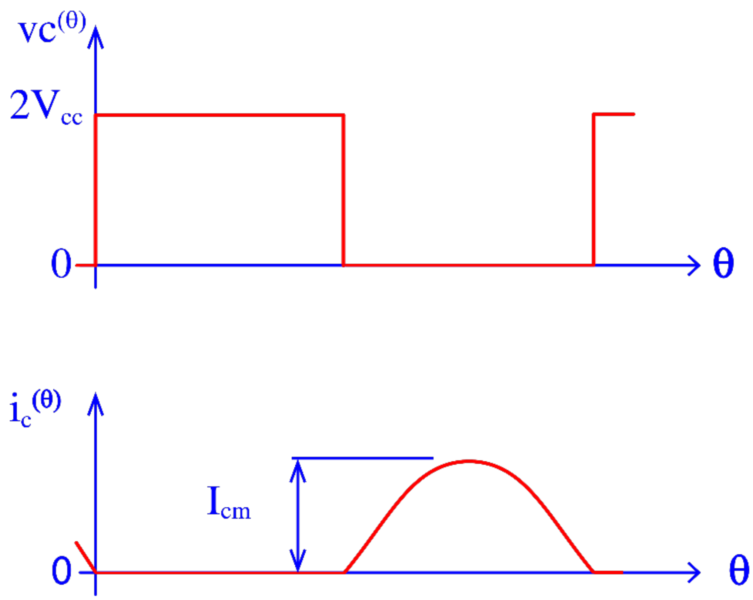

Fig 1. Class F Waveform

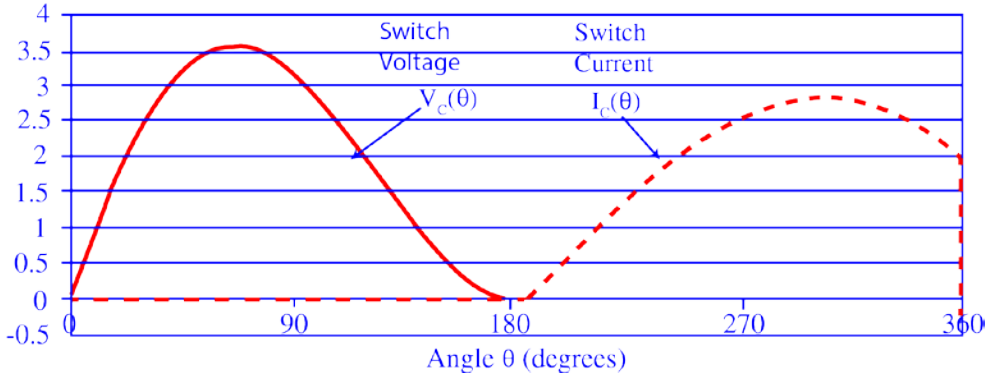

Fig. 2. Class-E Switch Waveforms

2. The Fallacies

In a 1967 paper Snyder [1] claimed that the Class-F waveforms shown in Fig. 1 could be realized using a Bipolar Junction Transistor (BJT). He reasoned that by applying a sinusoidal voltage between the emitter and the base, the transistor would be cutoff for half of the cycle and assuming that the collector current is equal to the emitter current the collector current would be that shown in Fig. 1. Further, if the load impedance short circuited all of the even harmonics and presented an open circuit to all of the odd harmonics the collector voltage would be that shown in Fig. 1 and the efficiency would be 100%. This reasoning however is not correct since the base-collector diode of a BJT must be back-biased; collector current does not flow when the collector voltage is zero. The collector current cannot drive the collector voltage to zero as the transistor will saturate; as a result of the ϐ of the transistor decreasing from approximately .99 to a much smaller value. Thus the Class-F waveforms shown in Fig.1 cannot be realized by a BJT.

Sokal [2], [3] proposed the Class-E power amplifier where the BJT operates as an on/off switch. The amplifier is analyzed with a switch that when on acts as a short-circuit with zero voltage across it, or whenit is off; has zero current through it. This does not properly represent a BJT in the switching mode since when the BJT is switched on the collector voltage is not zero. Thus the current and voltage waveforms for Class-E shown in Fig. 2, are not realizable with a BJT.

The waveforms shown in Fig. 1 and Fig. 2 cannot be realized by an FET as claimed by Raab [4]. The current density in the channel of an n-type FET is given by:

$$j = qnE \qquad (1)$$

where j is the current density, q is the electronic charge, n is the electron density and E is the Electric field. When the drain voltage is zero the electric field in the channel is zero and hence the current density is zero everywhere in the channel. The drain current is therefore zero when the drain voltage is zero as should be evident from the transistor curves for the FET which all start at the origin.

Cripps [5] analyzes FET amplifiers making the assumption that "This is an ideal strongly nonlinear transconductive device, represented here as a voltage controlled current source with zero output conductance and zero turn-on (or knee) voltage." The assumption of zero turn-on voltage means that drain current can flow when the drain voltage is zero. The waveforms presented under this assumption, for Class A, Class-B, Class-AB, Class-F, Class-D and Class-E [6] all have maximum drain current flowing when the drain voltage is zero and hence cannot be realized by an FET. It should be emphasized that waveforms which have current flowing when the voltage is zero cannot be realized by a BJT or FET.

3. Conclusion

The belief that an efficiency of 100% can be realized, by properly terminating an FET, disincentivized researchers from further analysis of the FET. Effort was therefore concentrated on synthesizing the terminating impedance [3], [7], [8]. Raab claimed [9] that by terminating all of the odd harmonics in open circuits and all of the even harmonics, 100% efficiency can be realized. Raab then analyzes the effect of terminating a limited number of harmonics [10]. It should be evident that it is not possible to achieve 100% efficiency with an FET. Since the channel of an FET has a resistance which is a function of the gate voltage and therefore when current flows through the channel there must be ohmic losses. Countless numbers of articles describe amplifiers which are claimed to be Class-E or class-F amplifiers [11], [12], [13], [14]. As discussed above these amplifiers cannot produce the waveforms shown in Fig. 1 and Fig. 2.

JFET and MOSFET amplifiers have been analyzed using the equations that describe the physics of the device, for the special case where the FET is always in saturation [15],[16],[17]. The maximum output power and the efficiency at the maximum output power for these amplifiers are presented, however no general analysis of these amplifiers has been performed and the maximum efficiency of the JFET or MOSFET amplifier has not been determined.

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