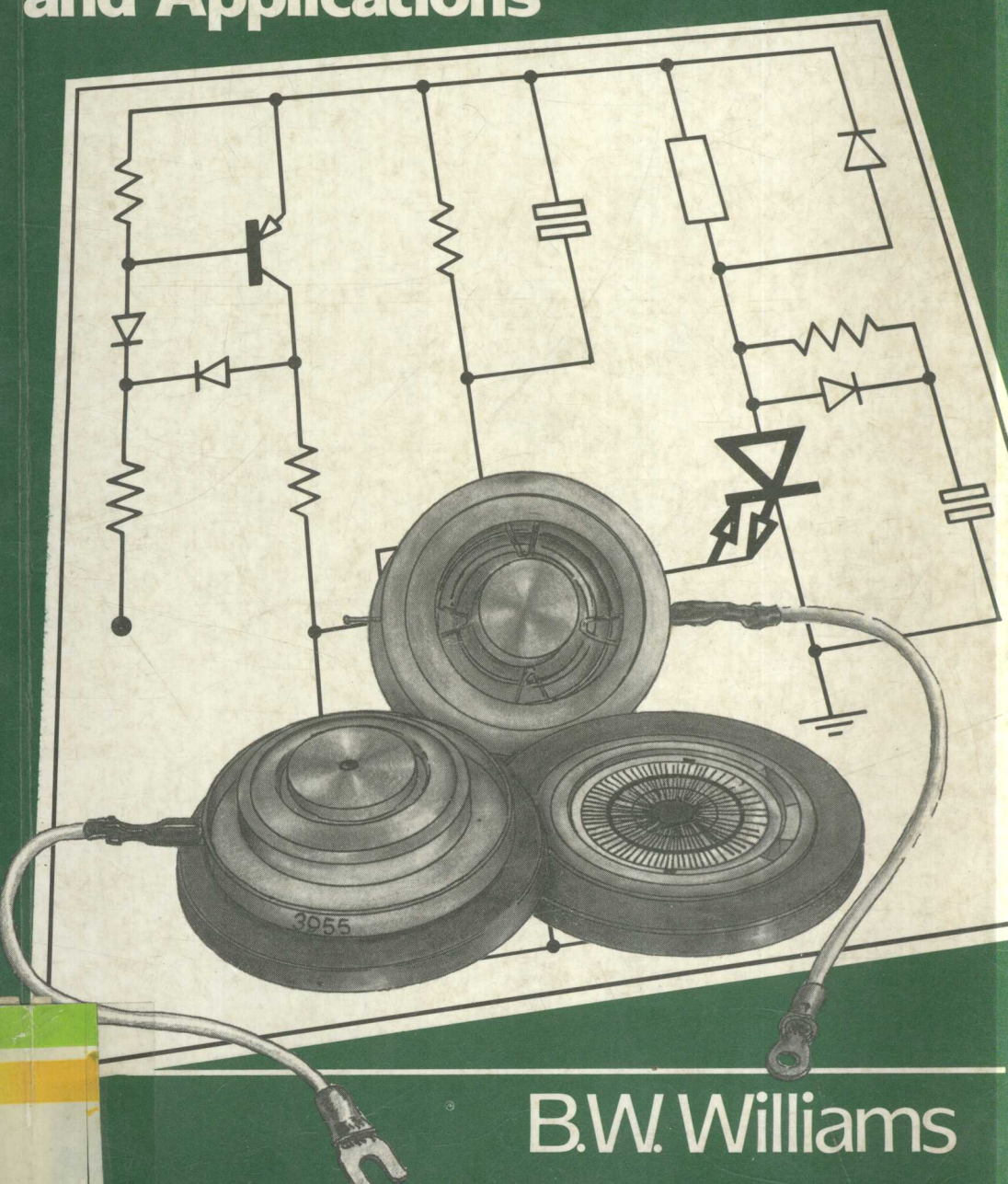


POWER ELECTRONICS

**Devices, Drivers
and Applications**



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Power Electronics

Devices, Drivers and Applications

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Preface

The objective of this book is to bridge the gap between semiconductor device theory and device application in the area of power electronics. The majority of existing books concentrate on one aspect at the expense of the other. They either analyse semiconductor physics and material aspects of devices without including any applications or, at the other end of the spectrum, they consider device applications with the device being treated as a 'black box'.

This book specifically considers high-power devices and in particular how a device's structure and construction are related to its terminal electrical and thermal characteristics. Only then, armed with an understanding of device characteristics, is it possible to select the correct device for a given application.

Emphasis is placed on the circuitry required to use power devices rather than treating them as ideal switches or considering just one device type. The structure and electrical characteristics of a device are related to its driving and protection requirements for a particular type of application.

The book is in three parts. Part 1 covers power device electrical and thermal characteristics and how they relate to a device's physical structure. Devices considered include the thyristor, gto, mosfet and bipolar transistor. Part 2 describes device driving and protection techniques and the final part gives a general selection of power electronic applications. Application areas other than those dominated by thyristors have been considered; in particular the growing area of switched-mode power supplies has been introduced.

The book gives a fundamental, yet detailed education in the art of power electronics. Since a basic knowledge of semiconductor physics and circuit techniques is assumed, it is a specialist subject book intended for university and polytechnic students, as well as for practising engineers wishing to broaden their understanding of power electronics. Non-trivial worked examples and problems have been included for the student, and each chapter has a specific reading list.

B. W. W.

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List of Symbols

| | |
|------------------|------------------------------|
| a | device tolerance |
| A | anode |
| b | base |
| b_t | base transport factor |
| B_{sat} | saturation flux density |
| c | collector |
| C | capacitance |
| C_{ds} | drain-to-source capacitance |
| C_f | heat-sink correction factor |
| C_{gd} | gate-to-drain capacitance |
| C_{gs} | gate-to-source capacitance |
| C_o | snubber transfer capacitance |
| C_s | snubber capacitance |
| d | drain |
| e_o | output voltage |
| e_s | step input voltage |
| E | circuit voltage source |
| E_i | input voltage source |
| ESR | equivalent series resistance |
| f_m | maximum switching frequency |
| f_s | switching frequency |
| g | mosfet gate |
| G | thyristor gate |

| | |
|--------------|-------------------------------------|
| h | heat transfer coefficient |
| H_s | flux intensity at saturation |
| i | current |
| i_b | base current |
| i_i | input current |
| i_l | inductor current |
| i_o | output current |
| i_{rr} | reverse recovery current |
| i_T | thyristor anode current |
| I_a | prospective fault current |
| I_c | collector current |
| I_{cbo} | collector leakage current |
| $I_{c(max)}$ | maximum allowable collector current |
| I_d | drain current |
| $I_{d(rms)}$ | rms drain current |
| I_D | mean diode current |
| I_F | forward current |
| $I_{F(av)}$ | average forward current |
| I_G | gate current |
| I_H | holding current |
| I_i | mean input current |
| I_l | leakage current |
| I_L | latching current |
| I_o | reverse leakage current |
| \bar{I}_o | mean output current |
| I_p | peak let-through current |
| I_{rr} | peak reverse recovery current |
| $I_{s/b}$ | second breakdown current |
| I_T | total current |
| J | junction |
| J_R | reverse recovery energy |
| k | transistor switching time ratio |
| K | cathode |
| K_{ID} | diode current form factor |
| K_v | voltage ripple factor |
| l_p | primary inductance |
| l_s | saturable inductance |
| L | inductance |
| L_s | linear snubber inductance |

| | |
|------------------|-------------------------------------|
| m | empirical transistor constant |
| M | avalanche multiplication factor |
| n | ratio C_s/C_o |
| n_i | intrinsic carrier concentration |
| N | turns or turns ratio |
| N_A | acceptor concentration |
| N_C | concentration |
| N_D | donor concentration |
| pd | percentage derating |
| P | power |
| P_d | average power dissipation |
| P_G | mean gate power |
| P_p | peak power |
| P_s | switching interval power loss |
| Q_G | mosfet gate charge |
| Q_o | diode total recovery charge |
| Q_R | diode reverse recovery charge |
| r'_b | base lateral resistance |
| $r(t_p)$ | thermal normalising factor |
| R_{be} | base-to-emitter resistance |
| $R_{ds(on)}$ | mosfet on-state resistance |
| R_g | gate resistance |
| R_L | load resistance |
| R_θ | thermal resistance |
| $R_{\theta j-c}$ | thermal resistance junction-to-case |
| s | source |
| S | maximum dv/dt |
| SOA | safe operating area |
| t | time |
| t_a | fuse arcing time |
| t_c | fuse clearing time |
| t_d | turn-on delay time |
| t_D | diode conduction time |
| t_{fi} | current fall time |
| t_{fr} | diode turn-on time |
| t_{fv} | voltage fall time |
| t_m | fuse melting time |
| t_{off} | turn-off time |

| | |
|------------|--|
| t_{on} | turn-on time |
| t_p | pulse width |
| t_q | thyristor turn-off time |
| t_{ri} | current rise time |
| t_{rr} | reverse recovery time |
| t_s | saturation delay time |
| t_T | transistor on-time |
| t_x | time of no conduction |
| T | temperature |
| T_a | ambient temperature |
| T_c | case temperature |
| T_j | junction temperature |
| T_{jmax} | maximum allowable junction temperature |
| T_m | main thyristor |

| | |
|---------------|---|
| v | voltage |
| $v_{be(sat)}$ | base-to-emitter saturation voltage |
| $v_{ce(sat)}$ | collector-to-emitter saturation voltage |
| v_D | diode on-state voltage |
| v_o | output voltage |
| V | voltage |
| V_a | common emitter avalanche voltage |
| V_{ac} | ac supply voltage |
| V_b | junction avalanche voltage |
| V_{be} | base-to-emitter voltage |
| V_{BF} | scr forward breakover voltage |
| V_{BR} | scr reverse breakdown voltage |
| V_c | collector voltage |
| V_{ce} | collector-to-emitter voltage |
| V_D | device voltage rating |
| V_{ds} | drain-to-source voltage |
| V_{fp} | diode turn-on peak forward voltage |
| V_{gs} | gate-to-source voltage |
| V_L | line-to-line rms voltage |
| V_o | mean output voltage |
| V_{PT} | punch-through voltage |
| V_r | rms output voltage |
| V_R | reverse applied voltage |
| V_{RI} | ripple voltage |
| V_{RM} | reverse overshoot voltage |
| V_s | dc supply voltage |
| V_{TH} | mosfet threshold voltage |
| V_Z | Zener voltage |

| | |
|------------|-------------------------------|
| w | thickness |
| W | energy |
| W_t | total loss |
| Z | impedance |
| Z_θ | thermal impedance |
| α | current transfer ratio |
| α_o | α in the linear region |
| β | current amplification factor |
| β_Q | gto turn-off gain |
| γ | injection efficiency |
| δ | duty cycle |
| ΔT | change in temperature |
| λ | thermal conductance |
| ξ | damping factor |
| ξ_m | peak electric field |
| σ | electrical conductivity |
| τ | period |
| ϕ | $\tan^{-1} (\omega L/R)$ |
| Φ | zero bias potential |
| ω | oscillation frequency |
| ω_o | natural oscillation frequency |
| \wedge | peak |
| \vee | minimum |

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PART 1:

DEVICES

