A HIGH FREQUENCY POWER TRANSISTOR MODEL

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ABSTRACT

The development of a large-signal power transistor model applicable at radio frequencies is described. This model which has its basis in the classical large-signal models is valid for cut-off and active region operation but does not include saturation operation. The model is intended primarily for use in broadband linear radio frequency amplifier applications and is useful up to frequencies of the order of 1/15 f_T.

The model is described by two first order nonlinear differential equations and a number of algebraic equations. Equation coefficients are determined from measurements made on the devices under study. Two methods are described for the solution of the model equations. The first and principal method is an iterative one requiring computer assistance whilst the second is analytical and depends upon piecewise linearisation of the device transfer characteristic. This analytical method whilst in some respects inadequate, e.g. distortion level predictions, is easy to implement and despite its limitations affords useful insight into output power capability and frequency limitations of specific devices.

The model contains all transistor nonlinearities and parasitic elements of significance and an important feature is the inclusion of device temperature as a model variable, resulting in good accuracy over a wide range of operating conditions. A simplified input impedance representation is evolved and it is demonstrated that input impedance measurements provide a useful window on model structure and aid in the evaluation of parameter values.

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CONTENTS

LIST OF SYMBOLS

A	Current carrying cross-sectional area of transistor
a_{11}, a_{12}, a_{21}, a_{22}	Coefficients in equations (2.9) and (2.10)
b	Reciprocal of thermal voltage
C, C'	Constants
C_d	Base diffusion capacitance
C_j	Junction capacitance
C_{TE}	Emitter-base junction capacitance
C_{TC}, C_o, C	Collector-base junction capacitances
D_N	N^{th} order distortion level
D_p, D_n	Hole and electron diffusion constants
E, E_x	Electric field strength
E_g, $E_g(T)$	Energy bandgap
f_T	Transition frequency
f_β	β cut-off frequency
G_m	Large-signal fundamental frequency transconductance
g_m	Small-signal transconductance
h	Iteration interval
I_B, I_C, I_E	DC components of base, collector and emitter currents
i_B, i_C, i_E	Instantaneous values of base, collector and emitter currents
I_{ES}, I_{CS}	Junction reverse saturation currents
I_n	Electron current
I_p	Hole current

I_S	$= \alpha_F I_{ES}$
$I_0, I_1, I_2 \ldots$	Modified Bessel Functions
J_p, J_n	Hole and electron current densities
k	Boltzmann's Constant
L	Self inductance
L_p	Hole recombination length
M	Miller Avalanche Multiplication Factor
M_E	Avalanche multiplication factor in equation (6.32)
m	Junction emission factor, <u>also</u> excess phase factor
N_A, N_D	Acceptor and donor atom concentrations
N_C, N_V	Density of state constants (§ 6.2)
n, p	Electron and hole densities
n_i	Intrinsic electron density
n_{po}, p_{no} (p_o)	Electron and hole equilibrium densities
$\hat{p}$	Excess hole density
Q_B	Total base charge
q	Electron charge
R, r	Resistance
R_B, r_x	Base parasitic resistances
R_C, R_E	Collector and emitter parasitic resistances
R_L, R_{LCC}	Load resistance
S	Storance
s	Complex frequency variable
T	Absolute temperature
T_{amb}, T_o	Ambient and reference temperatures
t	Time
V	Voltage
V_A	Early Voltage

V_{BB}, V_{CC}, V_{EE}	Circuit supply voltages
V_{CBO}, V_{CEO}	Transistor breakdown voltages
V_j	Junction voltage
v	Velocity
v_B, v_C, v_{BE}	Instanteous potentials at transistor terminals and circuit nodes. A second subscript denotes the reference point if other than the circuit common rail
W, W_B	Base width
W_E	Emitter width
α_F, α_R	Forward and reverse common-base current gains
α_{F0}, α_{R0}	Low frequency common-base current gains
α_T, α_{T0}	Base transport factor
β_F, β_R	Forward and reverse common emitter current gains
γ	Emitter injection efficiency
μ_n, μ_p	Electron and hole mobilities
ρ	Resistivity
θ_{j-c}	Thermal resistance junction to case
θ_{c-a}	Thermal resistance case to air
τ_B	Base minority carrier lifetime parameter (§ 2.3.1)
τ_b	Base region transit time
τ_F, τ_{BF}	Charge control model parameters
τ_p	Hole recombination lifetime
ψ_o	Junction barrier potential
ω	Angular frequency
ω_F, ω_R	Angular half power frequencies (Ebers-Moll model)
ω_T	Angular transition frequency

NOTE: Symbols listed are those which largely are not defined in the body of the text. Insofar as possible the symbols adopted are those considered to be in most common usage in semiconductor device modelling. In certain instances it has been considered appropriate to retain symbol definitions used in particular source references even when this results in multiple usage of a particular symbol. In these cases specific definitions have been included at the appropriate points in the text.