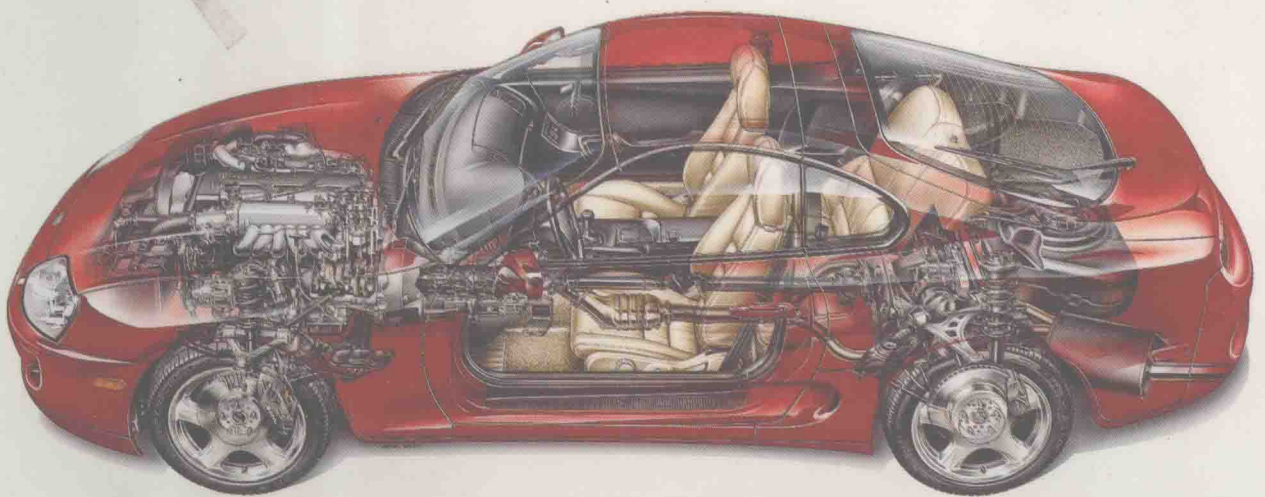


# Automotive Electricity and Electronics

Concepts and Applications



Boyce H. Dwiggins  
Edward F. Mahoney



# **AUTOMOTIVE ELECTRICITY AND ELECTRONICS**

CONCEPTS AND APPLICATIONS

**BOYCE H. DWIGGINS and EDWARD F. MAHONEY**



**Prentice Hall**

Englewood Cliffs, New Jersey Columbus, Ohio

**Library of Congress Cataloging-in-Publication Data**

Dwiggins, Boyce H.

Automotive electricity and electronics : concepts and applications / B.H. Dwiggins and E.F. Mahoney.

p. cm.

ISBN 0-13-359233-2 (pbk. : alk. paper)

1. Automobiles—Electric equipment. 2. Automobiles—Motors—Computer control systems. I. Mahoney,

Edward F. II. Title.

TL272.M24 1995

629.25'4—dc20

95-15895

CIP

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

**ISBN: 0-13-359233-2**

Cover art: Kevin Hulsey Illustration, Inc.

Editor: Ed Francis

Production Editor: Alexandrina Benedicto Wolf

Cover Designer: Proof Positive/Farrowlyne Assoc. Inc.

Production Manager: Laura Messerly

Marketing Manager: Debbie Yarnell

This book was set in Century Book and Kabel by The Clarinda Company and was printed and bound by Quebecor Printing/Semline. The cover was printed by Phoenix Color Corp.

Prentice-Hall International (UK) Limited, *London*

Prentice-Hall of Australia Pty. Limited, *Sydney*

Prentice-Hall of Canada, Inc., *Toronto*

Prentice-Hall Hispanoamericana, S. A., *Mexico*

Prentice-Hall of India Private Limited, *New Delhi*

Prentice-Hall of Japan, Inc., *Tokyo*

Simon & Schuster Asia Pte. Ltd., *Singapore*

Editora Prentice-Hall do Brasil, Ltda., *Rio de Janeiro*



© 1996 by Prentice-Hall, Inc.

A Simon & Schuster Company

Englewood Cliffs, New Jersey 07632

**This book is dedicated to the  
automotive technicians of tomorrow,  
who will need ever-increasing knowledge of  
electricity and electronics.**

# PREFACE

The largest single investment one usually makes is for the purchase of a home. The next largest investment, for most, is an automobile. Both of these investments have much in common: they require insurance, periodic maintenance, and needed repairs.

Homeowners require plumbers, electricians, carpenters, painters, and other specialized craftsmen for necessary repairs and maintenance. The same is true for car owners—they require automotive technicians who specialize in tune-ups, transmissions, brakes, air conditioning and cooling systems, and electrical systems. When a vehicle is taken to a specialty shop for air conditioning service, those working on the car have considerable experience in air conditioning diagnosis and repair. When a car is taken to a dealer or general repair facility, it will be worked on by Tom, who is the in-house air conditioning technician. If you were to visit a large garage or service facility, you would find that bays

(work areas) are assigned to technicians skilled in a particular service—Curt for brakes, Tim for transmissions, and so on. But skilled technicians are not always males; many are female. Today you may find Lara in the tune-up department and Karen in the electrical service department.

The purpose of this book, then, is to help the serious student, male or female, prepare to enter the automotive profession as an automotive electrician or an automotive electrical technician. We emphasize *serious*, because this text covers automotive electrical theory in depth. It is intended for those interested in becoming a part of the large team of automotive technicians dedicated to keeping today's modern vehicles operationally safe and sound.

B. H. Dwiggins  
E. F. Mahoney

# BRIEF CONTENTS

<b>UNIT 1</b> <b>Introduction to Automotive Electricity and Electronics</b>	<b>1</b>	<b>UNIT 13</b> <b>Semiconductor Integrated Circuits</b>	<b>139</b>
<b>UNIT 2</b> <b>Electron Theory</b>	<b>11</b>	<b>UNIT 14</b> <b>Alternating Current and the Alternator</b>	<b>147</b>
<b>UNIT 3</b> <b>Ohm's Law</b>	<b>21</b>	<b>UNIT 15</b> <b>Lighting</b>	<b>159</b>
<b>UNIT 4</b> <b>Electrical Circuits</b>	<b>35</b>	<b>UNIT 16</b> <b>Safety Systems</b>	<b>177</b>
<b>UNIT 5</b> <b>Magnetism</b>	<b>49</b>	<b>UNIT 17</b> <b>Panel Instruments and Warning Devices</b>	<b>189</b>
<b>UNIT 6</b> <b>Electrical Testing</b>	<b>57</b>	<b>UNIT 18</b> <b>Optional and Convenience Systems</b>	<b>205</b>
<b>UNIT 7</b> <b>Batteries</b>	<b>73</b>	<b>UNIT 19</b> <b>Comfort Systems</b>	<b>229</b>
<b>UNIT 8</b> <b>Capacitance and Inductance in dc</b>	<b>87</b>	<b>UNIT 20</b> <b>Sensing and Conversion Devices</b>	<b>241</b>
<b>UNIT 9</b> <b>Relays, Solenoids, and Motors</b>	<b>97</b>	<b>UNIT 21</b> <b>Ignition Systems</b>	<b>253</b>
<b>UNIT 10</b> <b>Electrical Power and Energy</b>	<b>111</b>	<b>UNIT 22</b> <b>Computer Controls</b>	<b>263</b>
<b>UNIT 11</b> <b>Wiring Circuits</b>	<b>117</b>	<b>APPENDIX A</b> <b>Powers of Ten</b>	<b>273</b>
<b>UNIT 12</b> <b>Semiconductor Devices</b>	<b>127</b>	<b>APPENDIX B</b> <b>Periodic Table</b>	<b>277</b>
		<b>INDEX</b>	<b>279</b>

# CONTENTS

## UNIT 1

### Introduction to Automotive Electricity and Electronics

1

Objectives 1

The Electronic Car 1

A Brief History 2

The Car of Today 4

The Car of Tomorrow 5

The Future of Automotive Electronic Systems 5

On the Drawing Board, 6 Automatic Highway Control, 6 Automatic Steering Control, 7 Computerized Energy Distribution and Automated Control, 7 Laser Optical System, 7 Radar Braking System, 7 Route Guiding System, 8 Vehicle Proximity Detection System, 8

Tomorrow 8

Summary 8

Review 8

## UNIT 2

### Electron Theory

11

The Structure of Matter 11

Bohr's Law 12

Insulators 14

Semiconductors 14

The Behavior of Electrons 14

Static Electricity, 14 Dynamic Electricity, 14

Voltage and Current 15

Analogy of Electricity 15

Open and Closed Circuits 18

Practical Exercise 19

Summary 19

Review 20

## UNIT 3

### Ohm's Law

21

Objectives 21

Current and Resistance 21

Resistance Values 22



<b>Resistor Color Code</b>	<b>23</b>
<b>Variable Resistors</b>	<b>24</b>
<b>Ohm's Law</b>	<b>24</b>
<b>Using Ohm's Law in Automotive Circuit Current</b>	<b>26</b>
Automotive Circuit Voltage, 27	Automotive Circuit Resistance, 27
<b>Resistance of Wires and Cables</b>	<b>27</b>
Resistance: Mil/Foot, 28	Length of Wire, 29
Stranded Wire, 30	Insulation, 30
<b>Wires and Cable: Summary</b>	<b>31</b>
<b>Practical Exercise</b>	<b>32</b>
<b>Summary</b>	<b>33</b>
<b>Review</b>	<b>33</b>

<b>Effects of Magnetic Fields</b>	<b>51</b>
Electromagnets, 52	Coil Strength, 54
<b>Practical Exercise</b>	<b>55</b>
<b>Summary</b>	<b>56</b>
<b>Review</b>	<b>56</b>

## **UNIT 6**

### **Electrical Testing** **57**

<b>Objectives</b>	<b>57</b>
<b>Electrical Test Equipment</b>	<b>57</b>
Electric Meters, 57	Analog Meters, 57
Ammeters, 58	Voltmeters, 59
Ohmmeters, 59	Digital Meters, 61
<b>Electrical Testing</b>	<b>62</b>
Voltmeter Use, 62	Ammeter Use, 63
Ohmmeter Use, 64	Other Test Instruments, 65
<b>Practical Exercise</b>	<b>69</b>
<b>Summary</b>	<b>70</b>
<b>Review</b>	<b>71</b>

## **UNIT 7**

### **Batteries** **73**

<b>Objectives</b>	<b>73</b>
<b>Internal Resistance</b>	<b>74</b>
<b>Batteries in Series</b>	<b>75</b>
<b>Batteries/Cells in Parallel</b>	<b>75</b>
<b>Maximum Power Transfer</b>	<b>76</b>
<b>The Automotive Battery</b>	<b>76</b>
<b>Battery Safety</b>	<b>76</b>
Neutralizing Sulfuric Acid, 77	
<b>Battery Components</b>	<b>77</b>
<b>Battery Chemical Action</b>	<b>78</b>
<b>The Electrolyte</b>	<b>79</b>
<b>Battery Power Ratings</b>	<b>80</b>
<b>Battery Care</b>	<b>80</b>
<b>Battery Testing</b>	<b>80</b>
Specific Gravity Test, 81	Drain Load Test, 81
<b>Loads</b>	<b>81</b>
Parasitic Loads, 81	Sneak or Phantom Loads, 82
Self-Discharge, 82	

## **UNIT 4**

### **Electrical Circuits** **35**

<b>Objectives</b>	<b>35</b>
<b>Complete Electric Circuits</b>	<b>35</b>
<b>Wire Resistors</b>	<b>35</b>
<b>Switches</b>	<b>39</b>
<b>Resistive Parallel Components</b>	<b>40</b>
<b>Parallel Circuits</b>	<b>41</b>
Product Over Sum Method, 43	Reciprocal Method, 44
Scientific-Calculator Solutions, 44	
<b>Series-Parallel Circuits</b>	<b>45</b>
<b>Practical Exercise</b>	<b>46</b>
<b>Summary</b>	<b>47</b>
<b>Review</b>	<b>47</b>

## **UNIT 5**

### **Magnetism** **49**

<b>Objectives</b>	<b>49</b>
<b>Magnets and Magnetism</b>	<b>49</b>
Natural Magnets, 49	Artificial Magnets, 49
<b>Magnetic Polarity</b>	<b>50</b>
<b>Magnetic Fields</b>	<b>50</b>
<b>Atomic Arrangement</b>	<b>51</b>



Capacity Test	82
Testing Maintenance-Free Batteries	82
Charging Rate	83
Jump Starting	83
Conclusion	85
Summary	85
Practical Exercise	85
Review	86

## UNIT 8 Capacitance and Inductance in dc 87

Objectives	87
Capacitance	87
Current Flow in Capacitive Circuits	88
Current, 88	Voltage, 88
RC Time Constant	89
Capacitor Construction	91
Capacitor Ratings	91
Inductance	92
Inductor Ratings	92
Current and Voltage Relationship	92
LR Time Constant	92
Summary	94
Practical Exercise	94
Review	95

## UNIT 9 Relays, Solenoids, and Motors 97

Objectives	97
Relays and Solenoids	97
Relays, 97	bemf Polarity, 98
Solenoids, 99	
Motor Principles	100
Torque	101
Starter Motor	102
Starter Motor Circuits, 103	Starter Control
Circuits, 105	Starter Drives, 105
Starter Motor	Update, 105

Motor Control	105
Series Resistive, 106	Pulse Width Modulation, 106
Summary	108
Practical Exercise	108
Review	109

## UNIT 10 Electrical Power and Energy 111

Objectives	111
Horsepower	113
Electric Energy	113
Measuring Electric Power	114
Summary	115
Practical Exercise	115
Review	116

## UNIT 11 Wiring Circuits 117

Objectives	117
Schematics	117
Schematic Symbols, 117	Color Coding, 121
Schematic Interpretation, 121	Schematic
Sequence and Arrangement, 123	
Wiring Harnesses	124
Summary	126
Practical Exercise	126
Review	126

## UNIT 12 Semiconductor Devices 127

Objectives	127
Semiconductors	127
Silicon Diodes, 127	Testing a Diode, 128
Diode Uses, 129	Zener Diodes, 129
Transistors	130
Bipolar Transistors, 130	The Transistor as a
Switch, 131	Transistor Amplifier, 132
Current	Gain, 132
Application of a Signal to the Emitter-	

Base Circuit, 133 Maximum Ratings and  
Electrical Characteristics, 133 Light-Emitting  
Diodes, 133 Photoconductive Cells, 133  
Photovoltaic Cells, 134 Phototransistors, 134  
Field Effect Transistors, 135 MOSFETs, 135

**Summary 136**

**Practical Exercise 136**

**Review 137**

## **UNIT 13 Semiconductor Integrated Circuits 139**

**Objectives 139**

**Semiconductor Devices 139**

**Gate Circuits 140**

**One-Shot Multivibrator 142**

**Flip-Flop Circuit (+5 V System) 143**

**Digital Counting 143**

**Large-Scale Integration (LSI) 144**

**Summary 144**

**Practical Exercise 145**

**Review 146**

## **UNIT 14 Alternating Current and the Alternator 147**

**Objectives 147**

**Generating ac Voltage 147**

**Generated Electromotive Force (Voltage) 147**

**Rotating Coils 148**

**Sine Wave 149**

**Three-Phase Power 149**

**Resistive ac Circuits 149**

**Capacitance in ac Circuits 150**

**Inductance in ac Circuits 150**

**Tank Circuits 150**

**Alternators 151**

**Induced Polarity 152**

**The Rotor 152**

**The Stator 153**

**Alternator Output 153**

**Diodes 153**

**Voltage Regulators 155**

**Summary 156**

**Practical Exercise 156**

**Exercise Summary 156**

**Review 157**

## **UNIT 15 Lighting 159**

**Objectives 159**

**Headlamps 159**

Headlamp Circuit Protection, 160 Headlamp  
Aiming, 160 Headlamp Dimmer Switches, 162  
Automatic Headlamp Control, 162 Twilight  
Sensing, 162 Headlamps Delay Off, 162  
Headlamp Switches, 162

**Parking Lamps 165**

**Tail Lamps 165**

**License Plate Lamp 165**

**Side Marker Lamp 165**

**Cornering Lamps 166**

**Clearance Lamps 166**

**Backup Lamps 166**

Lamps (Bulbs), 166

**Turn Signals 167**

OFF Position, 167 LEFT Position, 167 RIGHT  
Position, 167 Front Side Marker Lamps, 168  
Turn Signal Flashers, 170

**Hazard Lamps 171**

Hazard Flashers, 171

**Brake Lights 172**

**Courtesy and Convenience Lamps 173**

Dome Lamps, 173 Map Lights, 174 Door  
Lights, 174 Dash Lights, 174 Rheostats, 174

**Fiber Optics 174**

**Summary 175**

**Practical Exercise 175**

**Review 176**

## **UNIT 16 Safety Systems**

**177**

**Objectives 177**

**Windshield Wipers 177**

Nondepressed Park Systems, 177 Depressed  
Park Systems, 180

**Windshield Washers 183**

Electrically Operated Washer Systems, 183 Low  
Fluid-Level Warning Systems, 183

**Rear-Window Wipers 185**

**Rear-Window Defoggers 185**

**Rear-Window Deicers 185**

**Seat Belt Warning Systems 186**

**Summary 186**

**Practical Exercise 187**

**Notes 187**

**Review 187**

## **UNIT 17 Panel Instruments and Warning Devices**

**189**

**Objectives 189**

**Dash and Display Panel Instruments 189**

**Voltage Limiters 189**

**Thermoelectric Gauges 190**

**Sending Units 191**

**Fuel-Level System 191**

**Coolant Temperature System 192**

Gauges, 194  
Lamps, 194

**Oil Pressure System 195**

Gauges, 195 Gauges and Lamps, 196

**Charging System 196**

Gauges, 196 Lamps, 197 Gauges and Lamps,  
197

**Horns 197**

Horn Circuit Without Relay, 197 Horn Circuit  
With Relay, 198 Horn Buttons, 198 Horn  
Relays, 199

**Antitheft Alarm Systems 199**

**Speedminders 199**

**Speedometer Calibration Check 199**

**Key-in Warning Systems 201**

Quick Check, 201

**Headlamp-on Warning Systems 202**

Quick Check, 202

**Reverse Warning Systems 202**

**Door-Ajar Warning Systems 202**

**Hood and Trunk Lid-Open Warning Systems  
203**

**Summary 203**

**Practical Exercise 203**

**Review 203**

## **UNIT 18 Optional and Convenience Systems**

**205**

**Objectives 205**

**Front Seats 205**

Power Front Seats, 205 Seat Back Locks, 207  
Power Reclining Seat Backs, 208

**Power Windows 208**

Safety Precautions, 208 Power Tailgate  
Windows, 210 Power Window Adjustment, 210  
Power Window Motor Testing, 211 Power  
Window Electrical Testing, 212 Power Window  
Relays and Interlocks, 212 Sunroofs, 212

**Electric Door Locks 213**

Solenoid-Operated Door Locks, 214 Motor-  
Operated Door Locks, 214

**Automatic Door Locks 214**

Keyless Entry Systems, 214 Tailgate Locks,  
214

**Trunk Lock Release Systems 214**

**Trunk Lid Closing Systems 215**

**Power-Operated Rear-View Mirrors 217**

<b>Electronic Fuel-Injection Systems</b>	<b>217</b>
Electronic Control Unit, 218	Fuel Delivery System, 218
Air Induction System, 219	Sensor System, 219
<b>Fuel Pumps</b>	<b>219</b>
<b>Electric Overdrives</b>	<b>219</b>
<b>Speed Controls</b>	<b>219</b>
Electropneumatic Speed Controls, 220	Electrical Speed Controls, 221
<b>Electric Clocks</b>	<b>221</b>
<b>Radios and Sound Systems</b>	<b>221</b>
AM Radio, 222	FM Radio, 222
FM Stereo Radio, 222	Cassette Player, 222
Compact Disc, 222	CB Radio, 223
Cellular Telephones, 223	
<b>Antenna Systems</b>	<b>224</b>
Antennas, 224	AM/FM Antennas, 224
CB Antennas, 224	AM/FM/CB Antennas, 225
Cellular Phone Antennas, 225	
<b>Repairs</b>	<b>225</b>
<b>Summary</b>	<b>225</b>
<b>Practical Exercise</b>	<b>226</b>
<b>Review</b>	<b>226</b>

## UNIT 19 **Comfort Systems** **229**

<b>Objectives</b>	<b>229</b>
<b>Heaters</b>	<b>229</b>
<b>Air Conditioning Systems</b>	<b>231</b>
Mechanical Aspects, 231	Air Conditioning Physics, 231
Electrical Aspects, 232	Protective Switches, 232
Air Conditioner System Schematics, 233	
<b>Automatic Control Air Conditioning Systems</b>	<b>234</b>
Auto Temp II, 237	
<b>Summary</b>	<b>238</b>
<b>Practical Exercise</b>	<b>239</b>
<b>Review</b>	<b>239</b>

## UNIT 20 **Sensing and Conversion Devices** **241**

<b>Objectives</b>	<b>241</b>
<b>Position Sensing Switches</b>	<b>242</b>
Potentiometer, 242	Light Sensing, 242
<b>Temperature Sensors</b>	<b>242</b>
<b>Pressure Sensors</b>	<b>243</b>
Piezoelectric Sensors, 243	Capacitance Sensors, 243
<b>Light Sensors</b>	<b>244</b>
<b>Speed Sensors</b>	<b>244</b>
Magnetic Pickup Sensors, 244	Hall Effect Sensors, 244
<b>Oxygen Sensors</b>	<b>245</b>
<b>Air-Flow Sensors (Hot Wire)</b>	<b>245</b>
<b>Crash Sensor</b>	<b>246</b>
<b>Digital Conversion Circuits</b>	<b>246</b>
Analog-to-Digital Converters, 247	dc Voltage to Digital, 247
Frequency-to-Digital Conversions, 248	Digital-to-Analog Converters, 248
<b>Summary</b>	<b>250</b>
<b>Practical Exercise</b>	<b>250</b>
<b>Notes</b>	<b>250</b>
<b>Review</b>	<b>250</b>

## UNIT 21 **Ignition Systems** **253**

<b>Objectives</b>	<b>253</b>
<b>Motor Vehicle Ignition</b>	<b>253</b>
Conventional Ignition, 254	Ignition Waveform, 254
<b>Distributors</b>	<b>255</b>
Conventional Distributor, 255	
<b>Transistorized Ignition System</b>	<b>255</b>
Advantages, 256	Breakerless Ignition, 256
Reluctor Pickup, 256	Hall Effect Ignition, 256
Distributorless Ignition System (DIS), 258	Single-Sensor Electronic Ignition, 259
<b>Summary</b>	<b>260</b>
<b>Practical Exercise</b>	<b>260</b>
<b>Review</b>	<b>260</b>

<b>UNIT 22</b>	
<b>Computer Controls</b>	<b>263</b>
Objectives	263
Multiplexing	263
A Simple Multiplexing System	264
Operation, 264	Brake and Turn Signals, 265
Multiplexing of Digital Engine Data	266
Memory Cell, 267	Operation, 267
Parallel-to-Series and Series-to-Parallel Converters	269
Parallel-to-Series, 269	Series-to-Parallel, 269
Summary	270
Practice Exercise	270
Review	270
<b>APPENDIX A</b>	
<b>Powers of Ten</b>	<b>273</b>
<b>APPENDIX B</b>	
<b>Periodic Table</b>	<b>277</b>
<b>INDEX</b>	<b>279</b>

## ◆ UNIT 1 ◆

# INTRODUCTION TO AUTOMOTIVE ELECTRICITY AND ELECTRONICS

### OBJECTIVES

On completion of this unit you will be able to:

- Understand the early development of the car.
- Discuss the technology found in today's car.
- Anticipate some of the plans for the car of the future.

The increased use of electricity and electronics for control of systems and subsystems is evident in almost every industry. Production equipment is rapidly becoming automated through the use of digital computers tied through analog systems to handle repetitive processes.

The American automobile is becoming increasingly controlled by the use of electronic sensors and computers. Electronics is used in the blending of engine and transmission controls, advanced power train controls, spark timing, manifold boost, and fuel mixture. In today's world if it is mechanical and requires positioning control, it probably includes computer electronics.

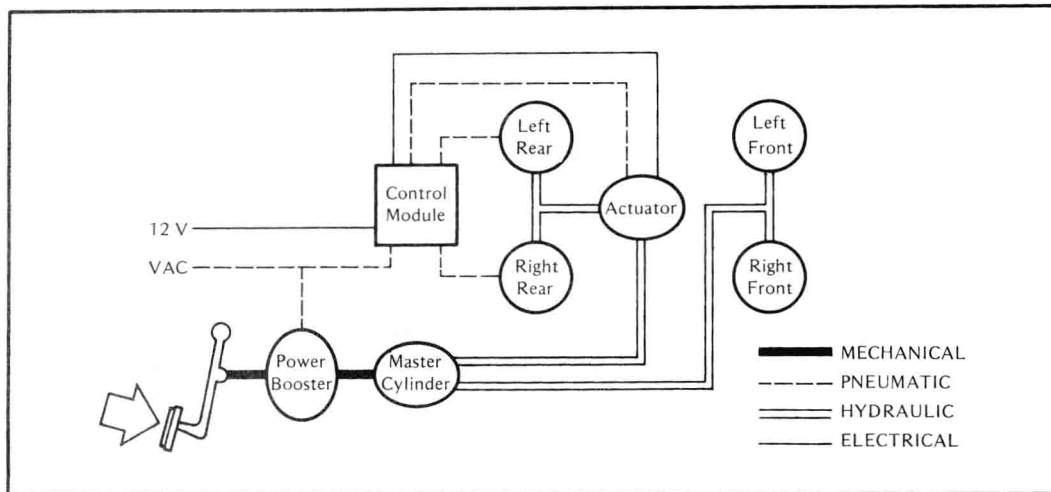
The purpose of this text is to help the serious student prepare to enter the automotive profession as an automotive electrician or automotive electrical technician. We emphasize "serious," because this text covers

automotive electrical theory in depth. It is intended for those interested in becoming part of the elite team of automotive technicians dedicated to keeping today's car operationally safe and sound.

### THE ELECTRONIC CAR

Electronic, by narrow definition, implies systems in which components are "purely electronic," such as integrated circuits (ICs) and various other solid-state devices. A broader definition, when applied to the automotive field, must include all types of hybrid electrically operated components, including those with pneumatic, hydraulic, or mechanical subsystem functions. A good example of this combination of components is the antilock brake system. When the brake pedal is applied (mechanical) by power assist (pneumatic), the on-board computer (solid-state electronic) "reads" the braking effort at each wheel and proportions individual wheel-braking effort (hydraulic) accordingly. Consequently, the term *automotive electronics* applies to any automotive electrical system or subsystem with pneumatic, mechanical, or hydraulic application (Figure 1-1).

When a key is turned in the ignition switch of a vehicle, the engine is always expected to start. Few realize, however, that starting a car's engine requires more



**FIGURE 1-1** Antiskid braking system: when the brake pedal is applied by power assist, the on-board computer (control module) “reads” the braking effort and proportions individual wheel braking action

electrical power than starting many home air conditioners—2500 to 3000 watts. The engine starter requires this great amount of power for only a short period of time, however. Once started, the maximum electrical power that is required, even when driving at night with lights and air conditioner, is about 500 watts or a little more. This power, taken for granted by most motorists, is supplied by the alternator charging system and battery—only two components of the total automotive electrical system. The automotive electrical system, because it is taken for granted, is one of the most neglected systems of the car.

## A BRIEF HISTORY

The “grandfather” of automotive electricity, Count Alessandro Volta (1745–1827), an Italian physicist-chemist, lived before the invention of the automobile and certainly did not know what his discovery would lead to when, in 1780, at the age of 55, he developed the first source of “constant current electricity” (later to be known as direct current), the voltaic pile. He, and other scientists, used the voltaic pile to decompose water by electrolysis, electroplate precious metals, and form electromagnets. For his achievement, in France, Volta was made a count and a senator of the kingdom of Lombardy, and he was awarded the Cross of the Legion of Honor. The greatest tribute for his discovery came more than 50 years after his death: the unit of electromotive force, the *volt*, was named in his honor in 1881.

Other physicists and scientists share credit for today’s modern electronics and electricity. Charles Augustine de Coulomb (1736–1806), a French scientist and inventor, discovered the principles for measuring the force of magnetic and electrical attraction. In 1884 the International Congress of Electricians named the electrical unit “coulomb” in his honor. A *coulomb* identifies the quantity of electrons ( $6.25 \times 10^{18}$ ) produced by a current of one ampere for one second.

Andre Marie Ampere (1775–1836), a French physicist, noted that two parallel conductors attract each other when current is passed through them in one direction and oppose each other when current is passed through them in the opposite direction. He discovered the unit of electrical strength, the *ampere* (often called *amp*), among other discoveries.

James Watt (1736–1819), a Scottish engineer and inventor, originated a method of determining steam engine power output in 1769. He named it “horsepower” because in Watt’s day power was determined by the work ability of the average draft horse. Today horsepower relates to the amount of energy required to raise 550 pounds (249.5 kg) one foot (30.5 cm) in one second. The electrical unit, watt, is named in his honor. Incidentally, one horsepower is equal to 745.7 (746) *watts*.

Georg Simon Ohm (1787–1854), a German physicist, discovered a principle known as Ohm’s law. Ohm’s law establishes the relationship between the current flow (ampere), the potential difference (voltage), and the resistance of individual components in a circuit (ohm). The original ohm, discovered in 1827, and the international ohm, established in 1893 by the Interna-



tional Electrical Congress, are almost identical. The absolute ohm is equal to 0.999505 international ohm. The unit of resistance is the *ohm*.

These five men—Volta, de Coulomb, Ampere, Watt, and Ohm—are largely responsible for modern automotive electronics and the methods by which we can understand, design, troubleshoot, and repair automotive electrical systems. Together their lives spanned less than 120 years (1736–1854); the last of them died just six years before a Belgian, Etienne Lenoir, patented the first gasoline-powered internal-combustion engine, in France in 1860.

Perhaps Charles Franklin Kettering (1876–1958) should be credited with the beginning of the electronic car. In 1908 he patented the first battery ignition system, the forerunner of the conventional ignition system. Kettering's system consisted of a battery, a coil, and a set of points (Figure 1–2). Or perhaps the credit should be shared by Henry Martyn Leland (1843–1932). With Kettering's help, Leland developed the electric starter available for the first time on 1912 Cadillacs. Regardless of who gets the credit, by 1912 the modern car was fast carving a notch in history, only 16 years after a Duryea “motor wagon”

was featured in a Barnum and Bailey Circus parade as a novelty (April 2, 1896).

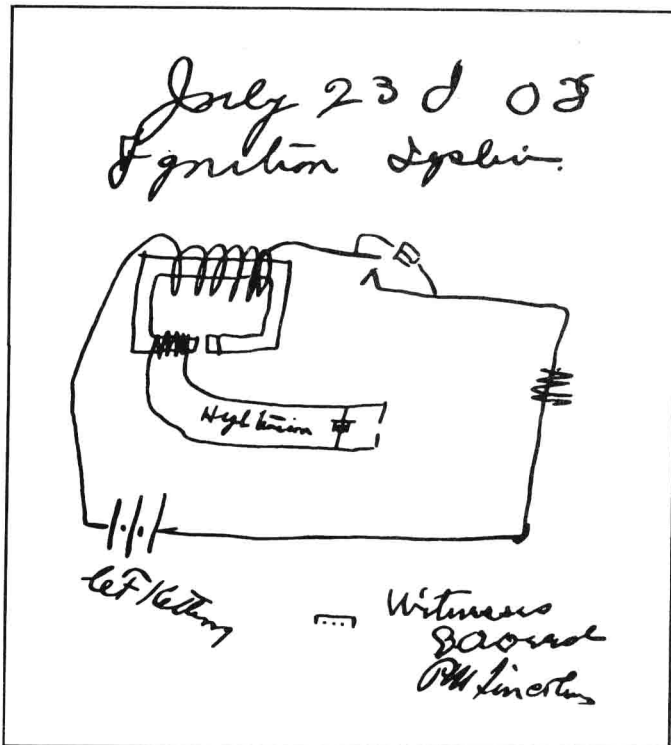
The car of the early 1900s was a product of the development begun by a German engineer, Karl Benz (1844–1929). In 1885 he built a three-wheeled vehicle using an engine designed by Gottlieb Daimler (Germany) and a carburetor designed by Fernand Forest (France). Benz added a magneto electrical system of his own design and produced the first known motor vehicle with an electrical system. Although several motor vehicles were built before Benz's effort, he sparked the continuing development of the motor vehicle.

After reading about Benz's achievements in *Scientific American*, two bicycle mechanics, brothers Charles E. and J. Frank Duryea, developed a two-cylinder car. The *Chicago Times-Herald* sponsored a 55-mile (88.5-km) race in 1895; of the Duryea car, a Benz car, and four other cars entered, only the Duryea and Benz cars finished. Duryea was the victor with an average speed of 5 miles per hour (8 km/hr) for the course. Average driving speed was actually 7 miles per hour (11.3 km/hr) if the time required for repairs is deducted. In the 11-hour race, more than three hours was required for repairs—considered average for those days.

The first electric battery manufacturing concern, known as the Electric Storage Battery Company, was formed by an American lawyer, Isaac L. Rice (1850–1915). Rice soon merged with the motor carriage division of the Pope Manufacturing Company to form the Electric Vehicle Company. Pope Manufacturing, the first electric motorcar factory, was founded in 1897 in Hartford, Connecticut. Its founder, Colonel Albert A. Pope, theorized that combustion-powered vehicles would not sell well because the gasoline engine was located under the driver's seat. As he rationalized, “You can't get people to sit on top of an explosion.” He also built gasoline-powered motor cars. Pope's theory held for the first two years of operation—he sold almost twelve times as many electric cars as gasoline-powered cars during that period. Incidentally, although Pope manufactured both electric- and gasoline-powered vehicles, he prudently continued to manufacture bicycles under the trade name Columbia. The Columbia bicycle, produced into the modern era, outlasted both his electric- and gasoline-powered machines.

Important events in the development of the car are shown in Table 1–1.

The war effort in the early 1940s greatly accelerated technological advancement and production methods and primed the automotive industry for today's level.



**FIGURE 1–2** A copy of the drawing submitted by C. F. Kettering to obtain the first U.S. patent for an ignition system

TABLE 1–1 Major events in the development of the car

1897	First commercial production of an automobile
1902	American Automobile Association (AAA) founded
1903	Henry Ford (1863–1947) founds the first of the “big three,” the Ford Motor Company
1905	The Society of Automobile Engineers (SAE) founded (The name was later changed to Society of Automotive Engineers.)
1908	The Ford Motor Company introduces the Model T, known as the “tin Lizzie.” Charles F. Kettering (1876–1958) patents the first battery ignition system. William C. Durant (1860–1947) founds General Motors Corporation.
1911	Henry M. Leland (1843–1932), with the help of Kettering, develops the electric starter first used on 1912 Cadillacs
1914	The first production line is started at Ford Motor Company. Henry Ford raises employees’ pay to \$5 per day, about twice the average pay of other manufacturers at the time.
1916	The Federal Road Act is passed
1921	The Federal Highway Act is passed
1923	Ethyl gasoline is developed
1925	Walter P. Chrysler (1875–1940) founds the Chrysler Corporation
1928	The average hourly wage for automotive workers is raised to \$0.75 per hour, about 27 percent higher than the average wage of other manufacturers
1935	The United Auto Workers (UAW) union is chartered
1940	The first turnpike is opened in Pennsylvania
1942	Civilian vehicle production is halted. All manufacturers produce military vehicles for use in World War II.
1943	The fiftieth anniversary of the Duryea car, now in the possession of the Smithsonian Institution, passes with little notice because of the war
1945	Production of civilian automobiles is resumed by all automotive manufacturers
1947	The fiftieth anniversary of commercial automobile manufacturing is celebrated in Hartford, Connecticut

THE CAR OF TODAY

Improved highways and automotive mechanical engineering technologies paved the way for faster speeds that, in turn, require precise and accurate timing of automotive functions. This, with the greater demand for comfort, requires much more sophisticated electronics than the car of yesterday.

Today’s average car has over 1600 feet (488 meters) of wire made up into about 50 individual wiring harnesses. There are more than 30 light bulbs in the modern car, depending on the make and model. The air conditioning system has sufficient capacity to easily cool a small two-bedroom home.

The electrical system of the car consists of many subsystems. The power system provides primary power with a battery and secondary power with an alternator that keeps the battery charged. The starting

system provides a means for starting the engine, and the ignition system provides low- and high-voltage power circuits necessary to keep the engine running. The lighting system includes several subsystems such as head/tail lamps, parking lamps, turn signal/brake lamps and courtesy/convenience lamps. The power system includes window, sun roof, and seat circuits. The safety system includes windshield wipers/washers, hazard lighting, seat restraint systems, and equipment failure warning lamps. Other electrical systems include heating/air conditioning, radio/sound equipment, and other accessory equipment (see Figure 1–3).

Electronics warn of low brake fluid level, worn brake linings, and other braking defects. Unsafe conditions of the wheels, the steering system, and the front-end parts are audibly and visually signaled to the driver. Other fail-safe devices may warn of low engine coolant and oil level. Safety problems are fed into an on-board