The University of Electro-Communications

# Microwave Class-F InGaP/GaAs HBT Power Amplifier Considering up to 7th-Order Higher Harmonic Frequencies

***Abstract*** **-** The first realization of a class-F InGaP/GaAs HBT amplifier considering up to 7th-order higher harmonic frequencies, operating at 1.9 GHz, is described. For a class-F amplifier design in microwave frequency ranges, not only increasing the number of treated harmonic frequencies, but also decreasing quantities of intrinsic and parasitic elements in a transistor is important. Measured PAE and collector efficiency are 78.7 % and 81.2 %, respectively, at $V_{cc}$ = 4.0 V and $f_0$ = 1.91 GHz in case circuit losses are de-embedded.

## INTRODUCTION

### • Class-F operation for a high efficiency amplifier

A high-efficiency amplifier in the microwave region

Class-F amplifier

Mathematical consideration (Fourier coefficients optimization)

Maximum efficiency of class-F PAs

4~6% up !!

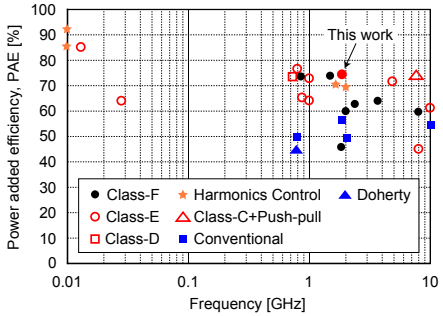
n,m : order of harmonics

Property of a transistor

| $I_m$ \ $V_n$ | n=1 | n=3 | n=5 | n=7 | n=∞ |
|---|---|---|---|---|---|
| m=1 | 50% (Class-A) | 57.7% | 60.3% | 61.6% | 63.7% |
| m=2 | 70.7% | 81.7% | 85.3% | 87.1% | 90% |
| m=4 | 75% | 86.6% | 90.5% | 92.3% | 95.5% |
| m=∞ | 78.5% (Class-B) | 90.7% | 94.8% | 96.7% | 100% (Class-F) |

F. H. Raab, IEEE Trans. MTT, vol. 49, pp. 1162-1166, June 2001.

Efficiency for various circuit constructions of amplifiers



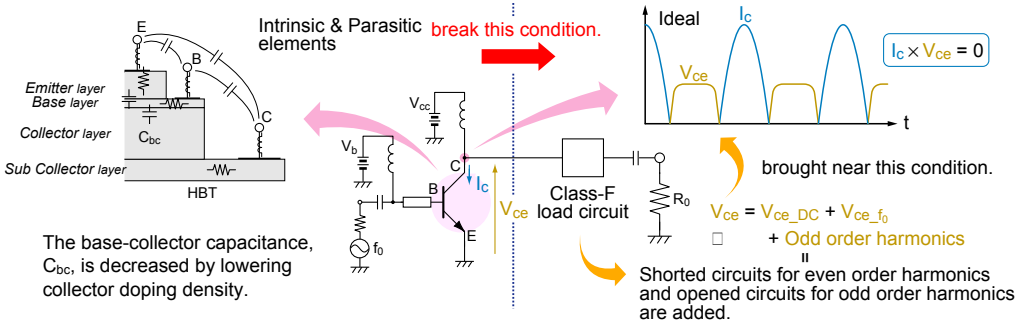

$$PAE = \frac{\text{Added RF power for output (= Output power - Input power)}}{\text{DC power supplies}}$$

$$\eta_c = \frac{\text{RF Output power}}{\text{DC power supplies}}$$

$\eta_c$ : Collector efficiency

### • Efficiency improvement

Device improvement & Circuit optimization

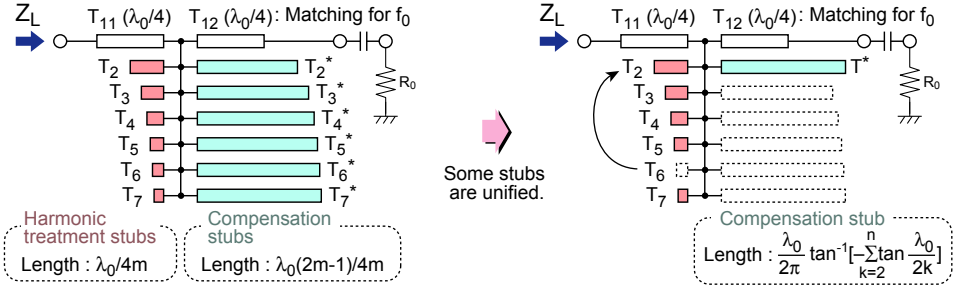



The base-collector capacitance, $C_{bc}$, is decreased by lowering collector doping density.

## CLASS-F LOAD CIRCUIT DESIGN

### • A topology of a class-F load circuit

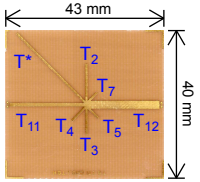
In order to obtain the voltage waveform, higher harmonic frequencies are treated to shorted or opened circuit conditions using distributed constant circuits (stubs).



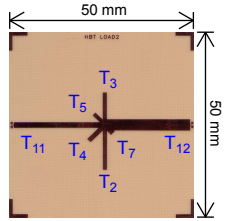

(m = 2, 3, •••, n) : Order of harmonics

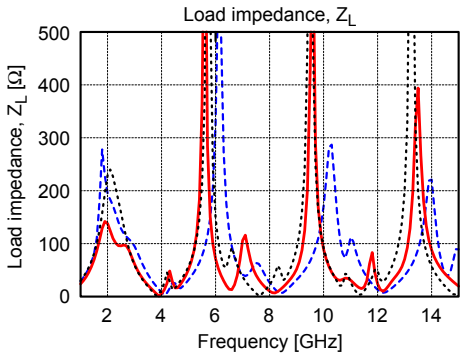
### • Characteristics of the fabricated class-F load circuits

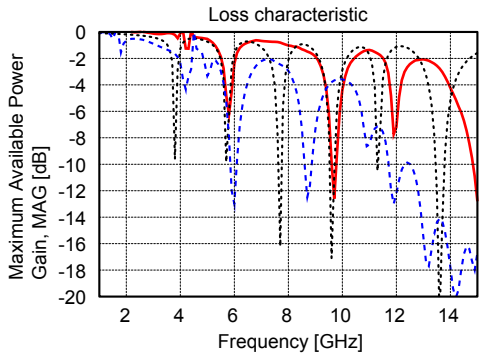
- FR4 epoxy
  - Thickness: 0.5 mm
  - $\varepsilon_r$ : 4.2
  - tanδ : 0.02
  - Metal thick. 40 μm
  - Fundamental frequency, $f_0$ 1.9 GHz




- Low-loss resin
  - Thickness: 0.6 mm
  - $\varepsilon_r$ : 3.6
  - tanδ : 0.0023
  - Metal thick. 32 μm
  - Fundamental frequency, $f_0$ 1.9 GHz




( MAG : Transmittance of a circuit adding loss-less matching circuits.)

=> Circuit losses break class-F load condition at higher harmonics.